

CITIES: Car Industry, Road Transport and an International Emission Trading Scheme – Policy Options

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ABSTRACT

This report evaluates existing regulations for climate change mitigation in the transport sector and investigates the effects of including transportation in emission trading schemes.

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Management Summary

Road transportation is confronted with major challenges. The global rise of greenhouse gas (GHG) emissions and its potentially devastating consequences – global warming – require a comprehensive regulatory framework for emissions, including those of the transport sector. Alternative fuels and vehicles are widely regarded as a possible solution strategy towards sustainable transport. Already a variety of existing regulations but also rising oil prices and concerns over limited resources incentivize the introduction of alternative fuels and vehicles, e.g. plug-in hybrids, electric vehicles. However, the current policy framework in the US and the EU is not necessarily fully effective and efficient in addressing GHG emissions in the transport sector.

Fuel producers, car manufacturers and consumers all have major influence on GHG emissions in transportation. Each of these agents has a range of options to mitigate overall emissions – and responsibilities that correspond to these options. Policy instruments address different actors and are designed to address respective responsibilities. Alternative fuels, such as electricity for electric vehicles, differ not only in magnitude and variance from conventional fuels, but also inherently display a different life cycle pattern: Whereas conventional fuels are mostly end-of-pipe, emissions of alternative fuels are further upstream, e.g. at power plants. Hence, with rising market shares of alternative fuels and vehicles, such as electric cars, does the current mix of policy instruments still appropriately address the responsibility of major actors and encourage the introduction of low carbon fuels and alternative fueled vehicles properly?

GHG emissions can be decomposed into carbon intensity, energy efficiency and total transport demand. While fuel producers can be held responsible for the carbon intensity of fuels, car manufacturers are accountable for the efficiency of vehicles, and consumers for total transport demand. In the European Union, the US, and California, car manufacturers are regulated in g CO₂ per km or mile, i.e. a measure that targets both carbon intensity of fuels and energy efficiency of cars. While this choice of units deserves merits in a landscape of a few conventional fuels with mostly constant life cycle emissions, this choice becomes inconsistent with increasingly varying fuel pathways that systematically shift emissions upstream. Beyond, the carbon content of electricity varies enormously between fuel sources (e.g. coal vs. wind). Life cycle emissions of biofuels vary to an equally wide degree according to production process, direct and indirect land-use emissions. Even fossil fuels have increasingly varying upstream emissions, consider, e.g., Canadian oil tar sands. All of these emissions can hardly be influenced by car manufacturers. As a result, policy instruments need to be more specific in addressing car manufacturers and fuel producers.

The quality of policy instruments can be evaluated according to a number of criteria, notably effectiveness and efficiency. Policy instrument for climate change mitigation also must have sufficient scope in capturing all emissions.

Current climate policies in the transportation sector are dominated by fuel efficiency standards. Standards are set in miles per gallon, liter per km and g CO₂ per km or mile. These standards are currently reviewed in order to link energy efficiency of alternative fuel vehicles to fuel efficiency of conventional vehicles. To consider the car manufacturers' and fuel producers' influence on alternative fueled vehicles along the life-cycle properly a regulatory framework has to reflect the responsibilities of different actors. For vehicle regulation, hence, standards need to specifically address tank-to-wheel efficiency. The consumption of alternative fueled vehicles can be converted into existing volume-based metrics such as liter per km. As long as g CO₂ per km or mile standards are still valid, these should reflect tank-to-wheel emissions, e. g. accounting 0 g per km or mile for electric cars. With significant market shares of different alternative vehicles, in the long term standards should be set purely in terms of energy efficiency, e.g MJ/km in order to define a common efficiency denominator for different fueled vehicles.

Carbon intensity and overall carbon emissions are best regulated at the level of fuel providers. Carbon intensity specific policies are dominated by renewable fuel standards (RFS) and other quotas for biofuels. These instruments are successful in increasing the share of biofuels in the transport sector. However, biofuel quotas insufficiently address life cycle emissions and provide no reliable GHG emission reduction. More advanced instruments such as low carbon fuel standards (LCFS) rely on full life-cycle emission accounting – a particular challenging and even epistemological difficult problem. Intensity-based standards are appropriate in promoting low-carbon fuels, but can have perverse effects in augmenting overall fuel emissions. Hence, a technology-neutral instrument for reduction of both carbon intensity and, crucially, overall carbon emissions is missing. Furthermore, the increase of alternative fuels and vehicles - shifting the responsibility and the influence of decarbonization to upstream emissions- requires a review of policy instruments. A suitable instrument addressing these concerns, encouraging the decarbonization of transport fuels, and acting as a complement to crucial fuel efficiency and/or GHG-standards does not need to be invented: it is called cap-and-trade (or its policy cousins).

How then can road transport fuels be included into GHG cap-and-trade systems? Clearly, a coherent price on carbon would constitute an important role in the transport climate policy mix. Concerns such as inefficiently high pre-existing fuel tax levels, potential conflicts between carbon pricing and regulatory policies, redundancy of carbon pricing with effective regulation in place, and lack of scale regarding the emission saving impacts from carbon pricing do not represent obstacles to carbon pricing.

Both, emission trading or taxation can be implemented to put a price on carbon. However, economy-wide emission trading is the more suitable instrument

in the context of quantitative climate policy objectives. Emission trading enables economically efficient attainment of a given emission budget. Under uncertainty, taxes could require politically costly adjustments not only within but across sectors to guarantee efficiency.

How is cap and trade for road transport suitably defined? For the point of regulation, the number of regulated entities needs to be kept low and all available abatement options must be incentivized. In particular, the point of regulation should be chosen upstream e.g. at refineries to keep transaction costs of emission trading low. In competitive markets upstream entities will pass on the cost of allowance downstream to final consumers, analogous to existing fuel taxes. Thus, in order to incentivize all abatement options, transport emissions need to be addressed upstream rather than downstream in virtually all fuel chains, including gasoline and diesel, biofuels, electricity, gas, and hydrogen. Auctioning of allowances is recommended in order to avoid windfall profits for upstream facilities (e.g. refineries) that would accrue under free allocation.

What kind of price effects can be expected? Concerns over carbon leakage in case of the transport sector joining a multi-sector cap-and-trade system feature prominently in the European debate. These concerns derive from the relatively steep abatement cost curve of road transportation, and the fear that road transport EU ETS inclusion would increase the EU ETS allowance (EUA) price, thereby intensifying concerns over carbon leakage in trade-exposed industries already covered by the EU ETS. Applying four marginal abatement cost curves for European road transport and assuming abatement targets set by EU policymakers (20% economy-wide reduction below 2005 by 2020) the EUA price would not increase. This is because (i) there are cost-efficient abatement potentials in the road transport sector, (ii) access to international carbon credit markets adds abatement options, and (iii) the 2020 transport sector abatement target envisaged by EU policymakers (7% below 2005 levels in 2020) is not very challenging. Crucially, current fuel efficiency standards already deliver a significant contribution to envisaged 2020 targets in EU and US.

Efficient climate policy requires harmonization of marginal abatement costs across sectors (even if they are not covered by a single policy instrument). Therefore, if efficient policies are in place, including transport to an ETS leaves the EUA price almost unchanged. Vice versa, substantial changes in allowance prices from inclusion would indicate substantial efficiency gains. However, emission trading in California, EU and in the US would guarantee a better contribution also from the transport sector by boosting additional measures upstream in the fuel supply chain, aiming at carbon intensity, and also by mitigating transport demand.

The prospect of linking regional emission trading systems as envisaged by the European Union promises to reduce carbon leakage, and increase competitiveness and efficiency of international climate policy. Challenges of international policy coordination need to be resolved and domestic trading systems need to be implemented in the first place to make this a viable policy option.

Altogether, to reign in overall GHG emissions in the transport sector and to address the shift of responsibilities upstream of fuel supply chains, road transport fuel inclusion to cap-and-trade, complemented by appropriate regulatory policies, such as tank-to-wheel based fuel efficiency metrics, is the most promising policy option for future climate policy regulation of the European, the Californian, and the US road transport sector.

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Part I: Transport climate policies revisited

The first part of this report, chapter 1-4, motivates transportation policies that mitigate climate change and reviews the effectiveness and efficiency of current transport policies that aim to regulate rising GHG emission in the transport sector.

1. Motivation

This report is motivated by the need a) to act on rising greenhouse gas emissions¹ in the transport sector; b) to evaluate requirements for a broader regulative framework as alternative fuel vehicles such as battery electric vehicles, PHEVs, and hydrogen fuel vehicles gain increasing market shares, and hence, by the need to provide a level playing field across fuels; and c) to do this in an effective, cost-efficient and appropriate manner such that instruments correspond to proper actors and set suitable incentives. In the following paragraphs, these three driving forces are elucidated.

Summary Chapter 1

- Rising greenhouse gas emissions and the risks of climate change demand a comprehensive policy framework for the transport sector in major world economies.
- Alternative fuels, from tar sand oil to electricity from fossile and regenerative sources, and technologies, such as electric vehicles, lead to a diversification of fuel supply chains. This leads to separate responsibilities in terms of process-specific GHG emissions which are currently inappropriately addressed.
- Existing and envisaged policy instruments are evaluated according to being environmentally effective, economically efficient, distributionally fair, and politically feasible.

1.1. Rising greenhouse gas emissions

The transport sectors accounts for more than half of the oil used worldwide and roughly a quarter of energy-related CO₂ emissions (IEA 2008). If emissions from feedstock and fuel production are included, the transport sector (including individual, passenger and good transport) is responsible for close to 27% of global GHG emissions. Globally, the sector's growth rate of energy consumption during 1990-2002 was highest among all the end-use sectors. In the USA, for instance,

¹ Where not otherwise indicated, we use the terms 'greenhouse gas (GHG)' and 'carbon' interchangeably throughout this report. Even though this is not entirely precise—carbon (or CO₂) emissions are generated in the combustion of hydrocarbon fuels (coal, oil, gas), and are only one GHG next to gasses such as CH₄, N₂O, HFcs and PFCs—we adopt this more casual use for convenience.

between 1990 and 2006, growth in transport emissions represented almost half of the increase in total US GHGs emissions (EPA 2009).

To prevent dangerous climate change, global emissions in 2050 will need to be at least halved from 2005 levels. Transport is supposed to play a vital role in abatement efforts. Yet world transport energy use and emissions are projected to increase by more than 50% by 2030 and will more than double by 2050 in a business-as-usual scenario. Around 75% of the projected total increase in world oil demand derives from the transport sector (Figure 1). In OECD countries, oil use shrinks in all sectors except transport. Virtually all (>95%) of transport energy comes from oil-based fuels, predominantly diesel and gasoline. While oil extraction is expected to peak and begin to decline in the near future, the shortfall is likely to be compensated with non-conventional oil (such as tar sands) and other fossil resources such as gas-to-liquids and coal-to-liquids. On average, these fuels are more carbon intensive than oil, further augmenting the sector's contribution to global warming. While international shipping and aviation contribute significantly to the projected rise in emissions, the highest share will still come from road transport, i.e. individual transportation and transportation of goods (Figure 1). Shifting towards a sustainable, low-carbon transport system is, hence, imperative for successful climate stabilization, and also to for dealing with ever more problematic congestion challenges in a rapidly urbanizing world.

Historically, fuel use and emissions were mostly bound to OECD countries. North America alone accounts for 33% of global transport CO₂ emissions while China contributes 6%. With their economic rise, future growth of fuel demand and emissions will be driven primarily by the developing world, most notably China and India (Creutzig and Edenhofer 2010; IEA 2009a). The main driver of this development is increased car ownership and use of increasingly affluent urban populations. In fact, the vehicle stock, excluding two- and three-wheelers, is projected to triple between now and 2030 in non-OECD countries. As a result, some developing countries will observe exponential growth in transport fuel consumption (Figure 2). Hence, OECD countries cannot manage global transport emissions by geographically restricted policy instruments alone. However, the development of robust and appropriate policy instruments must nonetheless be pioneered by these world regions because of current emissions, historical responsibility, and institutional feasibility. This study focuses on the European Union and the United States. Successful implementation of policy instruments in these world regions foregoes future action by developing nations that are either encouraged to adopt successful instruments or find other tools to reign in transport emissions. In fact, local environmental disbenefits such as air pollution and huge inefficiencies in urban transportation systems already motivate action in many non-OECD countries.

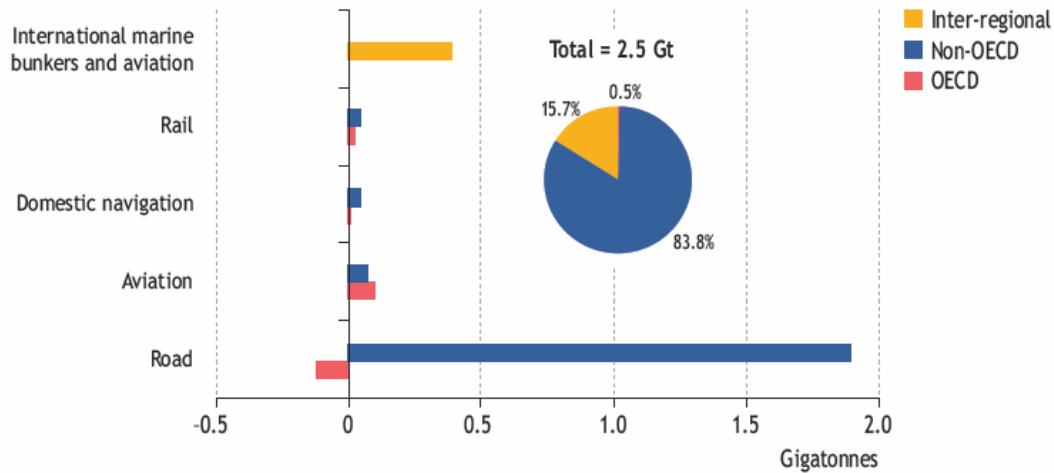


Figure 1: Change in transport sector CO₂ emissions by mode and region in a business-as-usual scenario, 2006-2030, including passenger and good transport (IEA 2008).

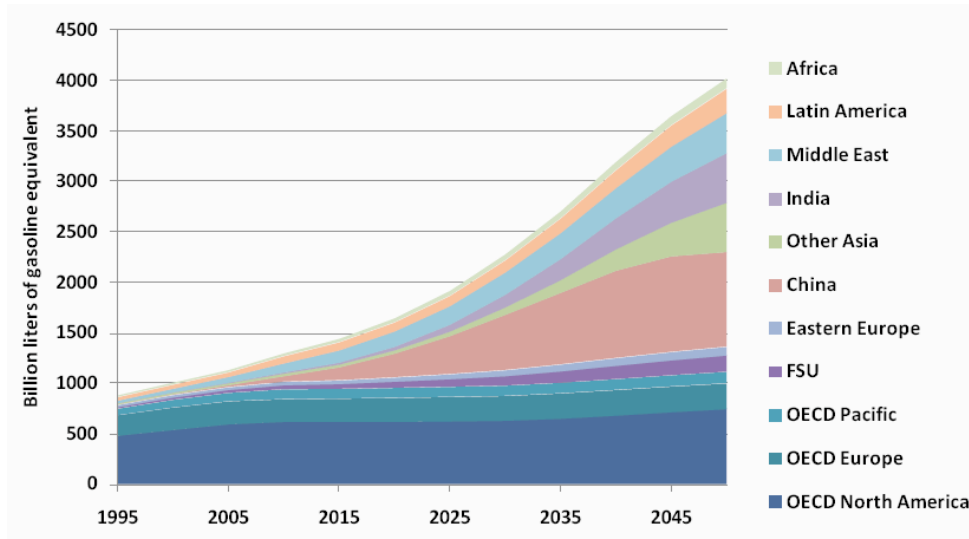


Figure 2: Projected fuel use for road transport by region (IEA 2009a).

1.2. A level playing field for all transport fuels

Alternative vehicles are expected to gain market shares in international automobile markets. Scenarios project global market shares of electric vehicles up to 12% in 2020 (BCG 2009), and significantly higher market shares in 2030 and 2050 (e.g., Mock et al. 2009; for details see Annex A). Irrespective of the detailed trajectory of their future market gains, alternative vehicles will imply a long-term shift in the energy supply underlying vehicle propulsion. However, with the diversification of propulsion technologies, supply chains become more important. Whereas conventional fossil fuels, gasoline and diesel, powered nearly all of road transport over the last century and still completely dominate the fuel market, it becomes clear that electricity and potentially hydrogen, but also non-conventional

fossil fuels, such as the Canadian tar sands, will provide a small but significant part of energy for vehicles within the next decade. As the carbon footprint of fuels diversifies, car manufacturers lose control over life-cycle emissions of their product. In contrast, energy companies and fuel producers can effectively influence the fuels' carbon footprint and can be regulated by national and international energy policies. From a climate perspective, only the global warming effect of these fuels matters. This leads to separate responsibilities in terms of process-specific GHG emissions which are not properly addressed. Hence, the current set of environmental policies in the transport sector must be adapted to this diversification of fuel supply chains. In the current policy framework, sometimes the more environmentally fuels are more tightly regulated with respect to greenhouse gas emissions than the more harmful fuel: For example, in the European ETS, electricity, powering trains, is part of a cap-and-trade scheme whereas conventional fuels are insufficiently covered by climate policies, such as the Fuel Quality Directive. This study analyses current transport climate policies with respect to their effectiveness in climate mitigation and their economic efficiency, and provides recommendation on how to adapt and complement regulation. Specifically, this study tries to clarify how policy instruments can provide a level playing field for all fuels. The aim is to find appropriate instruments such that alternative fuels are guaranteed to reduce overall GHG emissions, or at least do not raise them. After evaluating existing instruments in chapter 3 and 4, the focus will be on inclusion of the transport sector into emission trading schemes in chapter 5 and 6. We will argue that upstream emission trading can effectively and efficiently address greenhouse gas emissions and is optimally regulated upstream at the level of fuel producers. The combination of instruments, as discussed in this report, is summarized in Figure 3.

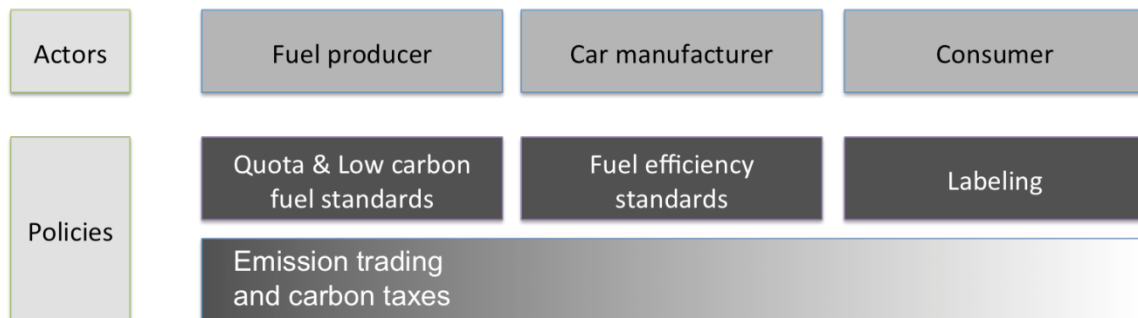


Figure 3: Overview on policy instruments as discussed in this report. This overview is used as orientation in subsequent chapters.

1.3. Three requirements for policy instruments

The rise of greenhouse gas emissions demonstrates the need for adequate regulation and policy instruments that mitigate dangerous global warming. Policy instruments for climate change mitigation require global scope, fulfill quality criteria, and address agents with appropriate incentives.

First, in the medium run, global coverage of all sectors by a mix of instruments is needed to avoid a plethora of indirect emission effects and to appropriately deal with the atmosphere – a global common good. This study focuses on the role of road transport, and how it can be embedded into an encompassing emission policy framework; this study also looks primarily at the European Union, the US and California – other world regions may follow suit within the next decade.

Second, good regulation is a) environmentally effective, b) economically efficient, c) politically feasible, and d) has a distributional fair outcome. Environmentally effective requires that overall greenhouse gas emissions are reduced by >50% globally and >80% in OECD countries by 2050 with front-up emission reductions being more effective than late emission reductions. Economically efficient entails that the economic costs of measures are minimal. Efficiency can be obtained by flexible mechanisms that guide investments into the most efficient mitigation options. In some cases measures introduced in the name of economic efficiency can compromise environmental effectiveness, e.g. when the *additionality* requirement of the Clean Development Mechanism is weakened. Economic efficiency also demands minimal transaction costs, such as administrative requirements, accounting procedures and enforcement mechanisms. Political feasibility is a criterion that includes political boundary conditions, e.g. the negotiation power of political parties, interest groups and administrative units. Politically feasibility can reduce environmental effectiveness substantially. This is because the most effective measures require structural change in the economy, redistributing market share even across sectors. Finally, the effects of the policy instruments should have a distributional just outcome. For example, in the first implementation period of the *European emission trading scheme*, certificates were distributed by *grandfathering*, a mechanism that partially puts profits into the pockets of emitters. A fair instrument avoids such outcomes. Good policy instruments are also not more complicated than necessary. In particular, simplicity of some degree can increase environmental effectiveness by reducing loopholes; can increase political feasibility as it increases comprehensibility among citizen-voters; and increases the chance of a fair outcome.

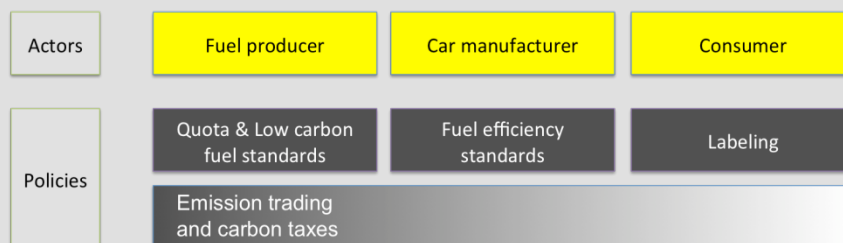
Third, policy instruments must appropriately match actors and incentives. In particular, in the transport sector a number of actors control different aspects of fuel use and, hence, greenhouse gas emissions. Oil companies provide fuel, car manufacturers influence emissions by vehicle efficiency, and consumers drive cars and other modes of transport – a large number of end users emitting GHGs. Instruments must be differentiated according to the range of options and responsibilities of agents.

2. Levels of regulations: actor perspective

Which actors are responsible for and can influence GHG emissions, and with what kind of action? This chapter tries to clarify this important question, and by this, establishes the basis for the analysis of policy instruments. It is instructive to understand the different technical factors underlying GHG emissions. Total emissions can be factorized into three components. First, *carbon content* describes the GHG emissions of one fuel energy unit in CO₂e/MJ. Second, energy intensity is the energy required per kilometer traveled. Third, total travel demand determines the total distance. The relationship is depicted in Figure 6 (see also Creutzig and Edenhofer 2010). Each factor corresponds to specific policy instruments or actions (Figure 6). This is similar to the Kaya identity (e.g. Nakicenovic et al. 2000) but is here specified for the transport sector. In addition to policy instruments corresponding to a specific factor, there are also policy instruments targeting total emissions, in particular price instruments such as a carbon tax or cap-and-trade. In the following, different actors in road transportation – and how each relates to this emission decomposition – are discussed. In this part and the next chapter, only those policy instruments are analyzed that directly relate to individual motorized road transport. Some other instruments, such as modal shift and land use policy are of crucial importance but are beyond the scope of this study. However, it will be highlighted how those instruments complement other instruments and contribute to *dynamic efficiency*. Three actors are discussed from here on: fuel producers, car manufacturers, and consumers. First, however, a short overview on fuel life-cycle analysis is given so that the respective role of all actors can be appropriately evaluated.

Summary Chapter 2

- Fuel pathways can be evaluated according to the global warming potential of its primary energy source and the efficiency loss across subsequent stages.
- Fuel producers can influence the carbon intensity of fuels, car manufacturers the fuel efficiency of cars, and consumers the overall transport demand.
- Specific policies that address different actors together form a coherent policy framework. While price signals by taxation or emission trading are crucial, more targeted instruments address dynamic efficiency and particular market failures, separated according the responsibilities of actors.



2.1. Overview on fuel life-cycle analysis

The regulation of greenhouse gas emissions in transport requires knowledge about life-cycle emissions of energy systems, or at least a detailed inventory of upstream emissions sources that must be considered in the design of any policy measure. This prerequisite knowledge is essential regardless of the precise nature of the policy instrument. However, in turn, it can motivate design of instruments. A detailed analysis of fuel pathways is given in Annex A. Here, a short summary of the main insights is given.

Fuel pathways can be characterized by two main factors: the *global warming potential* (GWP) of its primary energy source, such as coal or wind energy, and the efficiency loss at different stages. In the following, we provide a brief overview on the lifecycle emissions of alternative feedstocks and describe the issues associated with the different pathways:

- Conventional fuels (gasoline and diesel) have a high and fixed GWP per unit of primary energy. Some GHG emissions are produced at production (e.g. 7% for diesel) and by processing at refineries (e.g., 12% for diesel) (CARB 2009a). Conventional fuels are consumed in internal combustion engines. The majority of emissions occur at end use (70-90%). The decisive factor is fuel efficiency of vehicles. Diesel engines are more efficient than gasoline engines and produce 16-24% less emissions (Kahn Ribeiro et al. 2007).
- Unconventional fuels (e.g. Canadian tar sands) can have, at the stage of fuel production, about 4.5 times larger upstream GHG emissions than U.S domestic crude oil (US DOE, 2009). Hence, while fuel efficiency remains the dominant issue, carbon intensity of fuels becomes more important.
- *Biofuels* can follow a myriad of specific pathways, and produce GHG emissions at biorefineries and in agricultural feedstock production further upstream in the supply chain. The latter requires dealing with complex issues such as nitrous oxide emissions from fertilizer use (Crutzen et al., 2008), emissions from direct and indirect land use change (Farrell et al., 2006; Creutzig and Kammen, 2010) as well as emissions from alternative agricultural management practices (Kim et al. (2009). As a result, the GWP of biofuels varies dramatically with pathway. Uncertainty over life-cycle emissions can be substantial and make proper assessment challenging. The dominant US corn ethanol is estimated to have higher life-cycle emissions than gasoline (Hertel et al. 2010).
- Compressed natural gas has a lower GWP than conventional fuels. Total life-cycle emissions are 15-25% lower than for gasoline engines (Kahn Ribeiro et al. 2007).
- Electricity can have very high GWP when produced in a coal power plant, and close to zero emissions when generated by renewable sources. Electric motors are significantly more efficient than ICEs, and total *well-to-wheel* efficiency of BEVs ranges between 75-85%. Electricity can be deployed for

plug-in hybrids, full battery electric cars, or fuel cell hybrid electric vehicles. Alternative storage mediums such as compressed-air have much lower well-to-wheel efficiency (Creutzig et al. 2009).

- About 96% of hydrogen produced globally comes from fossil fuel feedstock. More specifically, 48% is produced via *steam methane reformation* (SMR) with natural gas as the feedstock, 30% comes from steam reforming or partial oxidation of petroleum and 18% from coal gasification. Electrolysis of water provides the remaining 4% (Balat and Balat 2009). GHG emissions can vary considerably across these different pathways. Hydrogen can be deployed for fuel cell cars, hydrogen ICE vehicles, or fuel cell hybrid electric vehicles

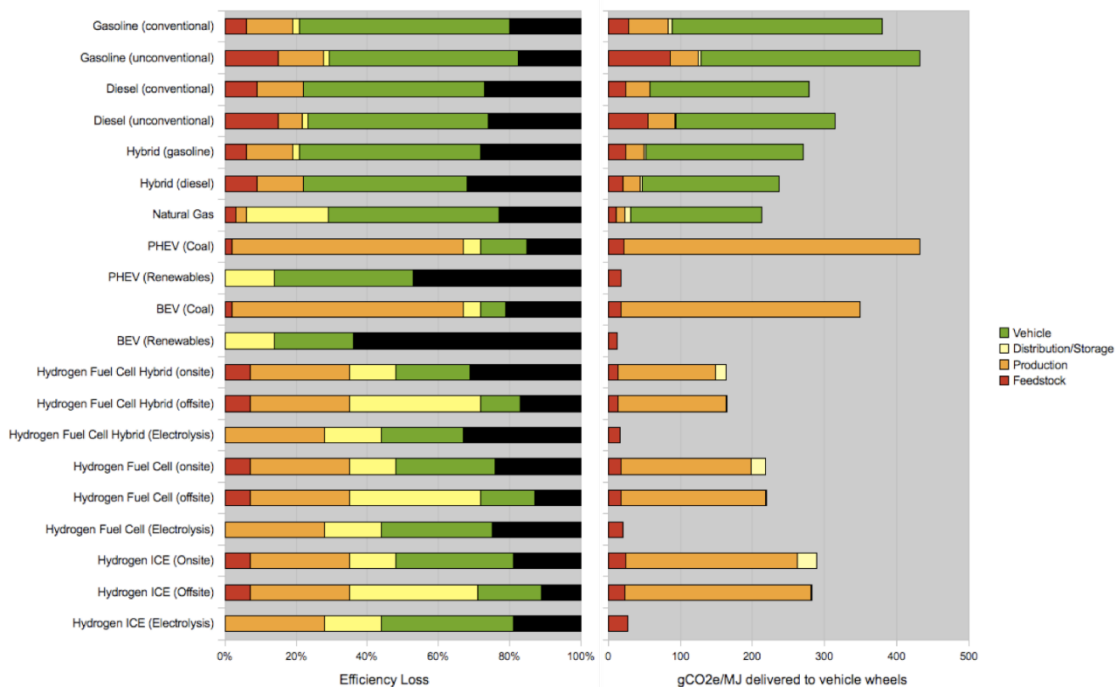


Figure 4: Overview on efficiency losses and life-cycle emissions of fuel supply chains.

Figure 4 provides an overview over the life-cycle emissions of different fuels. Full details are given in Appendix A. Figure 5 displays lifecycle emissions of different biofuels and natural gas. The following facts can be observed:

- Emissions of fossil fuels mostly occur downstream at the vehicle stage.
- Unconventional fossil fuels, such as those produced from Canadian tar sands, have significant additional emission at the stage of feedstock recovery.
- Emissions of alternative fuels mostly occur upstream at production stage.
- Emissions of BEVs or PHEVs vary considerably with upstream feedstock.

- Emissions of vehicles powered by hydrogen vary with vehicle technology, distribution system and feedstock.
- Emissions from biofuels crucially depend on specific feedstock. Uncertainties render accurate accounting difficult (not shown in the figure).

Crucially, fossil fuel emissions mostly occur with end use, while alternative fuel emissions occur upstream. For all of these fuels, proportionality between emissions and energy intensity is given for specific supply chains. Due to downstream mixing of upstream supply sources, however, carbon content cannot be determined from vehicle technology alone. Comprehensive policy instruments need to be adaptive to varying fuel supply chains in order to provide a level playing field across all fuels.

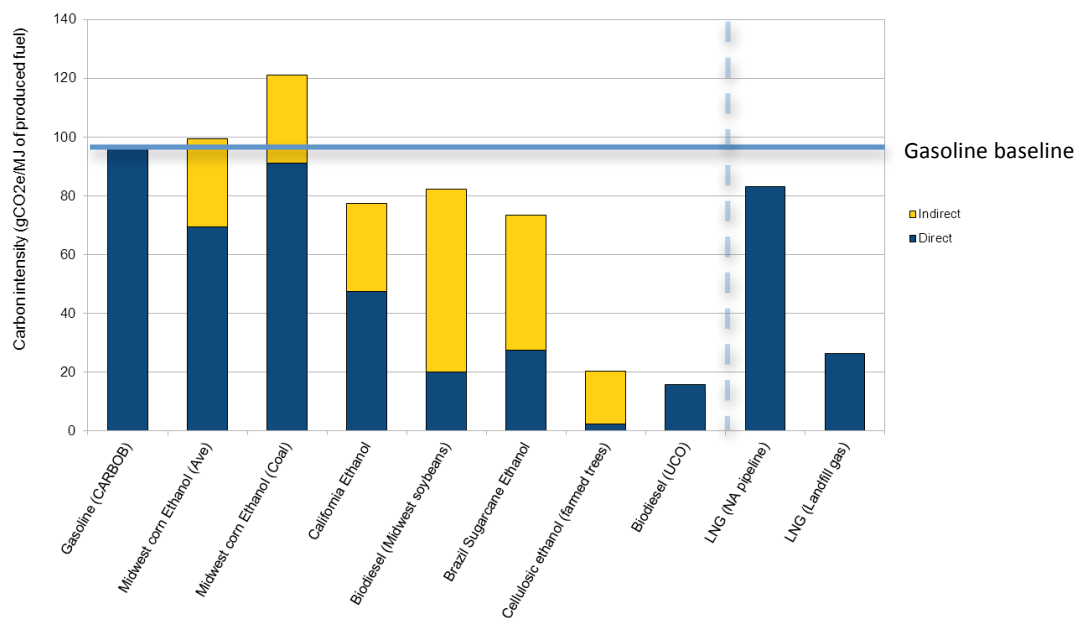


Figure 5: Overview on life cycle emissions of different biofuels and natural gas. Data are taken from CARB (2009b).

2.2. Economic actors

Fuel producers

There are a number of different fuel categories for transport: fossil fuels (including conventional and unconventional fuels), *biofuels*, electricity, and hydrogen. Fuel producers for all fossil fuels are here understood as refinery operators or, alternatively, as importers of refined petroleum. Biofuel producers are biofuel refinery operators (for detailed discussion see below). Hydrogen producers are operators of hydrogen production plants. Electricity producers are electric utilities. We focus on these actors for two reasons: A) Most of petroleum processing emissions occur at the stage of refineries; similarly electricity emissions occur at the power plant. B) Fuel producers, defined as above, comprise for all fuels a relatively small number of actors that control overall fuel supply. For fossil fuels, for example, it is the most upstream level where oil can be regulated within world regions that rely on oil imports.

Fuel producers have the following influence on GHG emissions:

1. Reduce processing emissions in refineries
2. Switch to low carbon fuels, e.g., from fossil fuels to low carbon biofuels such as sugarcane ethanol.
3. Shift to those fuels within a category that have lower upstream emissions, e.g. from oil from tar sands to conventional fossil fuels.

Specific instruments can be used to incentivize a reduction in the *carbon content* of fuels, e.g. renewable fuel quota, the Low Carbon Fuel Standard (LCFS) or emission trading for refinery emissions (see below for more detailed characterization). These instruments correspond to the carbon intensity factor in Figure 6. In addition, general price instruments such as a carbon tax or emission trading for all fuel related emissions (including downstream tail pipe emissions) could be applied at fuel producers. At this stage, the overall carbon content could be captured. Furthermore, price signals are induced at all relevant levels and provide indirect incentives for car manufacturers and consumers.

Car manufacturers

Car manufacturers cannot influence the carbon content of fuels. In particular, manufacturers of electric cars do not have influence on the GWP of electricity used to power the car. However, car manufacturers design motor and vehicle characteristics, and by this determine fuel efficiency, i.e. *tank-to-wheel* efficiency, and hence, also contribute to the life cycle characteristics of fuels in terms of GWP/distance. It is clear, that car manufacturers primarily should be incentivized and regulated in terms of tank-to-wheel efficiency. However, car manufacturers and fuel producers are to some degree dependent on each other. Supply (fuel producer) and demand (owners of fuel-specific vehicles) of different fuels has to match each other. This is mostly not a pure function of competitive markets as both the supply

and the demand side are oligopolies, and require high front-up investments in research, development and deployment and infrastructures. For example, electricity can only be delivered to electric vehicles but not to conventional cars. Electric cars would also profit from public charging stations or battery swap stations. For electric cars, a small number of electricity providers and national energy and climate policies, such as emission trading, have most influence on the fuels' carbon footprint. In fact, the provision of electricity for electric cars does not relieve the electricity providers from accounting for the respective carbon footprint. Similarly, conventional, and non-conventional liquid fuels and biofuels can have hugely varying emissions and environmental impact. Hence, fuel providers, including biofuel providers, need to be held fully responsible for the carbon and environmental footprint of their products. For more details, see chapter 3.4.

Consumers

Consumers can influence their transport induced carbon emissions through a series of decisions belonging to two categories:

Options to replace and reduce transport needs:

- Residential and work place location decision determine part of overall transport demand and, possibly, mode choice
- Offer and use of other transport modes (public transport, including taxis, non-motorized transport)

Options to influence the environmental impact of car driving:

- Decision on what kind of car, by this, determining fuel efficiency
- Decision of the use of fuel (e.g., in PHEVs or flex-fuel vehicles)
- Driving behavior, age of the car, constitution of the car

Crucially, consumers decide on their overall distance traveled. While there is some clear overlap with other factors, e.g. the consumer's decision on fuel efficiency, travel demand is the important factor to be incentivized and regulated at consumer level.

2.3. Policy framework

The case for complementary instruments

Policy instruments can be tailored to specific actors, or they can aspire to incentivize low-carbon activities economy wide. Both a carbon tax and a cap-and-trade system belong to the latter class. In fact, if policy makers want to effectively decarbonize economies until 2050, economy-wide instruments are necessary conditions. This statement will be fully motivated in chapter 5. Some economists argue that such an instrument is sufficient to achieve climate protection goals, and that other instruments would compromise efficiency and could harm the economy

(Sinn 2008). This perspective assumes a perfect market environment, where all agents behave completely rational and price signals can be effective. However, so-called market failures can have high impact, and induce major divergence from the social optima. Market failures in road transport are well known and motivate complementary instruments that incentivize specific actors. Crucially, the underlying reason for this misunderstanding is that perfect market equilibrium is mostly characterized in a static setting. However, when technological learning curves and front-up infrastructure investment become relevant, only a dynamic setting can characterize the social optimum. In the following, the specific case for two important policy interventions, fuel efficiency standards and infrastructure building, is shortly summarized.

The market for energy efficiency in the automobile industry appears to have a bias that leads to undervaluing future energy savings relative to their expected value. Markets tend to neglect apparently cost-effective energy efficiency options. Sometimes this is labeled the efficiency gap or energy paradox (Weber 1990). An important reason is insufficient information on the trade-off between higher technology investment and savings from better fuel efficiency at the point of purchase (OECD/ITF 2008). It is argued that the bias is chiefly produced by the combination of substantial uncertainty about the net value of future fuel savings and the loss aversion of typical consumers (Greene 2009). Loss aversion means that potential losses are valued more than potential gains, both measured from the status quo (Kahnemann et al. 1991). Future energy savings, of e.g. hybrid cars, are uncertain for several reasons (Greene 2009):

1. future energy prices are uncertain;
2. the energy efficiency realized in actual use is difficult to predict;
3. the quantity of use is not precisely known; and
4. the equipment's useful life is not known with certainty.

As a result of this uncertainty-loss-aversion bias (ULAB), consumers display a very steep discounting curve; consumers expect payback of automobile energy investments after 2-4 years. However, recent research shows that consumers do not even use lifetime discounting in evaluating automotive fuel economy. This is traditionally classified as 'market failure' but is not so much of a concern in as it displays consumer preferences. However, the phenomenon is problematic in so far as societal welfare (climate change, energy security) is considerably affected. Hence, policies addressing ULAB are justified from a social welfare perspective.

Another critical issue is the deployment of public infrastructure for transportation, comprising a road network for cars and public transport (and with less investment also bicycle lanes and pedestrian accessibility). The investment into car and public transport infrastructure determines the generalized marginal costs of usage of these modes. The generalized costs notably include time costs – in more affluent societies the major component of total transportation costs. Hence, public

investment decisions determine the relative attractiveness of different modes and the overall transport system sustainability. A mixture of transport demand management and public transport investment can produce significant co-benefits in dense cities (Creutzig and He 2009). A price mechanism on marginal costs, however, does not necessarily influence infrastructure decision of policy makers. Hence, marginal price instruments without appropriate infrastructure investments can produce suboptimal equilibria. This report focuses on policy instruments for fuel and energy producers and car manufacturers. Addressing consumer behavior and public infrastructure investment is beyond the scope of this study. In the following, the relationship between actors and relevant decomposition factors is discussed.

A decomposition factor for each actor

Arguing from an actor-based perspective, we suggest that each decomposition factor of GHG emissions in road transport can be predominantly attributed to a different actor.

- a. Fuel producers: carbon intensity
- b. Car manufacturers: energy intensity
- c. Consumers: travel demand (and realized mileage)

Hence, policy instruments should target actors by focusing on their respective decomposition factor. This principle is outlined in Figure 6.

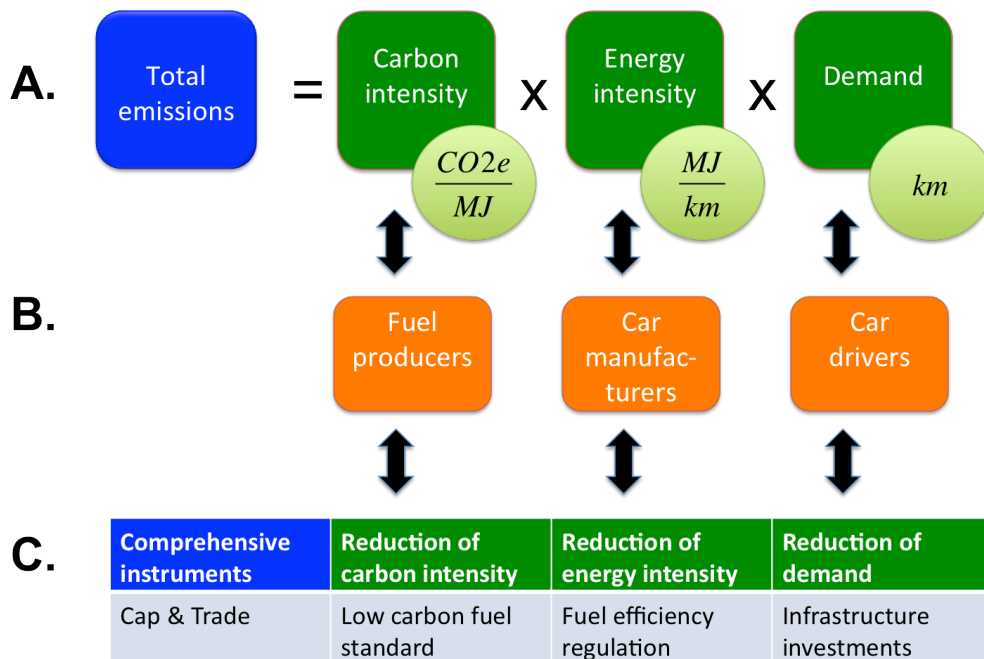


Figure 6. Decomposition of greenhouse gas emissions in the transport sector and corresponding policy instruments.

Responsibility for the GWP of fuels lies clearly with the fuel producers. The relevant measure here is the carbon intensity measured in CO₂e/kWh. For car manufacturers, responsibility goes with the energy intensity measured, e.g in MJ/km. This perspective is in contrast with current EU regulation where fleet averages are measures in g CO₂/km. In the current setting, which is vastly dominated by ICE, this is equivalent to fuel efficiency measured as energy intensity. The reason is the strict proportionality between GHG emissions and energy content of fuel. However, in the medium-to-long run, biofuels, electricity and hydrogen will gain larger market shares. For all of these fuels, proportionality between emissions and energy intensity is given for specific supply chains. Due to downstream mixing of upstream supply sources, however, carbon content cannot, in general, be inferred from energy intensity..

Interdependency between decomposition factors

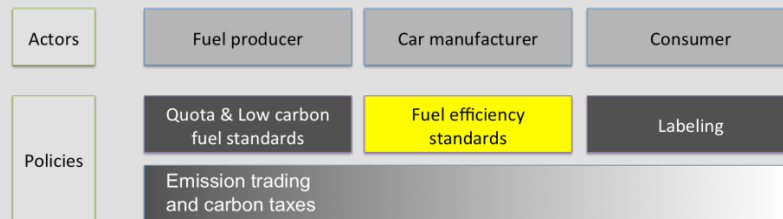
Carbon intensity and energy intensity are not completely independent from each other. For example, low carbon electricity requires electric vehicles to be utilized for transportation. In this case, the static incentives, however, align well: An electric vehicle has also higher tank-to-wheel efficiency (lower energy intensity) than an ICE. Nonetheless, dynamic efficiency cannot necessarily be guaranteed with this framework. For instance, electric vehicles could have too high initial investment costs, and face considerable obstacles to gain market shares, even if they are more cost efficient in the long run. In this case, however, we argue for instruments tailored to the dynamics of the so-called technological learning curve, but that should not be needlessly mingled with fuel efficiency standards, a static instrument.

More generally, in a pure market with perfect competition, a price instrument such as a carbon tax or cap and trade is sufficient to incentivize all options. Actor-specific regulation addresses market failures or dynamic inefficiencies of price instruments. In particular, fuel efficiency standards compensate for the so-called uncertainty loss-aversion bias of consumers. Car buyers systematically undervalue future fuel savings of more fuel efficient cars (Greene et al. 2009). Carbon intensity standards efficiently complement price instruments if price elasticity of gasoline is high, and competition is imperfect. Fuel producers would forward increased prices to consumers instead of investing into low carbon fuel infrastructures when there is no carbon intensity standard.

3. Regulating energy intensity

Summary Chapter 3

- The major world economies have adopted ambitious fuel efficiency standards for the timeframe until 2015-2020.
- Fuel efficiency standards are environmentally effective, and economically efficient with respect to climate change mitigation conditional on a suitable mix with other instruments.
- With increasing share of alternative vehicles, responsibilities for GHG emissions shift upstream in the fuel supply chain, requiring complementary instruments.
- If carbon intensity is regulated upstream, the car fleet is properly addressed in terms of energy efficiency or its volume-based equivalents.
- On the consumer side, informative color-labeling can induce purchase of more fuel efficient vehicles.



3.1. Existing standards

Fuel efficiency standards are mandated world-wide in the most important automobile markets in order to a) foster climate change mitigation and b) reduce oil dependency. Furthermore, in the light of tax and trading instruments as discussed in part II of this report, fuel efficiency standards can effectively complement price instruments that are not fully effective due to dynamic market failures (see also Plotkin 2008). In the following, an overview over fuel efficiency standards in different world regions is given.

European Union

The European Union started with a voluntary agreement, setting an industry-wide target of 140gCO₂/km to be reached collectively by members of each of the European, Japanese and Korean car manufacturers associations. In 2009, as not all individual members could fulfill their corresponding 25% reduction target, the EU mandated a industry fleet target of 130 g CO₂/km until 2015 with additional

10gCO₂/km to be achieved with complimentary measures, such as efficient tires, air conditioning, tire pressure monitoring, gear shift indicators (EC 2009c). As a weight-based average fleet standard, the manufacturer's individual target depends on its fleet characteristics and has to be fulfilled as a fleet average. That means a manufacturer offering smaller cars has to comply with a target below 130 g/km, vice versa a manufacturers focusing on upper car segments has to fulfill an overall target above 130 g/km. Beyond this, intermediate steps for the years 2012-2015 are also mandatory, e.g. 65% of the fleets must comply with the 130gCO₂/km target in 2012. For 2020, a long-term target of 95 g/km is defined. The latter will be reviewed in 2013. In order to foster the demand on fuel efficient vehicles 16 of 27 EU member states have CO₂- or fuel efficiency based registration and/or annual taxation.

Japan

Japan established mandatory fuel efficiency standards for 2010 and 2015 for gasoline and diesel vehicles under its Top Runner program (An et al. 2007). As in the EU, the fuel economy targets are fleet-based and weight-specific targets. The targets were derived from the best performance of current models. Additionally, acquisition and annual taxes are in place. In 2009, the Japanese government has implemented a limited tax incentive program fostering the purchase of low emitting and fuel efficient vehicles.

China

China implemented a weight-based fuel economy standards to reduce oil dependency. Standards are specific for each car. Currently an updated fuel economy standard for 2012/13 is discussed which would set fleet averages for each car manufacturer. In addition, excise and sales taxes incentivize the purchase of smaller-engine vehicles (Bradsher 2009). Current standards are relatively ambitious.

United States and California

In a joint rule making initiated by the Obama administration, the National Highway Traffic Safety Administration (NHTSA) and the Environmental Protection Agency (EPA) set an industry average target of 250gCO₂/mile (35.5 mpg) for vehicles in 2016, corresponding to the Corporate Average Fuel Economy (CAFE) target. As law makers allow EPA more flexibility in instrument design, the EPA regulation will be a little bit more stringent than the anticipated CAFE standard, i.e. by incentivizing direct and indirect efficiency improvements in air conditioning systems or taking into account off-cycle improving fuel efficiency technologies. The fuel efficiency standard is differentiated across two different vehicle classes, with 39 mpg for passenger cars and 30 mpg for trucks in 2016. California has already imposed rules on automakers that started in 2009 (Pavley I). These regulations will be harmonized with federal CAFE and GHG standards from 2012 onwards (CARB 2010a).

General observations

The historic development of fuel efficiency standards in different world regions is displayed in Figure 7. This figure is an update from (An et al. 2007) with

new and significant EU, US, and Chinese regulation. The data is displayed in MJ/km – as a possible measure of energy efficiency. This graph displays absolute fuel efficiency. Beside technology, the varying fuel efficiency standards can be explained by different fleet characteristics. For example, the US fleet is heavily tilted towards light trucks and diesel cars do not play a major role as in Europe.

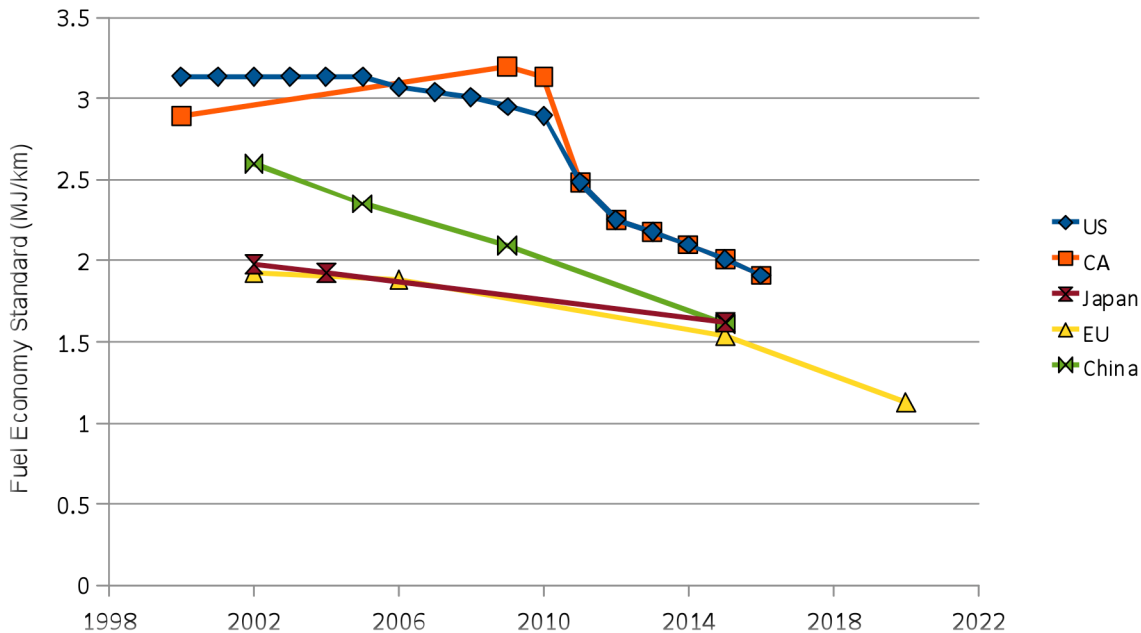


Figure 7. Energy intensity standards in selected world regions. Adapted from An and Sauer (2007).

The following observations emerge:

- Europe and Japan lead the world in terms of fuel efficiency.
- The US is still a laggard, but making huge progress with recent Californian and federal regulation, achieving the greatest absolute emission reduction from any global policy (An et al. 2007)
- For an emerging economy China sets impressive fuel efficiency standards, which are motivated by energy security considerations and strategic world-market positioning.

3.2. Evaluation

Fuel efficiency standards are here evaluated according to their effectiveness and their efficiency.

Effectiveness. Fuel efficiency can be effective a) with respect to reducing energy intensity and GHG emissions per car and b) with respect to absolute

reduction of GHG emissions. The first goal is generally fulfilled, or will be fulfilled, if fuel efficiency standards are controlled and enforceable, and penalties for non-compliances are sufficiently excruciating, i.e., higher than the corresponding compliance costs. This is the case for OECD countries, where non-compliance costs outweigh abatement costs. In general, fuel efficiency standards are effective in increasing fuel efficiency and reducing GHG per car.

An intensity reduction in terms of lower CO₂e/MJ is not necessarily equivalent to an absolute reduction in GHG emissions. Two different so-called rebound effects could compromise the desired outcome. First, car drivers could use the reduction in marginal cost from lower fuel use to increase total travel distance. Based on a review of 22 studies Greening et al. (2000) suggest a potential size of the rebound effect in the transport sector between 10%-30%, but highlight the existence of unmeasured components such as changes in automotive attributes related to shifts towards increases in weight (partially due to higher safety requirements), horsepower and acceleration of cars purchased. The rebound effect generally decreases with income and increases with fuel costs and level of congestion (Small & Van Dender 2007; Hymel et al. 2010). The sharp rise in oil prices in 2008 might therefore have led to stronger rebound effects than previously observed, but empirical evidence is currently still missing. Hence, this kind of rebound effect is low to moderate in magnitude and becomes less significant with rising real income.

Second, market forces could induce a higher additional production of fuel efficient cars without inducing a simultaneous reduction in gas guzzlers. To our best knowledge, there is no quantitative study on this effect. In fact, for quantitative evaluation, one would need to have access to pricing strategies of car manufacturers.

In spite of moderate rebound effects, total expected GHG abatement by fuel efficiency standards is significant and may be the single most effective climate policy in the transport sector (for quantitative evaluation see chapter 6.4 of this report).

Efficiency. Another key question deals with the efficiency of fuel efficiency standard. This can be split up into two questions. 1) Is the level of total fuel efficiency standards induced abatement options too low, more or less appropriate, or too much with regard to overall welfare? 2) Is this the most cost effective strategy to mitigate GHG emissions?

From a perspective of the economics of climate change, an overall reduction of GHG emissions of about 80% until 2050 is cost efficient (Stern et al. 2007, Edenhofer et al., 2010). For the EU, this implies 30-40% reduction till 2020, i.e. more than the currently envisaged 20% reduction. According to current EU regulation, the transport sector will reduce its GHG emissions by 7% until 2020 – and fuel efficiency standards are expected to contribute most. Hence, fuel efficiency standards certainly do not induce GHG emission reduction that are beyond the societal optimum. The question remains whether there are more cost efficient

options. According to the McKinsey cost curves and Delft, 65-80% of abatement options in the road transport sector below 100€/tCO_{2e} are automobile technologies and, hence, can be addressed with fuel efficiency standards. The remaining options are different kinds of biofuels. Hence, from this cost curve perspective fuel efficiency standards are cost-effective if the introduction of low-carbon biofuels is simultaneously addressed by policies – which is the case in most world regions. The details of policies that address the carbon content of fuels is given in Chapter 4. A comprehensive perspective on marginal abatement cost curves is given in Chapter 6.3.

Finally, what specific design of fuel efficiency standards is most efficient? For example, some world regions have fleet average requirements (e.g., EU) whereas other world regions have targets for each car of a specific weight class (e.g., China). Given the same level of overall ambition, the first rule is estimated to be more cost-efficient, as it gives flexibility to car manufacturers in determining where to invest into fuel efficiency.

In summary, fuel efficiency standards are an effective and efficient policy instrument to reduce GHG emissions in the road transport sector – if accompanied with policy instruments that also address other actors. In particular, fuel efficiency standards sufficiently address the responsibility of car manufacturers. Emissions that are outside of the control of car manufacturers, such as those related to the CO₂ intensity of fuels, must be addressed at the appropriate level, e.g. at fuel producers or suppliers. For example, fuel efficiency standards can address the energy efficiency of battery electric cars (BEVs). The CO₂ intensity of the electricity delivered must then be regulated at the utility.

Region	Target	Unit	Structure	Test
EU	CO ₂ emissions	gCO ₂ /km	weight-based fleet standard regression)	NEDC
California	GHG emissions	gCO _{2e} /mile	Absolute fleet standard for LDT1/LDT2	FTP 75
US	Fuel economy and GHG	mpg and gCO _{2e} /mile	Footprint-based fleet standards for cars/ light trucks	FTP 75
Japan	Fuel economy	km/l	Weight-based fleet standard	Japan 10-15
China	Fuel economy	l/100km	Weight-based fleet standard	NEDC

Table 1: Overview on fuel efficiency standards in some world regions.

3.3. Unit choice

In the light of the discussion in Chapter 2 and of the overview on existing standards, what is the appropriate unit to evaluate the environmental (climate

change) performance of automobiles? Vehicle fuel economy standards mandate a certain fuel use for some fixed distance traveled (e.g. litres/100km), or its inverse (e.g. miles per gallon). The EU explicitly sets CO₂ emissions standards in gCO₂/km. The Californian standard goes beyond CO₂ and regulates all GHG, including for example, nitrous oxides, measuring gCO₂e/mile. Here, gCO₂e is a shorthand for all GHG converted to CO₂ equivalent units. An overview of fuel efficiency standards in different world regions is given in Table 1. When the GHG content of fuel is known and constant – as is the case for the current fuel mix (gasoline and diesel) – then vehicle economy standards can easily be translated into CO₂ emission standards, since fuel use directly corresponds to emissions. This can be more challenging for other fuels, e.g. biofuels or electricity, where the GHG content is highly dependent on the fuel production process. How reasonable are each of the units? Relevant criteria are a) scope, b) adequacy, and c) perception. Each is explained in turn.

Scope. Measures based on liter or gallons of fuel required are limited in scope because they do not explicitly take alternative fuels such as electric vehicles or fuel cell vehicles into account. Currently, this is arguably irrelevant. However, with governments world-wide pushing for significant market penetration of electric cars, volume based measures become clearly outdated. GHG measures fulfill the requirement of scope in so far as they in principle cover all cars on an equal accounting base. The Californian measure goes beyond the EU measure in so far as non-CO₂ GHG emissions, such as nitrous oxides, are also accounted for. Energy-intensity based fuel efficiency standards, such as measures in MJ/km, would have sufficient scope. A conversion of MJ electricity into a equivalent volume based measures is also possible and under discussion. This would allow a smooth continuation of existing standards – that were implicitly based on energy-intensity.

Adequacy. Adequacy in this context refers to the question how appropriate the measure is with respect to incentivizing fuel efficiency measures of car manufacturers and simultaneously being accurate. From this perspective gCO₂e/km measures are in the medium-to-long run inadequate, because car manufacturers cannot influence the electricity mix which powers electric cars. Also, gCO₂e/km changes with consumer decisions. For example, in some countries consumers can chose providers that exclusively sell electricity from renewable sources, whereas the average mix can be heavily dependent on coal.

With increasing shares of alternative fuels and a corresponding shift for end-of-pipe to upstream emissions (chapter 2), car manufacturers' performance is best not evaluated in terms of life cycle emissions but in metrics that reflect tanks-to-wheel efficiency. Specifically, the tank-to-wheel efficiency of alternative vehicles can in the short-to-mid term be converted to established units of fuel consumption. For example, the performance of BEVs or PHEVs as measured in kWh or MJ per km or per mile would be translated in l/km or mpg based on the MJ content of one liter or gallon of gasoline.² In the long run, and with significant market shares of alternative

² People falsely believe that the amount of gas consumed by an automobile decreases as a linear function of the car's mpg, when in fact, the relationship is curvilinear (Larrick and Soll 2008). As a

vehicles a conversion to energy-based metrics, such as MJ/km is appropriate. Such measures would correctly address the car manufacturers' performance and can be in the long term common denominator for an efficiency standard for differently fueled cars – both fossil and alternative fueled cars.

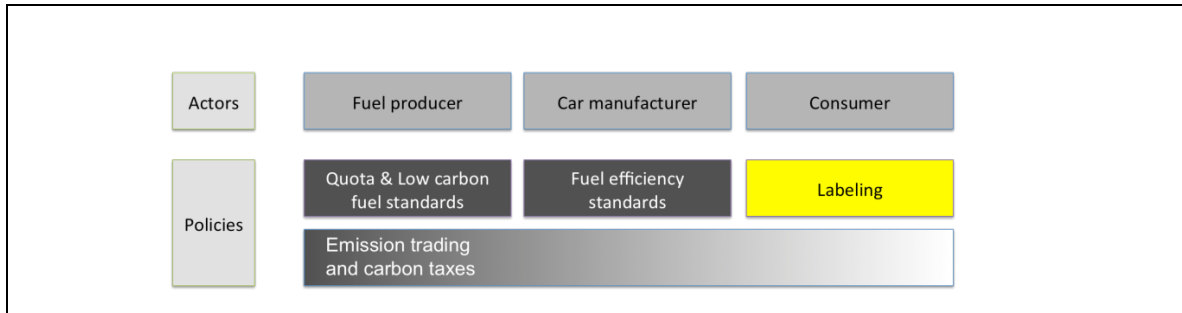
Box I: Parvley I

The Californian regulation from 2004 provides an interesting case study. California is the most advanced world region in regulating and incentivizing transport with respect to climate change. California is pushing forward a) emission trading, including the transport sector, b) a low carbon fuel standard and c) GHG regulation for vehicles. The latter is shortly reviewed in chapter 3.1. Vehicle performance is measured in gCO₂/mile. As indicated in the table below, this measure performs well in terms of perception and scope, but is not adequate. In particular, car manufacturers are responsible for upstream emissions with default values of 130gCO₂/mile for electric cars, 290gCO₂/mile for H₂ ICE cars, and 210gCO₂/mile for H₂ fuel cell cars. The burden of proof of lower emissions by, e.g. a more renewable electricity mix, sides with the car manufacturers. Also, default values provide no incentive to improve the efficiency of electric vehicles. For the next period, starting in 2012, California should convert to an energy intensity standard and harmonize regulation with the federal standard. The carbon intensity of electricity is better regulated further upstream.

In summary, a number of considerations favor an evaluation of fuel efficiency in terms of energy intensity, measured in established units of fuel consumption, and – in the long run - in MJ/km, providing a level-playing field across different kinds of cars. This is, however, only truly effective, if GHG emissions are regulated across all fuels upstream – to also provide a playing level field for the carbon content. As long as this is not the case, the current EU and Californian GHG measures should stay in place, as they provide a level-playing field for the currently dominating gasoline and diesel fuels and vehicles. As long as car performance is measured in terms of gCO₂e/km, BEVs and the relevant contribution of PHEVs can be considered as 0 gCO₂e/km – the CO₂ emissions related to electric cars must be addressed upstream where they can be controlled, i.e. at the utility level. In the medium run, and in the light of ever-more diversifying fuel supply chains for all kind of vehicles, car manufacturers should be coherently evaluated in terms of energy intensity – the factor they can control – and cease to be evaluated in terms of carbon intensity, better addressed at the level of fuel suppliers.

result, people underestimate fuel savings starting from a low baseline and overestimate fuel savings starting from a high baseline. Hence, for the purpose of purchase decisions, the US mpg values and the Japanese km/l values should be substituted by measures of fuel per distance, e.g., gallons per 10,000 miles, roughly corresponding to annual distance traveled.

3.4. Labelling



Fuel efficiency standards address car manufacturer. However, they potentially can also inform environmentally conscious people, or those who simply want to save fuel, on the cars performance upon purchase. In fact, markets work better, in general, when participants have complete information about the consequences of their purchase decisions. Labelling is an important instrument that provides information on fuel economy and CO₂ emissions and may lead to higher consumer awareness. In Europe, for instance, Directive 1999/94/EC requires all EU countries to display a fuel efficiency/CO₂ label on new cars. The label must include fuel consumption (l/100 km) and specific emissions of CO₂ (g/km) for that particular model. According to the directive, the new car fleet is sub-divided into colour-coded vehicle classes and the label indicates the fuel efficiency and CO₂ emissions class into which the particular vehicle falls (see, for example, the Dutch and French labels in Figure 8). In transposing the Directive, some member states developed labels which went beyond the requirements set out in the Directive (ADAC 2005). Holland and Switzerland (and the suggested German implementation) introduced energy rating systems with colour-coded classes (usually seven) along the lines of the household appliance energy label, i.e. color codes are specific for vehicle classes. Other countries have chosen absolute standards where labeling is absolute, i.e. colors are assigned irrespective of vehicle characteristics.

A review of the experience with EU energy and CO₂ labelling for cars concluded that its impact on consumer awareness and purchasing behavior has been marginal on average (TNO 2006). It appears that manufacturers' marketing strategies are often at odds with the label's 'ascetic' message. Labelling has not yet contributed significantly to actual emission reductions. But given its potential to raise consumer awareness, it should be used as part of a package of measures, which could include, for example, fiscal instruments. Moreover, the current decentralized approach is leading to diverse and disparate responses, reducing transparency and comparability across the EU. Regulators should therefore consider the harmonization of labelling based on the experience from those EU countries who have collected satisfying results with their schemes.

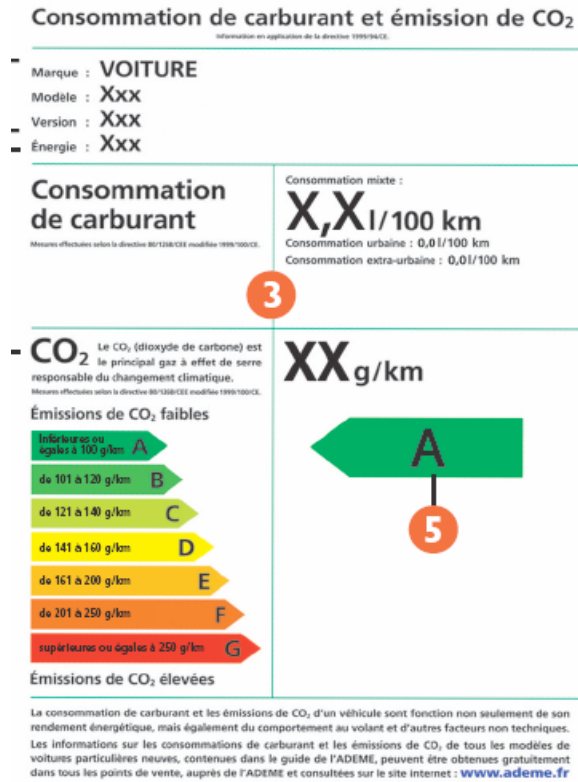


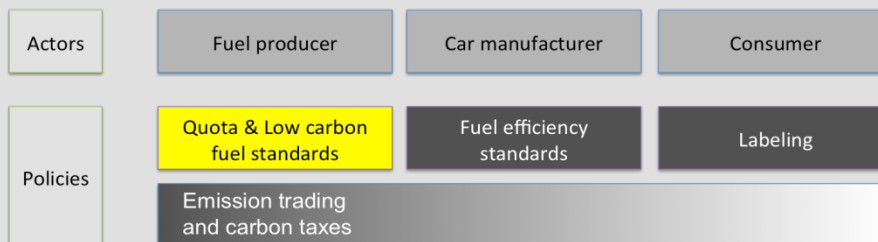
Figure 8: Dutch (left) and French (right) colour-coded label for cars' fuel and carbon efficiency

4. Regulating carbon intensity

This chapter deals with regulation and market-based instruments targeting the carbon content of transport fuels, excluding emission trading. Emission trading is thoroughly analyzed from next chapter onwards. Starting point are specific instruments such as renewable fuel mandates and then instruments with wider scope, such as low carbon fuel standards. Focus will be on the justification and evaluation of these instruments, highlighting policy effectiveness and limits.

Summary Chapter 4

- Renewable fuel standards push biofuels into fuel markets of major world economies but fail to account for carbon intensity and sustainability concerns.
- Low carbon fuel standards (LCFS) of California and the EU regulate the precise carbon intensity of fuels and incentivize the introduction of low carbon fuels.
- LCFSs fail to limit absolute carbon emissions, and, in fact, can generate perverse incentives.
- An additional comprehensive instrument, introducing a significant carbon price, can eliminate perverse incentives and complements the existing instrument mix.



4.1. Renewable fuel policies

Biofuels were seen as low or zero carbon sources of energy for transportation, and as a suitable mean to break oil dependency. Hence, the development of biofuels in countries and world regions has been supported by a range of policy instruments, including volumetric targets or blending mandates, tax incentives or penalties, preferential government purchasing, government funded RD&D (research, development, & deployment), and local business incentives for biofuel companies. To give a significant example: In Germany, tax breaks for biodiesel induced the production of 520,000 tons of biodiesel in 2005. This volume was significantly reduced to around 200,000 tons in 2009 after introduction of a tax

rate of 18 euro cent per liter (as of 2009) (Hogan 2009). The most powerful tool in the biofuel policy arena, however, are renewable fuel mandates. For example, the EU mandates 10% biofuels in the overall mix by 2020.

In the US, the Renewable Fuel Standard (RFS) program was originally created under the Energy Policy Act (EPAct) of 2005. As required under EPAct, the RFS increased the volume of renewable fuel required to be blended into gasoline to 7.5 billion gallons by 2012 (RFS1). Under the Energy Independence and Security Act (EISA) of 2007, the Renewable Fuel Standard program will increase the volume of renewable fuel required to be blended into transportation fuel from 9 billion gallons in 2008 to 36 billion gallons by 2022 (RFS2) (EPA 2010a). The RFS1 did not discriminate among biofuels and the quota was met mostly by domestic corn ethanol. The RFS2 sets explicit quota for cellulosic and other advanced biofuels, and biodiesel.

Non-discriminatory renewable standards are problematic as life-cycle emissions vary dramatically according to feedstock. Full life-cycle emissions comprise emissions from agricultural practice, refining, upfront land-use change and indirect land-use change. Major sources of uncertainty (and issue of political debate) are indirect land-use emissions (e.g., induced deforestation by higher world-market prices for ethanol) and nitrous oxide emissions. See Annex A for a full-fledged review of this issue. Conventional corn ethanol – currently dominating the biofuel market - is assumed to have higher GHG life cycle emissions than conventional gasoline (Searchinger et al. 2008, Hertel et al. 2010). The RFS2 has put regulation in place that requires different sorts of biofuels to cross certain threshold GHG emission reduction values (EPA 2010b).

A fundamental problem of biofuels is induced food insecurity by land competition between cash fuels and food. In order to attempt to solve this food security problem, the Chinese government, for instance, has forbidden new biofuel projects that use grain or other human foodstuffs, therefore supporting cassava bioethanol and the development of cellulosic bioethanol technologies (ICET 2008). Second and third generation biofuels are expected to have low life-cycle emissions, but, at the current stage, cannot be produced at competitive prices.

Box 2: The smallprint of RFS2³

As by volume the most relevant renewable fuel standard world wide, a closer look at the details of this regulation is worthwhile – to understand the issues behind decarbonization policies in transport. Specific lifecycle GHG emission thresholds for each of four types of renewable fuels were established, requiring a percentage improvement compared to lifecycle GHG emissions for gasoline or diesel. One of these fuels, ethanol produced from corn starch produced at a new natural gas facility using advanced efficient technologies *will meet the 20% reduction threshold compared to the 2005 gasoline baseline* according to EPA. Other fuels meet the 50% or 60% benchmark.

While the lifecycle methodology of the EPA is fairly comprehensive, a few important caveats were noted in a review of the RFS2 (Plevin 2010):

- EPA performs its analysis in a projected 2022 world, assuming a variety of technology changes. This is similar to accounting for today's emissions from coal power plants as if they had implemented anticipated CCS technology. In 2012 all and in 2017 most corn ethanol pathways analyzed by the EPA do not meet the 20% GHG reduction requirement, or even produce greater GHG emissions than the gasoline baseline.
- In the EPA model corn ethanol achieves productivity gains without additional use of fertilizer. The peak of corn ethanol production is achieved in 2016 - inducing most ILUC – while productivity assumptions refer to 2022 with additional 9.4% crop yield. Hence, ILUC are systematically underestimated.
- EPA attributes large soil carbon sequestration to biodiesel, most likely for increased use of no-till. However, no-till may increase N₂O emissions (Six et al). There is uncertainty on this issue, but EPA treats net soil carbon sequestration as a fact.
- Cellulosic ethanol obtains a low GHG rating by co-product credits generated by electricity from biochemical cellulosic refineries that displaces the average US grid electricity. Taking the average US grid as benchmark is a courageous assumption. More detailed analysis could significantly change the life cycle emissions.
- An additional supply of biofuels reduces the world market price of petroleum, by this increasing its demand. In one study, the global petroleum effect is estimated to be around 27% implying that each MJ of biofuel replaces 0.73 MJ of petroleum (Stoft 2009). Hence, biofuels that are less than 27% below gasoline baseline could have a net positive global warming effect. This effect is acknowledged but not modeled by EPA.

Most importantly perhaps is the treatment of uncertainty. EPA performs a basic uncertainty analysis. A number of uncertainties are completely ignored, most importantly the uncertainty about the fraction of land displaced by biofuels that must be replaced elsewhere and the assumed production period (Plevin et al. forthcoming). As a result, numbers are presented with relative certainty where

³ A modified version of this text has been published at Environmental Research Web (The smallprint of the RFS2, Felix Creutzig)

epistemic uncertainty dominates. Two additional important issues go beyond pure carbon accounting. First, there is considerable interaction between biofuel and food production. The EPA's comprehensive analysis treats reduction in food consumption, e.g. in India and Africa, as a GHG benefit. Without these shifts from food to fuel production, biodiesel from soybean would not meet the threshold. Second, the economic feasibility of large scale cellulosic ethanol production is unclear. For example, target values for biodiesel have already been scaled down by more than 90% for 2010. In summary, EPA's carbon accounting should be taken with some care. In particular, today's corn ethanol may have higher than baseline gasoline GHG emissions (Hertel et al. 2010). By focusing on potential 2022 technologies, this emission disbenefit is insufficiently reflected. Some policy maker pressure the EPA with respect to corn ethanol, arguing that corn ethanol production decreases energy independence and produces jobs.

4.2. Low carbon fuel standards

A low carbon fuel standard (LCFS) is different from renewable fuel standards in that a) it mandates a specific overall decrease in the average carbon intensity of all fuels and b) it accounts for the carbon emissions of each individual fuel, including non-conventional fossil fuels. The primary purpose of an LCFS is to reduce the carbon intensity of fuels for light-duty vehicles. As such, an LCFS provides a level playing field across all fuels, rather than mandating specific fuels of the RFS. It targets fuel suppliers – refiners, importers, and blenders of passenger vehicle fuels – and requires that the average GHG intensity of their fuel mix be reduced by a specified percentage of baseline carbon intensity. This gives supplier the flexibility to reduce emissions by switching fossil fuel feedstock, providing low carbon biofuels, electricity, and hydrogen, or by improving the efficiency of their fossil fuel supply chain. Lifecycle GHG intensity is defined as grams of carbon dioxide equivalent per megajoule of fuel energy (gCO₂e/MJ). Non CO₂-GHG, such as methane and nitrous oxide, are converted into CO₂ equivalent emissions (CO₂e). Emissions for each fuel are based on complete lifecycle analysis, including resource extraction, cultivation, pipeline transport, processing, conversion, production, distribution and consumption. The maximum GHG level is reduced over time. Suppliers that reduced the average carbon content of their fuels below target receive credits that can be sold to other suppliers.

Implementation

California. Executive Order S-01-07 from January 2007, issued by Californian Governor Schwarzenegger, mandates an emission reduction of 10% from the entire fuel mix by 2020 (Schwarzenegger 2007; CARB 2009b). The final rules were adopted by the Californian Air Resources Board (CARB) in April 2009; implementation started in January 2010. Gasoline and diesel and their substitutes have been assigned carbon intensities in gCO₂e/MJ based on lifecycle GHG intensity, adjusted for corresponding vehicle drive–train efficiency. The so-called default and opt-in rule provides a conservative estimate of GHG estimate for each fuel, adjusted

for processing. Companies may chose to opt-in and obtain additional credits by providing evidence that the fuel they produce has lower GHG intensity than the default value. The two regulated fuels, gasoline and diesel, and their substitutes need to decrease their GHG intensity by 10% from 2010 until 2020 (CARB 2009b). The LCFS utilizes market-based mechanisms to extend choices to suppliers for reducing emissions while responding to consumers; fuel providers may a) reduce emissions from processing or b) buy and blend a low-carbon biofuels, such as ethanol, into gasoline or diesel products or c) purchase credits from power utilities, based on their average carbon intensity, or hydrogen owner at the point of delivery, supplying low-carbon certificates for electric or hydrogen vehicles. Eleven U.S. states in the Northeast and Mid-Atlantic Regions, and British Columbia and Ontario have signed letter of intents, and partially legislation, to introduce LCFS in coordination with California (Massachusetts Government 2008; Taylor et al. 2008).

European Union. In the EU, the Fuel Quality Directive COM-2007-18 requires 6% reduction in CO_{2e} of transportation fuels from 2010 to 2020 (EC 2009c). Subject to further regulation, an additional 2% reduction should be obtained through the introduction of electric cars and environmentally friendly capture and storage technologies. An additional 2% reduction is to be obtained through the purchase of credits under the Clean Development Mechanism. The Fuel Quality Directive allows reduction of CO_{2e} in the fossil fuel lifecycle, e.g. by improving the efficiency of exploration and processing, and also via the introduction of renewable fuels that have lower lifecycle emissions than conventional fuels. Indirect life cycle emissions are not (yet) part of EU life cycle accounting. Electricity is not part of the 6% target; hydrogen could be included in future regulation.

Expected effects of LCFS

The LCFS will be effective in creating incentives to increase efficiency in exploration and processing of conventional fuels, and switching to low-carbon fuels. In the EU, most reduction in carbon content is expected via introduction of renewable fuels (EC 2009c; Arnold 2009). However, due to low penetration of flex-fuel vehicles in Europe, a high percentage (above 10%) of ethanol in the overall fuel mix is challenging. Hence, as a result a lower percentage of renewable fuels with high GHG reduction could be used, rather than a high percentage of renewable fuels with relatively low GHG reduction; for example, CNG and biomethane (Arnold 2009). In California, savings of the LCFS are estimated to be \$11 billion from 2010-2020; 25 new biorefineries could be built (CARB 2009b).

4.3. Evaluation

The LCFS is the first policy implemented that successfully addresses the carbon content of all fuels in transportation, treating gasoline, unconventional fuels, renewable sources and electricity on equal footing. For the first time, a full lifecycle analysis for all fuels is required.

However, four key shortcomings can be identified:

1. **Leakage/Shuffling.** Companies will seek to comply at lowest costs, for example by shifting the consumption of renewable fuels from other states to California while gasoline made from tar sands will be exclusively sent to non-LCFS states (Sperling and Yeh 2009). The global rebound effect (additional consumption in other world regions caused by lower fuel prices) could be 25% percent or more in which case the LCFS is less effective than anticipated (Stoft 2009). A broad international coverage of the LCFS is expected to reduce the shuffling and rebound effect (Farrell and Sperling 2007).
2. **Perverse incentives.** From an economic perspective, the LCFS creates perverse incentives: The LCFS acts as a tax on high carbon fuels but as a subsidy on low carbon fuels. If demand and/or supply of high carbon fuels is relatively inelastic, additional production of low-carbon fuels is incentivized which can increase total GHG emissions (Holland et al. 2007).
3. **Uncertainty in lifecycle emissions.** *Lifecycle analyses* are more comprehensive than in the RFS2 in including all fuels, not only biofuels. Furthermore, uncertain projections into the future are avoided. However, major uncertainties **with respect to ILUC** and to a lesser degree nitrous oxide emissions of biofuels remain, and a comprehensive policy strategy for this issue is lacking. Further research is needed to continuously increase the data accuracy on ILUC and update the look-up table.
4. **Inconsistency in setting incentives.** Electric utilities generate credits by fueling electric cars. Utilities are credited with the carbon intensity gain between gasoline and electricity times factor 3. As accounting is based on the average electricity mix, no significant incentive is given to reduce the carbon intensity of its electricity mix. Furthermore, those who invest into low carbon technologies (manufacturers of alternative vehicles) are not rewarded but instead are burdened with 130 g CO₂ per mile from the upstream supply chain. A more encompassing instrument would also incentivize the electricity sector.

Shuffling, leakage and perverse incentivizes can hardly be cured by different design of LCFS and its European counterpart, the FQD. In fact, these shortcomings motivate a complementary quantity-based price instrument, such as cap-and-trade, as discussed in part II of this report. However, the specific inconsistencies can be treated by changes in design. Low carbon fuel standards are motivated by the lack of low-carbon fuel infrastructure of fuel providers. If such a market failure persists, low carbon fuel standards are justified but should be specific in addressing actors who bear responsibility. For example, a LCFS may focus on liquid fuels. Feed-in-tariffs or similar instruments may simultaneously incentivize low-carbon resources in the electricity sector.

Here, we end with the discussion of specific policy instruments in the transport sector and hand over to a comprehensive view of cap-and-trade as a fully effective and efficient price instruments providing a level playing field over all fuels. We will discuss the role and interaction of current specific and potential economy-wide policy instruments in Chapter 7.

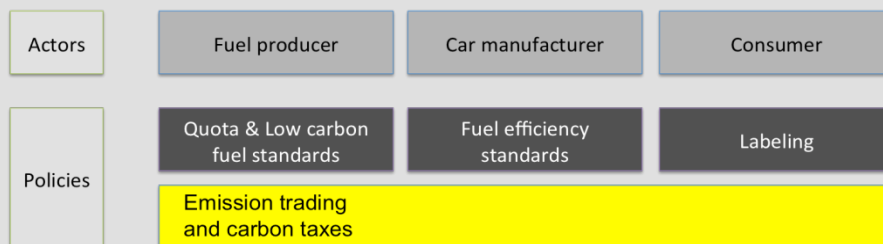
Part II: Closing the policy gap with cap-and-trade

Part II investigates the rationale, design and economic impacts of cap-and-trade for road transportation. Chapter 5.1 reviews the central role of market-based instruments in the climate policy instrument mix. Chapter 5.2 examines the choice between fuel taxes and emission trading as carbon pricing tools. Chapter 6.1 proceeds to discuss central design elements of a road transport cap-and-trade system. Chapter 6.2 applies marginal abatement cost curves (MACC) to analyze economic impacts of European road transport inclusion to the EU ETS in terms of EUA price changes and shifts in sectoral abatement. Chapter 6.3 estimates the quantitative impact of existing transport climate policies on 2020 targets, and hence potential inclusive emission trading schemes, in Europe, USA and California. Finally, chapter 6.4 reviews the option of linking regional ETS comprising road transportation.

5. Why market-based instruments are essential

Summary Chapter 5

- Compared to standards, market-based instruments are better suited to internalize the climate externality. They incentivize all abatement options at harmonized marginal abatement costs, eliminate rebound effects, create a level playing field for competing technologies, and feature lower informational requirements. Where price signals are ineffective, standards have an essential complementary role to play
- With policymakers relying on quantitative emission reduction targets and implementing cap-and-trade for other sectors in the economy, cap-and-trade for road transport has advantages over a carbon tax



5.1. Carbon pricing: central pillar in the climate policy portfolio

Climate change is appropriately characterized as the 'largest market failure the world has ever seen' (Stern et al. 2007). The standard economic prescription for addressing externality-related market failures is putting a price on the harmful activity to correct the system of relative prices and economic incentives. Hence, market-based instruments like carbon taxes and cap-and-trade systems are an appropriate starting point for systematically examining climate policy in the road transport sector.

In theory, a price on GHG emissions from road transport fuels will signal producers and consumers the scarcity of the atmospheric carbon sink and incentivize all available price-responsive abatement options in fuel production (including introduction of renewables), car manufacturing, and road transport consumption (see Figure 6). A carbon price will trigger all abatement options that are cheaper than the cost of complying with the price signal, i.e. paying a carbon tax or delivering valuable emission allowances. Efficient climate policy will set a single harmonized GHG price not only within, but across sectors and regions to ensure that the cheapest available abatement options are harnessed and more expensive measures need not be utilized, thus minimizing welfare losses (Böhringer et al. 2009). In technical economic jargon this condition for static efficiency is called harmonization of marginal abatement costs (MAC). Credibly announced future carbon prices will foster dynamic efficiency by extending the price signal over time and stimulate research and development (R&D) efforts, the market introduction of new technologies, and longer term behavioral adjustments (Edenhofer et al. 2006/Jaffe and Stavins).

Market-based instruments implementing a harmonized price on emissions are technology-neutral and create a level playing field across all fuel and technology chains in the road transport sector. This aspect will become increasingly more important as road transport fuels and technologies will be more diverse in the future and compete with each other for market shares (Chapter 1.3). For example, in Europe the power sector is already included in the EU ETS while gasoline and diesel are not facing an explicit carbon price. This puts electric vehicles on an asymmetric footing with traditional vehicle drive trains in terms of carbon pricing. In addition, market-based instruments enable the regulator to harmonize marginal abatement costs within and across sectors without need for assembling detailed techno-economic information, thus reducing informational requirements.

This combination of efficiency, comprehensiveness, technology-neutrality and frugality in terms of informational requirements distinguishes market-based instruments from the more targeted non-market approaches discussed in Part I of this study. By design, standards fail to efficiently incentivize all abatement opportunities and involve significant informational requirements to be efficient. Thus, carbon pricing lends itself as the appropriate central pillar in the climate

policy instrument mix. On these grounds economists such as William Nordhaus (2008) and Nicholas Stern (2007), in disagreement over a number of key issues regarding the economics of climate change, agree that carbon pricing is the central element of any climate policy instrument portfolio.

However, carbon pricing is not a panacea and non-market policies have an important role to play. In presence of plausible and well-established market imperfections that exist in addition to the original GHG externality (Chapter 2.3), complementary policy instruments will be required to ensure efficiency, even if non-price regulations entail the peculiar challenges discussed above (Fischer and Newell 2008). The basic reason is that the number of policy objectives (e.g. internalization of externalities) needs to be matched by the number of policy instruments (Tinbergen 1952). A single policy instrument cannot be specified so as to optimally address each of several market failures (Knudson 2009). Therefore, where well-established market imperfections inhibit efficient carbon price responses by relevant actors, complementary policy instruments such as fuel efficiency standards are required in the climate policy instrument mix.

Having established the case for market-based instruments as a key element in the road transport climate policy portfolio, we briefly discuss three concerns that are often put forward against its application:

- i) There will be adverse interaction with pre-existing fuel taxes
- ii) Market-based instruments do not significantly affect abatement and with standards already in place, they are redundant
- iii) Market-based instruments fail to set dynamically efficient incentives

Adverse interaction with pre-existing fuel taxes

It is sometimes argued that existing levels of road transport fuel taxation especially in Europe are already very high, and that further increases are not expedient from an economic perspective (e.g. Paltsev et al. 2004; Abrell 2009). In Germany, aggregate gasoline taxes (mineral oil tax plus VAT) amounted to 0.85€/liter (2.59\$/gal) on average in 2009 (MWV 2010). This corresponds to 367€ (455\$) per ton of CO₂ contained in gasoline..⁴

However, road transport generates several negative (non-climate) externalities that are addressed via Pigovian fuel taxes and other policy instruments (Parry et al. 2007). In addition, the state generally needs to raise revenues to finance public goods, including road infrastructure. The aggregate optimal⁵ transport fuel

⁴ Combustion of one litre gasoline leads to 2.315 kg CO₂ emissions (Carbon Trust 2008). Throughout part II, the exchange rate from € to US\$ is 1.24 (ECB 2010).

⁵ If the fuel tax is used to tackle different externalities simultaneously, it is principally not possible to achieve the first best outcome as argued above (Tinbergen 1952; Knudson 2009). Also, the fuel tax can only indirectly control some important externalities such as congestion, accidents, noise, and

tax hence derives from the combination of several Pigovian fuel tax elements, plus the rationale for raising funds for public goods (Parry and Small 2005). Specification of the optimal level of the Pigovian fuel tax is subject to substantial debate as it involves the identification and contested evaluation of negative externalities such as noise, accidents, congestion, energy security (including monopsonic behavior vis-à-vis OPEC), social costs of Middle East conflict, and the less tangible cost of other geopolitical conflicts (Parry et al. 2007). Conceptually, if externalities are not correlated with each other the optimal fuel tax is equal to the sum of marginal costs of the externalities, and a carbon tax would simply be added to the aggregate Pigovian tax (Newbery 1992)

Optimal taxation considerations also touch upon the question of optimal instrument choice. Some externalities (local air pollution, congestion, accidents) are related to distance or area and time of day travelled rather than fuel consumption. Road tolls would be the more appropriate tools to tackle these. Where these alternative instruments are not considered feasible, fuel taxes are usually used as a reasonable proxy (Stern 2003). For tackling the GHG externality of road transport fuels, carbon pricing is widely considered the perfect policy instrument (e.g. Parry et al. 2007; Stern 2003).

Some analysts find that present European Union fuel tax levels are not justified by transport externalities and general taxation requirements (e.g. Paltsev et al. 2004; Parry and Small 2005) while others consider EU fuel taxes as too low (Stern 2007; Proost et al. 2009). In the United States, fuel taxes are much lower than in Europe at around 0.08€/liter (0.24\$/gal) (EIA 2010) and there is agreement that this level is not overly high (Paltsev et al. 2004), with some analysts arguing that US fuel taxes should be raised (Parry and Small 2005). This report assumes that governments must view current taxes to be optimal, otherwise they would have changed them (Newbery, 1992). Where carbon taxes are not already implemented, a price on carbon would add to the current fuel tax.

Redundancy and lack of scale

In the extreme case of strong non-price regulations there is a concern that carbon pricing is obsolete if all available options are exogenously triggered by standards (Kågesson 2008). Indeed, the analysis of non-market policies in the European Union, United States and California in Section 6.3 demonstrates that substantial emission reductions can be expected.

But there are two arguments against this objection. First, under incomplete information there can be unanticipated abatement potentials that are not captured by standards but would be induced by carbon pricing. Second, Part I demonstrated that even a combination of standards will likely fail to incentivize *all* available abatement options, in particular demand side reductions.

local air pollution. Hence, a fuel tax tackling several and only indirectly related externalities can be optimal in a second-best sense only (Parry and Small 2005).

This point is illustrated by Figure 9. It shows an aggregate MAC curve (MACC) from CE Delft (Blom et al. 2007) for road transportation, and its decomposition into two MACCs comprising only technical abatement options and behavioral adjustments. The behavioral MACC is based on a constant price elasticity of fuel demand of 0.2, i.e. a 10% increase in fuel price would induce 2% reduction of fuel consumption. Even if all of the technical measures are implemented by means of standards, the demand side MACC is still responsive to a carbon price. Hence, carbon pricing is not obsolete even in presence of strong technology standards. Finally, standards cannot address rebound effects (chapter 3.2) while cap-and-trade will do so as they directly control the volume of emissions.

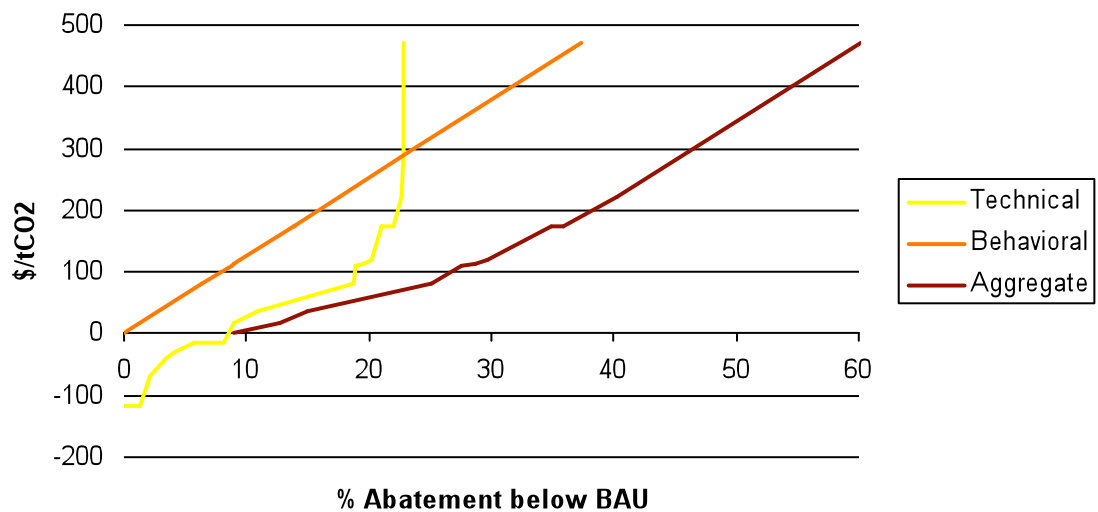


Figure 9: The CE Delft road transport marginal abatement cost curve as an aggregate, and decomposed into technical and demand side behavioral options. Even if all technical measures are implemented via standards, there is still a behavioral response to a price on carbon.

It is sometimes argued that the behavioral response to gasoline fuel price increases of 0.035-0.07 €/liter (0.10-0.20\$/gal) resulting from a carbon prices of 15-30€ (19-37\$) per ton CO_{2e} are 'too small' to trigger 'substantial' quantities of abatement (Ellerman et al. 2010, p.22). But empirical studies of fuel price elasticities show that on aggregate people and companies do indeed respond to fuel price changes, with short-term elasticities of 0.25 and long-term elasticities of 0.64 (Goodwin et al 2004; a price elasticity of 0.25 means that 1% fuel price increase lead to 0.25% reduction of fuel demand). In addition, classifying price increases as 'small' requires a benchmark. One proper benchmark is the price that is required to achieve the environmental benchmark. With a cap-and-trade system in place the amount of emissions is determined by the cap, and the carbon price will adjust automatically to ensure goal attainment (alternatively, a carbon tax can be adjusted to achieve a quantity goal). If 'low' carbon prices suffice to meet the environmental

target this is not a sign of climate policy failure but an indication of sufficient low-cost abatement options in the system. Specification of the environmental target is an important but separate question from that of policy instrument choice. A bottom-up rationale on the complementarity between market-based and non-market-based instruments in road transport climate regulation is given in the companion paper (Creutzig et al., 2010).

Dynamic efficiency

In view of the scale of the challenge of decarbonizing road transportation over the course of the 21st century (Chapter 1.1), it is sometimes argued that market-based instruments are insufficient to trigger the level of non-marginal technological change that will be required.

But for stringent climate policies carbon prices are expected to rise over the 21st century (Edenhofer, Knopf et al. 2010), and innovators will anticipate this development. Consumers who have to pay for GHG-intensive fuels will be willing to invest in more efficient capital in order to evade these costs. Thus, they will take rising costs of carbon into account in their investment and development decisions. However, there are plausible market failures that suggest that market-based policies alone are insufficient to ensure dynamic efficiency (i.e. optimal technological change) in road transport abatement. These include concerns over the credibility and long-term incentive effect of carbon pricing (Brunner et al. 2010), socially beneficial R&D spillovers that private actors do not account for (Fischer and Newell 2008), or the anticipation that consumers will not reward energy and carbon efficiency of low carbon vehicles (Chapter 2.3). Thus, dynamic efficiency provides a central rationale for adopting policy instruments that complement the carbon price to remedy these market imperfections. On balance, this concern provides no genuine reason *not* to implement carbon pricing in the road transport sector, but calls for the adoption of supplementary instruments.

5.2. Taxes versus emission trading for road transport fuels

The previous section outlined the general rationale for market-based climate policy in the road transport sector. The question now arises which of the two major market-based instruments—a carbon tax or cap-and-trade—is preferable (e.g., Schäfer and Creutzig 2008). This section argues that against the backdrop of current international and national climate policy approaches cap-and-trade has some advantages over taxation.

The two approaches

A GHG cap-and-trade system⁶ creates a carbon price by requiring regulated entities to deliver an emission allowance for each emitted unit of the covered greenhouse gases. By restraining the overall level of usable allowances (the cap) below emission levels than would occur absent the trading system, a scarcity price for tradable allowances emerges on allowance markets. Economic agents will take this price into account in their activities, i.e. they will avoid emissions if this is cheaper than using an emission allowance. Among the most important cap-and-trade design choices are the setting of the cap, determining the point of regulation and sectoral coverage (i.e. which entities need to report emissions and deliver allowances), methods for allocating allowances to the market (free allocation or auctioning), and the use of revenues from auctioning. Provisions regarding regional and temporal flexibility in using allowances have an important bearing on system performance. Chapter 6.1 provides a detailed discussion of design choices relevant for a road transport fuel cap-and-trade system.

By contrast, a GHG tax does not directly control the level of emissions but obliges entities to pay a price for each emitted unit of the covered greenhouse gases (Nordhaus 2008). Economic agents will react in the same manner as when facing an allowance price, i.e. they will avoid emissions if this is cheaper than having to pay the tax. The main design issues in setting up a carbon taxation scheme concern the setting of the level of the tax and determining the point of regulation (i.e., which entities need to report emissions and pay the tax). Another important question – analogous to distribution of allowance value in a cap-and-trade system – regards the use of tax revenues (e.g. Burtraw et al. 2009).

In absence of uncertainty and market imperfections, a carbon tax and trading system are equivalent instruments. In theory, the most important asymmetry between taxes (prices) and trading (quantities) is their performance under uncertainty over marginal cost and benefit curves (Weitzman 1974; Hepburn 2006), and with respect to fossil fuel supply side dynamics (Sinn 2008; Kalkuhl and Edenhofer 2010). Importantly, with the Kyoto Protocol representing a quantity

⁶ We focus our discussion on cap-and-trade for road transport fuels since crediting systems bear much higher transaction costs (e.g. Nordhaus and Danish 2003). Stavins (2007) and Nordhaus and Danish (2003) discuss the design of cap-and-trade for the US case, while Ellerman et al. (2010) review the economic and regulatory lessons from the first years of EU ETS operation.

approach and the 2°C objective emphasized in the Copenhagen Accord (UNFCCC 2009)⁷ the international community appears to be heading for a quantity approach to climate policy.

The remainder of the Chapter is structured as follows. First, prominent arguments favoring taxes over trading for road transportation are reviewed. Then it is argued that given current policy targets and instrument choices emission trading is the preferable approach.

Arguments favoring taxes over trading

In the EU context several authors (e.g. Holmgren et al. 2006, Blom et al. 2007, Kampmann et al. 2008; Kågesson 2008) have warned that the inclusion of the growing transport sector with its relatively steep abatement cost curve into a pre-existing trading system may cause rising ETS allowance prices. Higher allowance prices intensify concerns over carbon leakage in trade-exposed and GHG intensive industries that are already covered by the trading system. As discussed in Box 3, even if allowance prices in such a trading system were to rise as a consequence of road transport inclusion a number of further conditions need to be fulfilled to turn this into a significant problem. With each regional context requiring a case-specific review, our analysis of road transport impacts on EUA prices in Chapter 6.2 finds that in the most plausible policy scenario allowance price changes in the EU context would be zero. Therefore, already the first of the conditions outlined in Box 3 would not be met.

Second, it has been argued that transaction costs of road transport inclusion may be high, in particular if the point of regulation is with the final consumer (Ecofys 2006). However, as discussed in Chapter 6.1 and supported by the overwhelming majority of studies investigating this issue, with upstream coverage of emissions transaction costs should be manageable and at the same order of magnitude as for other EU ETS participants, where they are not prohibitive (see Ellerman et al. 2010, pp245). Also, transaction costs for monitoring, reporting and verifying (MRV) emissions are identical for carbon taxation and trading. The additional cost from a carbon trading system arises only from the requirements of organizing a well-functioning carbon market.

⁷ See Meinshausen (2009) and WBGU (2009) for the global emission budget implications of achieving the 2°C objective.

Box 3: Conditions for legitimate concerns over carbon leakage

Carbon leakage occurs if climate policies in one region lead to a shift of emissions to other world regions e.g. as industries reschedule carbon intensive production. For carbon leakage being a significant concern for industries already regulated by a cap-and-trade system as a consequence of road transport inclusion, a number of conditions need to be met simultaneously:

1. The allowance price change induced by road transport inclusion is significant, since minimal changes do not trigger significant leakage.
2. If the allowance price rises substantially the carbon price elasticity of leakage is significant. These rates are largely unknown and methodically difficult to determine.
3. No policy instruments for effectively mitigating carbon leakage due to regionally asymmetric carbon pricing are in place.
4. The welfare loss from carbon leakage is larger than the efficiency gain from harmonizing marginal abatement costs, and a transport carbon tax better balances efficiency gains and carbon leakage costs

Our analysis in chapter 6.2 and 6.3 demonstrates that under plausible assumptions even the first condition will not be met in the EU, Californian and US case.

Preferability of trading in the transport sector

Two observations inform the argument of this section: (1) marginal abatement costs are uncertain; and (2) policymakers prefer quantitative emission targets and sometimes implement cap-and-trade in other sectors of the economy. To illustrate uncertainty over marginal abatement cost curves (MACCs), Figure 11 displays MACC estimates from several models for the European road transport sector in 2020. The differences are striking: at a carbon price of 50\$/tCO_{2e}, abatement estimates differ by a factor of ten from 2% (Enerdata-POLES) to 20% (CE Delft) of business-as-usual emissions.

Concerning policy targets, the EU 2020 climate policy package is based on a 20% quantitative reduction target relative to 2005 emissions by 2020 (EC 2009a, b, c). The United States envisage a quantitative target of 17% emission reductions below 2005 levels by 2020 (United States 2010; APA 2010). The announcements by China and India to reduce carbon intensity of GDP by 40-45% (China) and 20-25% (India) below year 2005 levels by 2020 also relate to emission quantities rather than to carbon prices. Hence, with quantitative economy-wide emission reduction targets envisaged by major economies, the academic debate over the generic preferability of quantities or prices appears to have been decided in favor of quantity controls on the international political level. In addition, in Europe the EU ETS already covers emissions from the power and industry sectors. The same situation will very likely soon apply to California, and possibly the United States,

where trading system are envisaged at least for the power sector (Point Carbon 2010).

Against this background, the argument for the preferability of trading over taxation in road transportation is twofold: First, where quantitative targets are to be achieved economy-wide cap-and-trade systems offer superior certainty in achieving the policy goal. Second, in presence of a trading system for other sectors, inclusion of road transportation into a cross-sector cap-and-trade system has a better prospect for efficiency.

When a fixed carbon tax is used to manage a carbon budget and marginal abatement costs curves turn out to be higher than expected, there will be a shortfall in abatement and failure in attaining the quantitative policy objective. The tax rate could be adjusted over time to ensure that the cumulative quantity target is achieved. But repeated adjustment of carbon taxes will involve delays, transaction costs and political controversies. Cap-and-trade system will attain quantity objectives by definition.

This also implies that it does not matter in which sector abatement ultimately occurs since the aggregate emission target will be achieved in the least cost manner anyways. Hence, if road transport fuels are part of a well-designed economy-wide cap-and-trade system, it does not matter which fuels are used in vehicles and how they are generated. For example, whether power for electric vehicles is generated using coal or renewable energy is irrelevant – the environmental target will be achieved. By setting the annual or cumulated cap, the regulator directly controls the aggregate level of emissions.

If a road transport carbon tax differs from marginal abatement costs in other sectors e.g. because these are covered by a cap-and-trade system with an allowance price higher or lower than the carbon tax, overall economic efficiency will be compromised. When transport fuels are generated in several sectors (e.g. crude oil refining, biofuel refining, power generation) facing different marginal abatement cost, this also implies a distortion within the transport sector. Bühler et al. (2009) explore this distortion for different transport modes in Germany, pointing out the competitive disadvantage of rail vis-à-vis road transportation. While power generation is regulated under the EU ETS, road transportation faces no explicit carbon price. By contrast, if road transport is included into an economy-wide emission trading system, the allowance price will adjust dynamically across sectors, thus ensuring efficiency as abatement takes place where it is cheapest.

The validity of this line of reasoning favoring emission trading over carbon taxes for road transport fuels clearly depends on the magnitude of the potential policy failure and potential inefficiencies. If the errors in policy-making turn out to be small, and minor failures in achieving quantity targets can be tolerated and

mitigated e.g. by means of compensation via flexibility mechanisms, the asymmetry between tax and trading will be weak.⁸

Illustrating the potential order of magnitude of welfare losses from sectorally diverging marginal abatement costs, Böhringer et al. (2009) compare three analyses of the recent EU climate package. They find that the asymmetric carbon prices in EU ETS and non-ETS sectors as implied by the EU climate package raise year 2020 climate policy costs by 0.25-0.6% in terms of total welfare, or 25-30% above the cost of the efficient policy.

Finally, a distinct argument favoring trading over taxes is related to the prospect for building an international climate regime. International emission trading would facilitate cooperation (e.g. via indirect transfers in form of allowance allocation), and the harmonization of allowance prices across countries as compared to harmonization of domestic taxes promises enhanced efficiency (see also Chapter 6.3). For this reason, the next chapter analyses the expected effects of cap and trade for road transport.

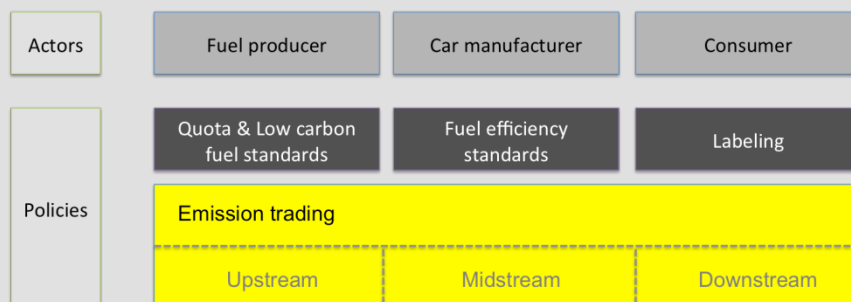
⁸ The EU climate package enables compliance in non-ETS sectors by means of CDM credits for about 3% of the emissions in these sectors. Also, EU countries can use statistical transfers of non-ETS sector reductions to comply with their reduction burdens, essentially enabling government level emission trading in these sectors (EU 2009a). Both provisions add flexibility in achieving the fixed quantity objectives. Another flexibility mechanism was proposed in the American Power Act of 2010, which would link the cap-and-trade allowance price and the road transport carbon tax (see Box 4). The design enables mutual adjustment of marginal abatement costs between the tax and trading regime by a complex mechanism.

6. Cap-and-trade for road transport fuels

This chapter first investigates the appropriate design of cap-and-trade for road transport fuels with a focus on the proper point of regulation. Then, an economic analysis of price and quantity effects of road transport integration to the EU ETS based on a comparison of marginal abatement cost curves from different institutions is conducted. It concludes with an assessment of the year 2020 abatement volumes induced by existing non-market policies and standards in the European Union, the United States and California.

Summary Chapter 6

- The point of regulation can be flexibly chosen as long as (1) coverage is comprehensive and avoids double counting, (2) all mitigation options are incentivized, and (3) transaction costs remain low. The feedstock and fuel production levels are recommendable points of regulation for all considered fuel chains, except for biomass where only refineries are recommended.
- Upstream regulation is preferable to midstream regulation.
- A comparative analysis based on year 2020 marginal abatement cost curves shows that for current EU climate policy objectives inclusion of the road transport sector to the EU ETS will leave EU allowance prices unchanged.
In the mid-to-long term, global emission trading by linking domestic systems markets delivers efficiency gains and levels the carbon playing fields across major markets and economies.



6.1. 6.1. Design

Point of regulation

The point of regulation specifies where in the transport fuel supply chain emissions are monitored and emission allowances are delivered to the regulator. While previous studies (e.g. Hargrave 2000; Winkelman et al. 2000; Stronzig and Bühler 2002; Bergmann et al. 2005; Kampmann et al. 2008; Kågesson 2008; Hartwig

et al. 2008; UK DfT undated) exclusively focused on points of regulation for gasoline and diesel, we consider five fuel chains that might become relevant in the future road transport mix (Figure 10).

Commodity chains can be characterized by up-, mid- and downstream processes and actors. For road transport fuels we distinguish the production of feedstock, fuel production (e.g. refining, power generation, hydrogen production), distribution and storage, and vehicle fuel consumption. Feedstock production is the most 'upstream' level in the fuel chain, while fuel consumption represents the most 'downstream' level. All other steps are somewhere in between, but are commonly referred to being upstream or downstream relative to other stages in the fuel chain.

Some (or parts) of fuel chains feature strict proportionality between the energy carrier and ('embedded') greenhouse gas emissions: The amount of CO₂ emissions that will ultimately be released from burning gasoline or diesel produced from one barrel of crude oil can be easily calculated. By contrast, where fuel production (at biorefineries, power plants, or hydrogen plants) uses heterogeneous primary energy inputs with different emission factors (coal, gas, oil, renewables, different biomass stocks) to produce a homogenous output (electricity, hydrogen, biofuels), only average values can be determined using life-cycle analysis (Creutzig et al., 2010).

This has two consequences for determining the point of regulation. Strict proportionality of downstream fuel consumption to life cycle GHG emission implies that any point of regulation can be chosen. However, homogenous final fuels with varying supply chains require coverage to be sufficiently far upstream to ensure there is an incentive for switching between primary energy carriers with different emission factors.

Another important aspect is that in competitive markets upstream costs of surrendering an allowance upstream (e.g. at the refinery) will be factored into the fuel price. In Germany, for example, fuel taxes are collected at tax warehouses but their burden is shifted to consumers.

Three principles govern the choice of the most effective and efficient point of regulation:

1. All fuel chain emissions should be covered and double counting excluded (effectiveness)
2. All emission reduction options in the sector should be incentivized (efficiency)
3. Transaction costs should be minimized (by choosing the point in the fuel chain where there are the fewest entities, where costs of monitoring and compliance are lowest, or where proper administrative structures are already in place)

With three principles, four potential points of regulation (feedstock production, fuel production, fuel storage and distribution, final consumption), and five fuel chains a comprehensive discussion needs to cover 60 facets. This is beyond the scope of this report, and we restrict the discussion to major issues in each fuel chain. Figure 10 provides an overview of fuel chains and their key characteristics.

Gasoline, diesel and natural gas exhibit substantial structural similarity. CO₂ emissions per unit energy are proportional throughout the fuel chain, and upstream process emissions e.g. in tar sand processing or oil refining may be covered separately. The major abatement options are switching away from carbon intensive feedstocks (e.g. tar sands, coal-to-liquid) and avoiding combustion of the final fuel altogether. The process emissions from tar sand or coal-to-liquid operations can be covered separately from the fuel content of the produced final fuel. Effectiveness and efficiency considerations enable regulation at any point in the fuel chain, thus transaction cost considerations will be the decisive factor. Since a detailed analysis of the relative transaction costs of the potential points of regulation is not available and beyond the scope of this study, only the downstream level of vehicles is excluded from the set of recommendable points of regulation as it would literally involve millions of actors. All other points of regulation are generally suitable for effective and efficient cap-and-trade inclusion. For fuels imported from regions that lack comparable carbon pricing systems, the proper point of regulation is at the import of the refined product.

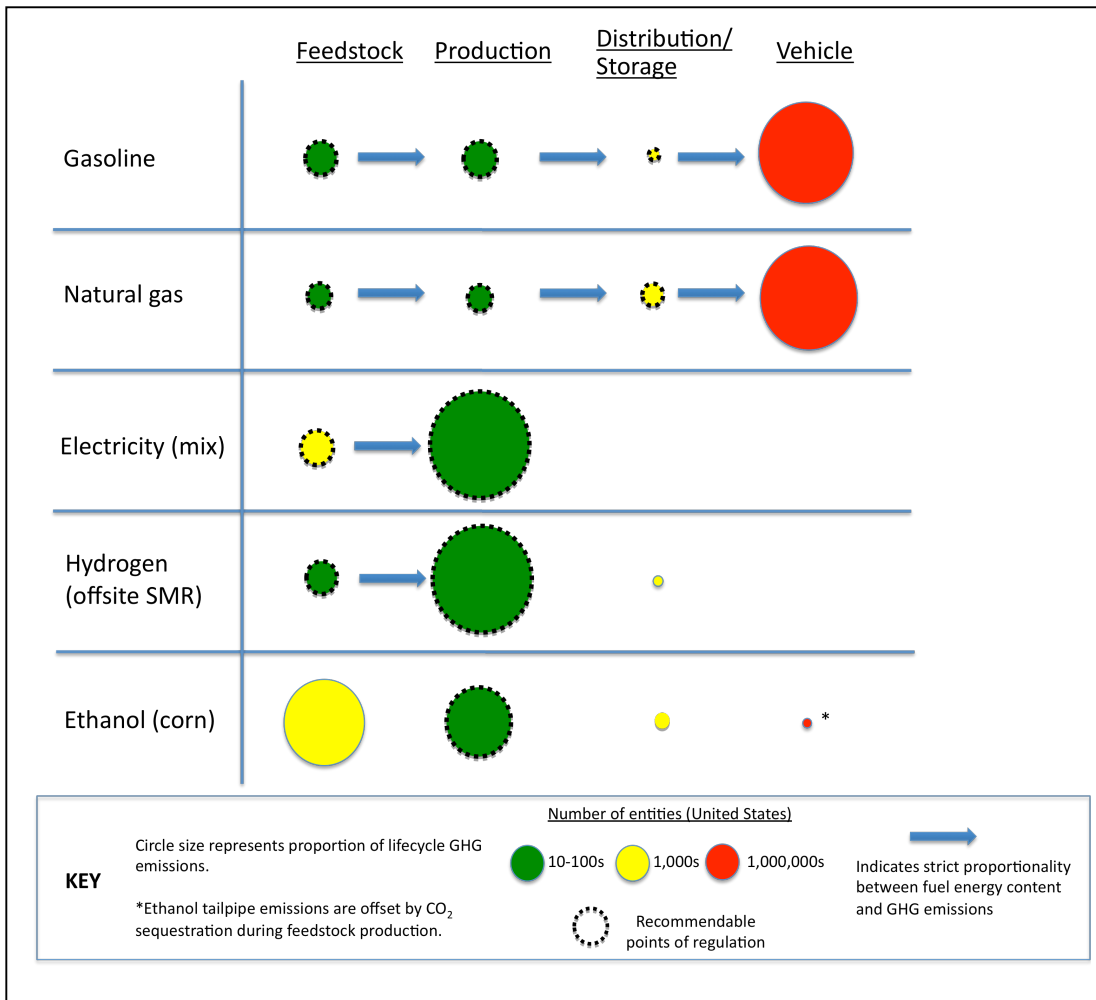


Figure 10: Optimal point of regulation for different transport fuel chains. Data sources: CARB 2009; Hargrave 2000; NREL 2010; Stavins 2007.

Upstream coverage of fossil-based road transport fuels e.g. at the level of fuel refining is not only widely recommended by the literature (see Kampmann et al. 2008 for a review), but all legislative proposals for cap-and-trade coverage of gasoline and diesel envisage inclusion of emissions at the level of fuel production (ACESA 2009; APA 2010 (see Box 4); California 2009; Australian Government 2008). In the EU ETS, refinery process emissions are already covered (EC 2003). Coverage at the fuel production level—i.e. oil and gas refining and importing companies—is considered an elegant approach which would enable a comprehensive economy-wide trading system at low administrative costs (Stavins 2007). Alternatively, the distribution level (e.g. gas distributors, fuel tax warehouses) has been proposed where pre-existing fuel taxation administration structures can be utilized to contain transaction costs (California 2009; Bergmann et al. 2005).

The hydrogen and electricity fuel chains also share crucial characteristics.

Both involve a homogenous final energy product (electricity and hydrogen) that can be created from a wide range of feedstocks with different emission factors (coal, gas, oil, renewables). Hence, switching to low-carbon primary energy inputs is only incentivized if the point of regulation is upstream at the level of feedstock or fuel production. For electricity and hydrogen imported from regions that lack comparable carbon pricing systems, the proper point of regulation is at the import of the product with average emission factors of fuel production systems in the country of origin have to be applied as the best proxy for accurate accounting.

Biofuels represent the most significant challenge for inclusion to cap-and-trade due to the substantial technical greenhouse gas accounting difficulties (Creutzig and Kammen, 2010; Creutzig et al. 2010). Emissions associated with biomass production will differ across crops, regions, farmers and even fields. Accurate monitoring of emissions at the farmer and acre level would involve significant transaction costs making this approach basically infeasible. In addition, even if such a system was put in place in one region but not on a global scale, *indirect* global effects of domestic biomass production still arise as world agrarian market prices will be affected by domestic production inducing changes in global emission levels that depend on market dynamics and land-use and land-use change patterns. Hence, lifecycle accounting at the level of biofuel production facilities appears as the second best point of regulation, as it enables differentiation across different crops that tend to feature different net emission factors. In analogy to electricity and hydrogen, this would enable switching across more or less GHG-intensive biomass feedstocks which would not be possible with regulation of homogenous biofuels (e.g. ethanol) further downstream. Imported biofuels from regions without a comparable carbon pricing system have to be accounted by using average values from lifecycle analyses.

Another proposal suggests to include vehicle manufacturers into cap-and-trade system by attributing their vehicle sales with expected lifetime emissions and requiring delivery of allowances from the manufacturer at the time of vehicle sales - effectively frontloading allowance expenditures for fuels for the consumer (Winkelman et al. 2000). This so-called midstream approach suffers from two fundamental problems. First, it is inefficient because there is no incentive to adjust driving behavior and fuel production. Second, attributing lifetime emissions to vehicles requires cumbersome definition of uniform emission factors for fuels and cars. Policy design is further complicated by the need of multi-year trading periods to enable car manufacturers surrendering allowances for vehicle emissions several years ahead.

In summary, there is some flexibility in choosing the appropriate point of regulation without compromising effectiveness and efficiency if (1) coverage is comprehensive and avoids double counting, (2) all mitigation options are incentivized, and (3) transaction costs remain low. The feedstock and fuel

production levels are recommendable points of regulation for all of the considered fuel chains, except for biomass where only refineries are recommended due to prohibitive transaction costs at the farming level. While it is theoretically possible to determine different points of regulation for different economic sectors (Hargrave 2000), consistency is necessary for avoiding loopholes and double-pricing.

Box 4: Road transport fuels in the American Power Act

The American Power Act (APA) introduced to the US Senate on May 12th by Senators Kerry and Lieberman includes road transport fuels at the level of refined fuel providers, i.e. refineries and importers of refined fuels. Overall, the scheme foresees inclusion of about 7,500 major stationary sources responsible for ~88% of year 2005 United States GHG in 2020 (APA 2010; CAIT 2010).

Road transport fuels are included by a special provision: every quarter, the Administrator (EPA) determines the next quarters' expected demand for allowances by the transport sector, based on historical fuel consumption. These allowances are deducted from the total quarterly allowance auctioning volume of the system. The road transport allowances are then sold at a fixed price to fuel providers, this price being equal to the previous quarter's auctioning clearing price in the ETS. Road transport sector allowances cannot be traded or banked, i.e. their use is restricted to compliance by fuel providers. In an indirect manner, this mechanism enables mutual adjustment of prices and quantities in the ETS sectors and road transportation: Changing auctioning prices in the ETS translate to changes in the fixed transport allowance price, inducing changes in transport fuel demand. Changes in transportation fuel demand alter the quantity of allowances eligible for auctioning in the ETS, thus ensuring a full feedback loop between the sectors that will contain the efficiency loss of not directly including transport to the ETS.

Other design features

We examine four additional choices in designing a cap-and-trade system including road transport fuels: i) setting of the cap, ii) allocation of allowance value, iii) temporal flexibility, and iv) quality of offset credits. Regional flexibility attained by linking different cap-and-trade systems is examined in Chapter 6.3.

The cap, i.e. the total of emission allowances allocated to the covered entities, is the central feature of a cap-and-trade system as it determines the level of environmental ambition. At least two aspects need to be taken into account when considering optimal sector caps: global climate policy objectives and economy-wide efficiency considerations. Sectoral caps in regional trading systems should relate to a region's global long term climate policy target such as the 2°C objective endorsed at Copenhagen (UNFCCC 2009). The major implication is that caps should be sufficiently stringent to achieve such ambitious reduction targets (Meinshausen et al. 2009; WBGU 2009).

In presence of an economy-wide emission reduction target setting an ETS cap inevitably implies a residual cap for non-ETS sectors. To ensure efficiency, the ETS cap should be chosen so as to harmonize explicit MAC (allowance prices) in ETS sectors with MAC in non-ETS sectors (e.g. Böhringer et al. 2009). If some road transport fuels are added to an already existing ETS – as could be the case in Europe – perfect policy design prior to the integration would imply that road transport inclusion has no impact on ETS allowance prices. The (implicit) pre-integration cap for road transportation should already imply identical MAC for transport and ETS sectors. Rising or falling allowance prices due to road transport inclusion can therefore be interpreted as signaling the inefficiency of pre-integration policy.

Allocation of allowances to the market has two important aspects, one touching upon efficiency considerations, the other concerning distributional consequences. We consider auctioning of allowances as the best approach for good performance on both dimensions. Regarding efficiency, theory states that allocation and efficiency are fully independent, but there are plausible empirical circumstances that can violate this presumption. These include perverse incentives when future free allocation is based upon current emission levels, market entry barriers if incumbents receive allowance for free (but new entrants do not), and the social costs of rent seeking as companies lobby for generous free allocation (e.g. Hepburn et al. 2006). These problems do not exist with auctioning of allowances.

Concerning distributional considerations, free allocation represents a transfer of wealth to the recipients of the allowance value. In competitive markets companies will pass through the opportunity costs of using emission allowances for compliance to consumers - even if they received these for free - because they might alternatively have sold the allowances on the carbon market (Sijm et al. 2006). With auctioning of allowances, companies will pass on the cost of allowances to consumers as well but auctioning proceeds remain with the general public. Allowance auction revenues could be returned to citizens to offset increased fuel prices ('cap-and-dividend'), thus reducing the net costs of carbon trading to households. Lump sum transfers of auctioning revenues will have progressive distributional climate policy effects (Burtraw et al. 2009), whereas free allocation ultimately benefits the usually more wealthy shareholders of the receiving companies and, hence, is regressive. Alternative uses for auctioning proceeds include reduction of distortive taxes (Goulder 1995) or financing low-carbon research and development efforts.

Cap-and-trade systems usually provide for temporal flexibility of abatement by enabling banking and, to a lesser extent, borrowing of allowances. Banking refers to the possibility of saving allowances for later use, thus setting an incentive to purchase allowances and/or implement early abatement to hold allowances as an asset. Banking will occur if the risk-adjusted value of allowances is expected to rise more than the general interest rate. As a result, allowance prices are smoothed over time. Borrowing, by contrast, refers to the possibility of lending allowances from future periods and will occur if it is expected that future interest-adjusted prices will

be lower than current prices. Enabling borrowing will have the effect of reducing present allowance prices. In all cap-and-trade systems, borrowing is limited to avoid the accumulation of debts that may undermine the integrity of the system when they are not honored e.g. due to bankruptcy. In general, temporal flexibility is desirable to smooth allowance prices over time which improves dynamic efficiency.

If cap-and-trade systems enable the use of credits e.g. produced by the CDM, this regional flexibility adds a set of new abatement options to the system, thereby shifting the MAC curve downwards and dampening ETS allowance prices (see Figure 12). For the environmental integrity of a trading system it is imperative that credits meet the additionality criterion. Additionality means that the project or policy which generated a credit actually reduced emissions below the levels that would have occurred in absence of the project. Without additionality, the use of credits will compromise environmental integrity of a cap-and-trade systems: credits not representing emission reduction crowd-out abatement in the covered sectors. Concerns over additionality in the CDM are reported e.g. by Schneider (2007). To respond to these concerns, sectoral crediting and trading approaches have been proposed to foster reliable additional mitigation while maintaining the regional flexibility and efficiency offered by the concept of credits (e.g. EC 2009d).

6.2. Economic impacts in the European case

This Chapter provides a brief economic analysis of EU road transport inclusion to the EU ETS based on marginal abatement cost curves from several institutions. General implications are equally valid for other world regions, but quantitative estimates may differ.

Concepts, data and policy scenarios

Marginal abatement cost curves (MACCs) are a standard tool for analyzing price and quantity effects in carbon markets (Ellerman and Decaux 1998; Criqui et al. 1999; Stankeviciute et al. 2008; Anger 2008). The global McKinsey (2009) cost curve is a popular example for such a curve. The basic idea of a MACC is to rank abatement options according to their cost per ton of GHG avoided (vertical axis), and indicate the quantities of abatement associated with each option (horizontal axis).

Marginal abatement cost curves can be derived in several ways, reflected in the varying assessments of different institutions (Clapp et al. 2009). Important choices when constructing MACCs concern the model structure (e.g. top-down vs. bottom-up model framework; scope of considered technologies and behavioral reactions; assumptions over discounting;), baseline assumptions (e.g. energy prices; economic growth; technological innovation) and policy scenarios (policies in the baseline).

Figure 11 displays several marginal abatement cost curves for the European road transport sector in the year 2020, and one aggregate MACC assessment of the

EU ETS sectors for 2020.⁹ A significant number of vehicle-based abatement options are already implemented due to current fuel efficiency standards. Of the aggregate road transport MACCs only CE Delft explicitly includes demand side responses.¹⁰ Including demand side reactions would unambiguously lower the other cost curves (see Figure 9). Also, taking the standards comprised in the 2009 EU climate package (Chapter 3.1) into account would also unambiguously lower these cost curves, none of which consider the effects of the policy package. Higher energy prices and lower economic growth would have the same effect: with higher energy prices, fuel savings from abatement entail higher benefits, thereby reducing the cost of achieving a specific amount of emission reductions. And with lower economic growth, a given abatement target can be achieved at lower cost because less emissions need to be reduced. Sluggish economic growth will reduce emissions already in the baseline.

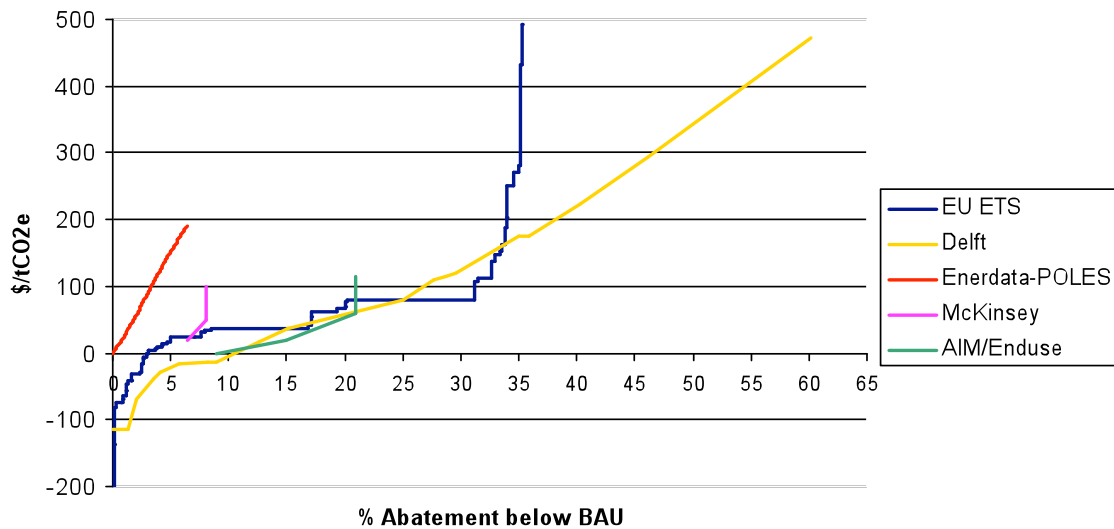


Figure 11: Comparison of year 2020 EU road transport sector marginal abatement cost curves from CE Delft (Blom et al. 2007), Enerdata-POLES, McKinsey and AIM/Enduse (as published in Clapp et al. 2009).

The EU ETS curve depicted in Figure 11 is adopted from Blom et al. (2007) and based on the Ecofys GENESIS and the Icarus database. Blom et al. state that their estimate is rather conservative, i.e. it tends to underestimate abatement potentials and to overestimate emission reduction costs. They report that this is the case because (i) the Icarus database is conservative in terms of emission reduction costs, (ii) it does not take end-use reductions (e.g. from increased electricity prices) into account, (iii) its technological learning assumptions are rather conservative, and (iv) it does not consider demand side substitution effects.

⁹ We thank Bettina Kampman from CE Delft for providing the MACC data set of their study (Blom et al. 2007), and Enerdata-POLES for providing the year 2020 EU road transport MACC from POLES.

¹⁰ We could not clarify this point for POLES/Enerdata.

In the MACC framework the possibility to use credits in a cap-and-trade system can be represented by adding the volumes and prices of credits to the schedule of available abatement options (Figure 12).

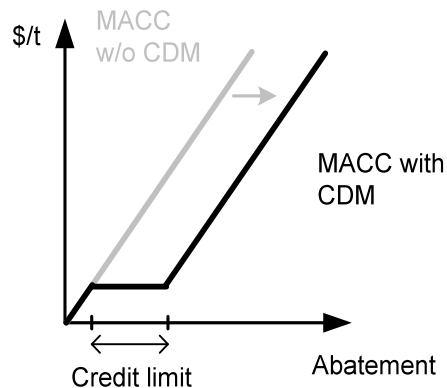


Figure 12: Including limited credit supply into a sector MACC. The supply of credits gives access to additional abatement options, with the price of abatement from credits being set by the credit world market. This formulation assumes that sector demand for credits does not impact the credit world market price, i.e. the ‘credit lever’ in the curve is flat.

The EU has specified a complicated set of rules determining the availability of credits for the 2013-2020 trading period in the EU ETS (see European Union 2009b). Our estimate for credit use is the mean of the average annual estimates summarized in Capoor and Ambrosi (2009, p.8), which amounts to 150Mt per year. We assume a CDM world market price of 30\$/t. As a new sector, road transport would increase the amount of credits available in the EU ETS. The reformed EU ETS Directive (EC 2009b, Article 11a) suggests that road transport would increase the amount of available credits in the EU ETS by 4.5% of year 2020 road emissions. In the policy scenario where EU emission reductions are enhanced from 20% to 30% relative to 2005, we assume that 50% of the additional abatement effort can be covered by credits.

Figure 13 illustrates the price and quantity impacts of integrating additional sectors to an existing cap-and-trade system. The horizontal axis depicts the sum of required abatement from both sectors. In our example, the section left of Q_{set} represents the abatement target for the ETS already in place, while the section to the right of Q_{set} denotes the abatement target for the road transport sector to be included. The vertical axis indicates the costs of abatement in \$ per ton GHG. The marginal abatement cost schedule for the ETS sectors originates at the left hand vertical axis and runs to the upper right. The transportation MACC originates at the right hand vertical axis and runs towards the upper left. The ETS pre-link allowance price P_{ETS} is determined by the intersection of ETS MACC and policy target (Q_{set}), while the Transport sector shadow-MAC is symmetrically given by P_{trans} . The optimal sector allocation of abatement and the corresponding optimal allowance price level are indicated by Q^* and P^* in the right hand panel of Figure 13. In this

example, it is profitable not to implement the most expensive abatement options in the transport sector but rather purchase allowances previously used in the ETS sector up to the equilibrium price P^* . In the ETS sectors, it is profitable to conduct additional abatement and sell (free allocation) or refrain from purchases (auctioning) the more expensive allowances to the transport sector. The aggregate welfare gain is indicated by the shaded area. Note that the situation depicted in Figure 13 indicates inefficient pre-integration design of climate policy: the marginal abatement costs differed between sectors.

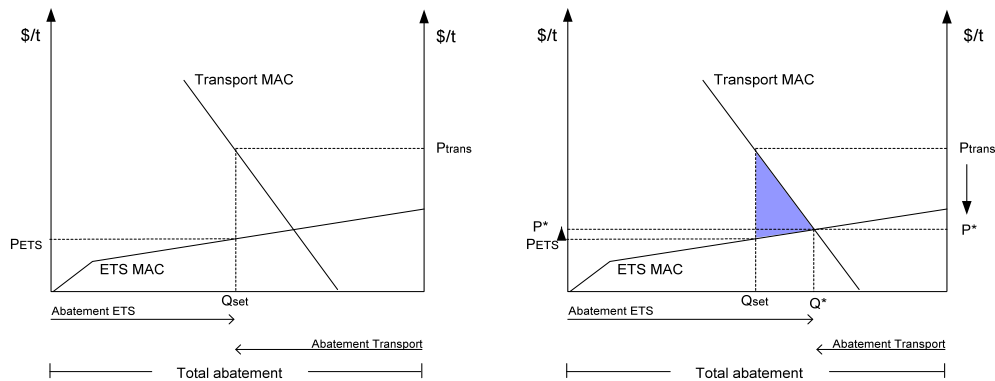


Figure 13: Pre- and post-link carbon market equilibria and efficiency gain of trade. The left figure displays the pre-link allocation of abatement across sectors, implying higher marginal abatement costs for transport. The right figure indicates the direction of price changes when integrating the transport sector, with the shaded area denoting the efficiency gain from trade.

With these tools and empirical estimates of EU abatement cost curves for road transport and the EU ETS at hand we can derive allowance prices and quantity impacts of EU road transport fuel inclusion to the EU ETS. Our assumptions on abatement targets in the default policy scenario are based on the EU-wide GHG reduction target of 20% below 1990 levels by 2020, as specified in the climate policy package adopted in 2009 (EC 2009a, b). The European Commission (EC 2008a) reports that EU policymakers adopted an implicit sector emission reduction burden-sharing where the EU ETS sectors need to reduce their year 2020 emissions by 21% below 2005 levels. The transport sector is supposed to reduce emissions 7% below its 2005 level by 2020. The Commission claims that these are the efficient burden-sharing levels as determined in modeling exercises, i.e. marginal abatement costs in these calculations are supposed to be harmonized across sectors.¹¹ Table 3 summarizes historic emissions, future projections, sector caps and abatement targets for the EU ETS and the considered road transport MACCs. The table displays

¹¹ In the EU Commission staff analysis (EC 2008a), the year 2020 carbon price level without CDM use is 48\$/t. CDM use is reported to lower the carbon price level to 37\$/t.

varying assumptions in BAU scenarios and projected abatement, illustrating overall uncertainty in future emission trajectories. All results are based on these key data.

Unit: Mt CO ₂ e	EU ETS (Delft)	Road Transport			
		Delft	Enerdata-POLES	McKinsey	AIM/Enduse
2005 emissions	2014	895	895	895	895
2020 BAU emissions	2363	1116	893	1000	1100
2020 cap in 20% scenario	1591	832	832	832	832
2020 abatement below BAU, absolute	771	284	61	168	268
2020 abatement below BAU	33%	25%	7%	17%	24%

Table 2: Year 2005 reference emissions, baseline emission projections, policy targets under the 20% EU-wide reduction target, and corresponding abatement target for the EU ETS and transport MACCs under consideration (in MtCO₂e) (Sources: Year 2005 emissions EEA 2010; for MACCs see Figure 11).

In addition to the 20% default policy a scenario with 30% reduction below year 2005 emission is investigated (EC 2010). For this enhanced EU effort we assume that EU ETS and road transport uniformly increase their abatement effort by 50%. Thus, modified ETS and road transport reduction targets are 32.5% and 10.5% below year 2005 emission, respectively. In a third policy scenario, we investigate the impact of the 20% default policy scenario while excluding the link to crediting schemes. This illustrates the relevance of regional flexibility in achieving emission reductions within the EU.

Results

Figure 14 displays the results of this exercise for the MACC estimates provided by CE Delft and Enerdata-POLES in the policy default case (see Appendix C.1 for all policy cases and models). Figure 15 summarizes the price impacts on the EU ETS and the road transport sector, and Figure 16 shows shifts in abatement quantities in the three policy scenarios for all models.

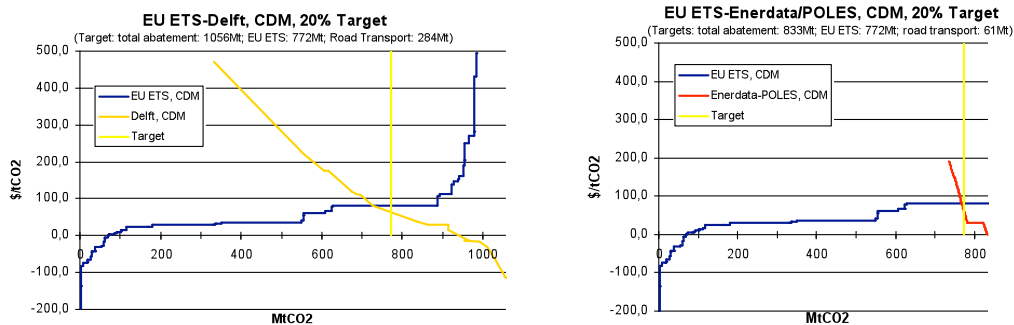


Figure 14 : Economic impacts of integrating the EU Road transport Sector to the EU ETS by 2020. The MAC curves include CDM access. The left hand figure shows impacts given the Delft transport MACC, the right hand figure for the Enerdata-POLES model. Pre-link prices and quantities are determined by the intersection of the MACCs with the vertical yellow line 'Target'. Post-link equilibrium results where the two MAC curves intersect. Both for the Delft (left) and Enerdata-POLES (right) transport MACC, transport integration incurs no price change in the EU ETS, because ample abatement opportunities exist at the respective price level.

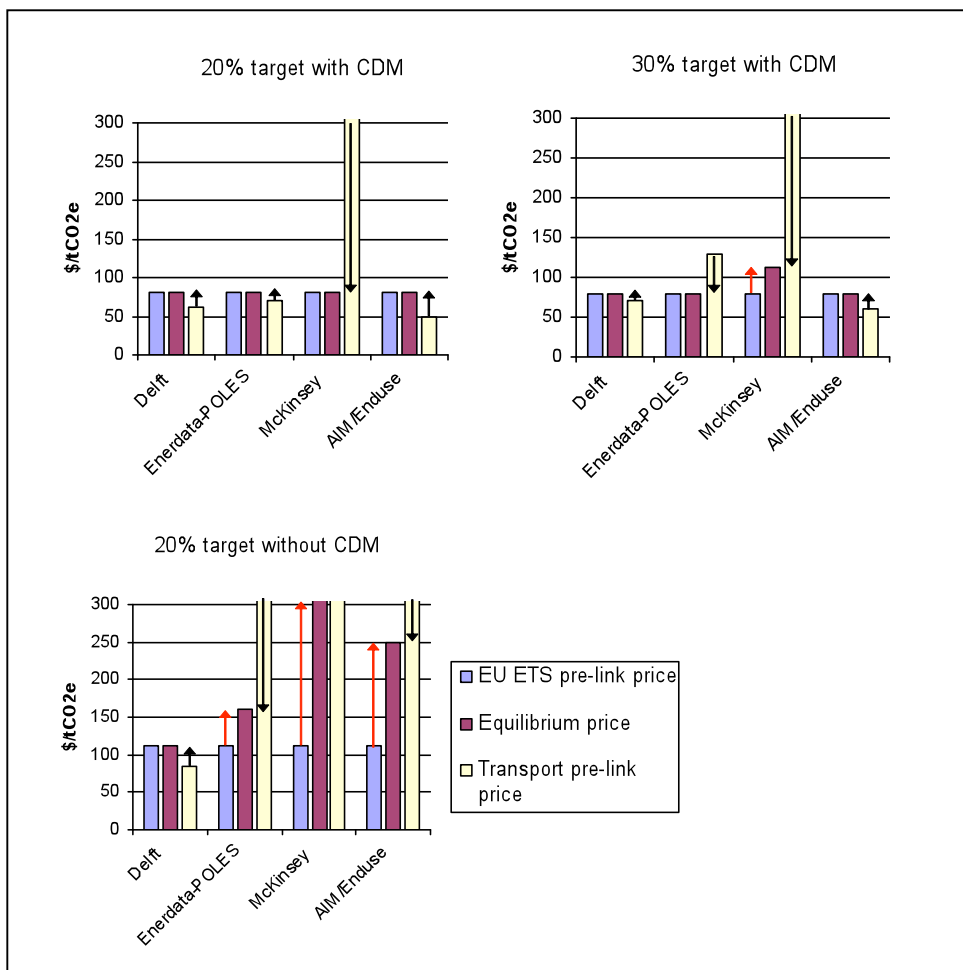


Figure 15: Price effects of EU road transport integration into EU ETS in 2020 for three policy scenarios. The figure shows pre- and post-link marginal abatement costs in the EU ETS and transport sector, with arrows indicating the direction of price adjustment. Bars exceeding 300\$/t indicate that the abatement target cannot be achieved for the given abatement target and MACC due to insufficient abatement potentials in the model given the policy target.

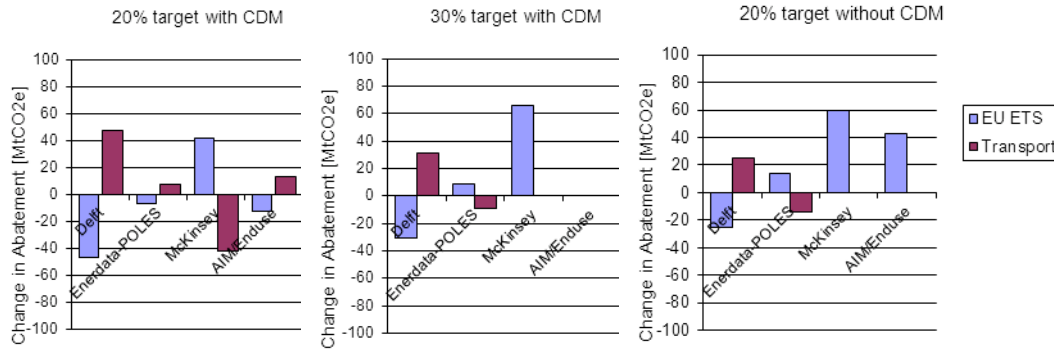


Figure 16: Change in sector abatement quantities when including EU road transport into EU ETS in 2020 for three policy scenarios. Positive values mark increased abatement activity in a sector, negative values indicate reduced abatement activity. Where positive and negative values for EU ETS and transport sectors do not cancel out – indicating a welfare-improving shift of abatement across sectors – the quantity objective is not achieved prior to transport integration.

As the most striking result, the EU ETS allowance price remains unchanged in the default policy scenario (20% reduction and CDM use). Both for the Delft and Enerdata-POLES transport abatement cost curve (Figure 14), transport integration keeps prices constant in the EU ETS, because ample abatement opportunities exist at the respective price level. This is in contradiction to previous MACC-based assessments, which concluded that transport integration would lead to rising EUA prices (Holmgren et al. 2006, Blom et al. 2007; COWI 2007; Hartwig et al. 2008). Consequently, the integration of road transportation would actually reduce the amount of abatement required from EU ETS sectors for all but the McKinsey curve (Figure 16). Data from most studies indicate, that the cost efficient contribution of road transport would be larger than a 7% reduction relative to 2005.

This result can be explained by the combination of (i) available abatement potentials in road transport as represented in the MACCs, (ii) the possibility to meet part of the abatement target with CDM credits, and (iii) the 7% reduction target below 2005 levels does not represent a very large abatement challenge for road transportation in view of the available abatement options. The widespread assumption that road transport integration to the EU ETS would necessarily lead to an increase of EUA prices results from assuming very little or non-existing abatement potentials in road transport, ambitious reduction targets for this sector, or both.

The EUA price of 80\$/t CO₂ for the year 2020 is quite high relative to the 37\$/t CO₂ reported by EC (2008) modeling, or private sector estimates of 37-50\$/t as reported by the Capoor and Ambrosi (2009, p.8). This reflects the rather conservative EU ETS cost curve estimate by CE Delft (see above).

In the 30% reduction scenario, the picture remains largely the same except for the McKinsey cost curve. In this model the policy constraint becomes so tight that the EUA price needs to rise to trigger more expensive abatement options in the EU ETS. The graphs depicted in Annex C1 also indicate that for the 30% objective the intersection of EU ETS and transport MACCs moves very close to the point where both curves become very steep, i.e. abatement in 2020 can become quite expensive in terms of marginal abatement costs for the MACCs considered here. However, the curves are based on prerecession data. As EU emission plummeted with the onset of the financial crisis, it can be expected that the 30% target can be obtained without high abatement costs less reductions below business-as-usual will be required.

The third policy scenario (20% reduction target without access to CDM) leads to considerably different outcomes for all but the CE Delft transport curve. Even for the CE Delft case, however, the pre-link EUA price level is higher than in the default scenario because more expensive domestic abatement options are triggered in absence of credit access. The pre-integration marginal abatement cost in road transport also rise substantially for all but the CE Delft curve as the target is not attainable. When the transport sector is included to the EU ETS allowance prices rise to induce additional and more expensive domestic abatement in EU ETS sectors. This case illustrates the importance of regional flexibility for containing EUA prices.

We conclude: First, the unchanged EUA price in case of road transport inclusion in the 20% default policy scenario for all cost curves demonstrates that concerns over carbon leakage from transport inclusion appear less well-founded than is often suggested in the literature.

Second, the relatively moderate sector differences in pre-link marginal abatement costs and the correspondingly modest changes in sectoral abatement quantities in case of transport integration for our default policy scenario indicate that EU policymakers perform rather well in terms of sector burden-sharing.

Third, the McKinsey and AIM/Enduse curves ignore demand side responses and only represent technical abatement options. Taking behavioral responses into account would lower the transport MAC curves. Therefore EUA price increases for these curves would be lower than indicated here (Clapp et al. 2009, p.50; see also Figure 9).

Fourth, our analysis in this section does not include non-price policies as embodied by the EU climate policy package of 2009 (EC 2009a, b). A detailed analysis is beyond the scope of this study. It is conceptually clear, however, that inclusion of non-price policies would lower road transport marginal abatement cost

curves (more abatement would occur at any given carbon price), thereby reducing the price impact of road transport EU ETS integration on EUAs. Sketch estimates for abatement volumes from non-market policies are given in the next subchapter for the EU, but also the US and California.

Finally, any results based on marginal abatement cost curves need to be treated with great care due to the sensitivities concerning uncertain and crucial parameters such as the speed of technological innovations or the large uncertainties about behavioral responses. We used cost curves from four different institutions in an attempt to reflect part of this uncertainty. Clearly, a more systematic and comparative analysis of several models exploring key sensitivities with regard to baseline assumptions, model structure and complementary policies would significantly improve the robustness of our knowledge of economic impacts of road transport fuel inclusion to cap-and-trade systems.

6.3. Contribution of current transport policies

The modeling exercise in the previous Section gives an insight to changes in abatement quantities and prices when including road transportation into the European emission trading scheme. Another important question is the impact of existing transport policies which were not considered in these analyses.

Conceptually the impact of non-market instruments, i.e. current fuel efficiency standards resulting in the implementation of a number of technology options, will shift the road transport marginal abatement cost curve downwards, as illustrated in Figure 17. Standards induce some amount of 'exogenous' abatement as represented by the line 'abatement standard'. If standards induce abatement options that are more costly than the allowance price in their absence, taking them into account will lower the equilibrium allowance price from P^* to P^s . Hence, taking standards into account in the analyses of the previous Section would further lower allowance prices.

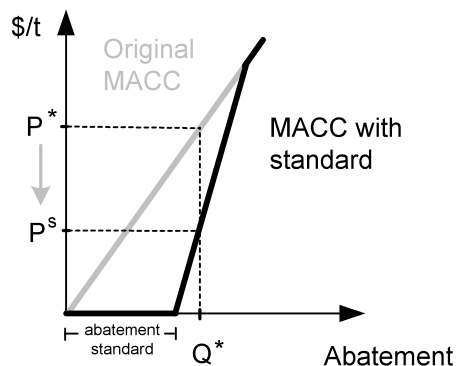


Figure 17: Impact of non-market policies on the marginal abatement cost curve and the cap-and-trade allowance price.

The remainder of this chapter essentially calculates the distance 'abatement standard' for the European Union, United States and California, i.e. expected emission reductions from major non-market policies in these regions are computed.

European Union

The current EU regulation of emission intensity of new vehicles dates from April 2009 (EC 2009c) and, hence, has not been included in previous models of transport inclusion into emission trading. The regulation mandates the average carbon emissions from newly sold vehicles to decrease from 167gCO₂/km in 2005 to 130gCO₂/km in 2015, and to 95gCO₂/km in 2020 (see also chapter 3). This corresponds to 40% reduction in emissions intensity of new vehicles sold by 2020.

How large is the emission reduction in the transport sector in the EU in 2020 given by this and other policies (see Chapter 4)? New vehicles, of course, do not substitute the current car fleet. A good working assumption is a 10% turnover rate every year. The question can be broken down in different parts. What were the average emissions per vehicle in 2005? Data is available for the year 2000, with average emissions per vehicle in 2000 being 186 gCO₂/km (EC 2000). Emission intensity of newly sold vehicles between 2000 and 2005 were relatively constant at around 167 gCO₂/km (An and Sauer 2007). Assuming a 10% annual turnover rate, the average 2005 fleet average was 178 gCO₂/km.

Average emission intensities for 2020 are more difficult to estimate. Newly sold cars after 2015 will have less than 130 gCO₂/km on average, as the average heads towards the 95gCO₂/km value of 2020. These vintages may constitute around 40% of the overall fleet. Linear interpolation of fuel economy values between 2015 and 2020 then yields an average fleet intensity of 125 gCO₂/km in 2020.

Additional measures, such as improved air conditioning and tires, but also biofuels are expected to deliver another intensity reduction of 10 gCO₂/km until 2015. To be on the conservative side, we omit the car-related measures. We do include the more specific Fuel Quality Directive COM-2007-18 which requires 6% reduction in CO_{2e} of transportation fuels from 2010 to 2020 (EC 2009c). At the same time, total road transport demand is projected to rise from 4700 Gpkm in 2005 to 5800 Gpkm, an increase of 24% (EC 2008b). We omit any rebound effects. Taking together, carbon emissions from road transport (not including other transport, such as air traffic) will be reduced by around 11% in 2020. This would even exceed our assumed road transport reduction target of 10.5% in presence of a 30% economy-wide EU abatement target (see above). This result may be overly optimistic for four reasons:

1. The extrapolation is linear in annual improvement of fuel economy. However, car manufacturers may choose, according to current regulation, to back-off investments till the 2015 or 2020 deadlines respectively.

2. Car renewal rate is estimated to be around 10%. In recession times, the car renewal rate could be lower. However, total transport volumes would also drop.
3. Rebound effects are omitted here. They can be regarded to be part of the overall uncertainty in growth of travel demand.
4. The environmental effectiveness of the Fuel Quality Directive COM-2007-18 is not guaranteed due to the current accounting procedures that does not foresee detailed life cycle analysis including indirect land use emissions.

However, even if these caveats reduce overall GHG reduction, current EU regulation seem to guarantee that at least the 7% reduction target (below 2005 levels by 2020) is achieved even without carbon pricing. This rough calculation also confirms the result from chapter 6.2 that including road transport into EU ETS – given current quantity targets – will actually reduce the burden on current ETS sectors.

United States

The United States has similarly ambitious targets for fuel economy in relative terms, i.e. taken the currently more inefficient vehicle fleet into account. Including extra measures such as improved air conditioning, tire pressure and biofuels, the revised GHG standard foresees the average fuel efficiency of newly sold vehicles to increase from 355 gCO₂/km in 2005 to 250 gCO₂/mile in 2016. For the calculation it is assumed that mandated fuel economy remains constant from 2016 to 2020. With a fleet renewal rate of 10%, and average fuel economy of 394 gCO₂/mile in 2005, the average fuel economy of the passenger car and light truck car stock in 2020 in the US is then projected to be 299 gCO₂/mile, corresponding to a total improvement of 24% relative to 2005. At the same time, US vehicle miles travelled are expected to increase by 27% (EIA 2008). Given this projected development and policies, and omitting rebound effects, overall GHG emission reduction by 2020 in road transport is 3% relative to 2005.

California

According to AB 32, California intends to reduce 2020 GHG emissions to 1990 levels. From 1990 until 2005 California GHG emissions increased by 12.5% (CARB 2010b). Road transport emissions increased by 24%. Emissions from the transport sector declined by 4.4% in 2008. However, the transport sector remained the largest end-use sector in 2008, contributing 36.5% of all GHG emissions (CARB 2010b). From 2008 levels, an economy-wide 11% reduction is needed to reach the 2020 target. The transport sector would need a 14.5% reduction from 2008 to reach its 1990 level in 2020. Pavley I (or more or less equivalently, updated federal CAFE standard), contribute around 23.5% to emission reductions in 2020. The LCFS reduces carbon intensity of fuels by 10%. Meanwhile the total travel demand (including population growth) is expected to increase between 1.54-1.86% per year (CEC 2007). Omitting rebound effects, this yields transport sector emission reductions of 14-17% in 2020. However, the contribution from the LCFS is relatively

uncertain, as it relies on the deployment of competitive low carbon fuels (see also chapter 4). Possible rebound effects could increase travel demand.

Furthermore, SB 375, a legislative measure addressing land use policies, is intended to reduce transport demand below the baseline. Probably most land use measures will impact GHG emissions only after 2020. Still, the Californian scoping plans expect 5 MMT CO₂e reduction in regional travel, i.e. 3% reduction below 2005 levels. Altogether, and also due to the recession and high oil prices, current Californian road transport sector policies would will reduce sector GHG emission back to around 1990 levels.

Impact of the recession

In both the United States and Europe the financial crisis and 2009 recession had a significant impact on total transport demand measured in vehicle km travelled, putting a negative sign on the growth rates. The specific dynamics are different in both world regions with the US having more vehicle km reduction but also returning to positive growth rates earlier than the EU. De facto, however, growth in transport demand is delayed in the US and EU by 2 years (conservative estimate). In the following, it is assumed that there is no rebound effect, i.e. that post-recession growth do not compensate for the recession. In that case, the EU emission intensity standards would lead to a 14% (instead of 11%) reduction in GHG emissions from 2005 to 2020, clearly exceeding the 10.5% reduction target that might be adopted in case of a more ambitious EU overall effort with 30% reductions below the 2005 level. This also implies that EU ETS sectors – subject to the recession as well – will need to deliver less abatement. Hence, concerns over rising allowance prices in case of adopting the 30% target for Europe and including the road transport sector are even less warranted, and moving to this target can be recommended. The US would experience 6% instead of 3% reduction in GHG emissions from 2005 to 2020. California road transport emissions may be reduced by an additional 3% relative to 2005 (in the calculation above 2008 recession and oil price effects were already included).

Implications

In all jurisdictions where emission trading for transport is under discussion, existing transport policies contribute significantly to GHG reduction targets. EU transport policies induce more mitigation in the transport sector mostly because a) transport demand grows slightly less and b) standards are set already until 2020, whereas US standards are set only till 2016. If the US continues to tighten standards after 2016, more GHG emission reductions will be induced.

What do these analyses imply for emission trading in the transport sector? Emission trading would effectively address some weaknesses of existing policies:

- Current policies are not guaranteed to achieve emission reduction targets. Emission trading, in addition, would guarantee reaching the target.

- The shift of responsibilities from car manufacturers to fuel producers because of higher expected market shares of alternative fuel vehicles is addressed: upstream emissions are regulated. Vice versa, car manufacturers are held responsible for the efficiency of cars and the tank-to-wheel-emissions by standards. Such an instrument mix would encourage the decarbonization in the transport sector appropriate.
- The full potential of emission reductions for both fuel providers (carbon intensity reduction) and consumers (dampening demand growth) would be incentivized.

For the EU, post-recession estimates of transport emissions indicate that the transport sector more than fulfills its 2020 reduction target. If the same is true for industry and the electricity sector, a 30% 2020 target is more appropriate to reflect the EU capabilities, but also in terms of historic responsibility, demonstrating the feasibility of decarbonization, and to foster its competitiveness in low-carbon technologies.

Including the road transport sector into the Californian (or Western State) trading scheme is particularly recommended. California is a special case due to the high share (37%) of transportation in overall GHG emissions, which is much higher than in most other regions of the world and the US. While uncertainty over future travel demand and carbon intensity make projections on the exact magnitude of GHG emission reduction in the California transport sector difficult, our calculations find that current policies will be sufficient to achieve the emission goals of AB32 only if transport demand growth is low and the LCFS is truly effective (and does not perversely regulate utilities selling electricity to BEVs). Cap-and-trade will ensure that this target can be achieved, fully incentivizing low carbon fuels and a reasonable dampening in transport demand growth.

In addition, excluding the dominant driving force of travel demand from climate policy reduces flexibility for climate change mitigation significantly and without any good reason. Furthermore, California has a special automobile market, offering attractive niche markets for alternative fuel vehicles (partially due to ZEV mandates). California is expected to spearhead the introduction of electricity as fuel for cars. An emission trading scheme across sectors provides a level playing field across a possible plethora of alternative fuels in a very effective manner. Finally, California fuel taxation levels are far lower than in Europe, and the fuel price increase due to carbon pricing will deliver even more significant co-benefits such as reduced congestion and local air pollution.

6.4. Linking regional trading systems

A global carbon market comprising all major countries and industries is widely regarded as a cost-effective tool to control global emissions (Stern et al. 2007; Lazarowicz et al. 2009; Tirole 2010). However, top-down implementation of a global emission trading system through an international climate treaty seems unrealistic in light of recent negotiation outcomes (UNFCCC 2009). Thus, an incremental approach resting on nationally implemented carbon trading systems is discussed as a central pillar of the future international climate policy portfolio (e.g. Edenhofer et al. 2007; Jaffe and Stavins 2007; Flachsland et al. 2009a, b). Trading systems are being considered or in the process of implementation in the United States, Australia, Japan, New Zealand. Sub-national initiatives exist in the USA with the Regional Greenhouse Gas Initiative (RGGI), California and other US states and Canadian provinces organized in the Western Climate Initiative (WCI), and the Midwestern GHG Accord. In Japan Tokyo has set up a local ETS. Figure 18 provides an overview of these initiatives.

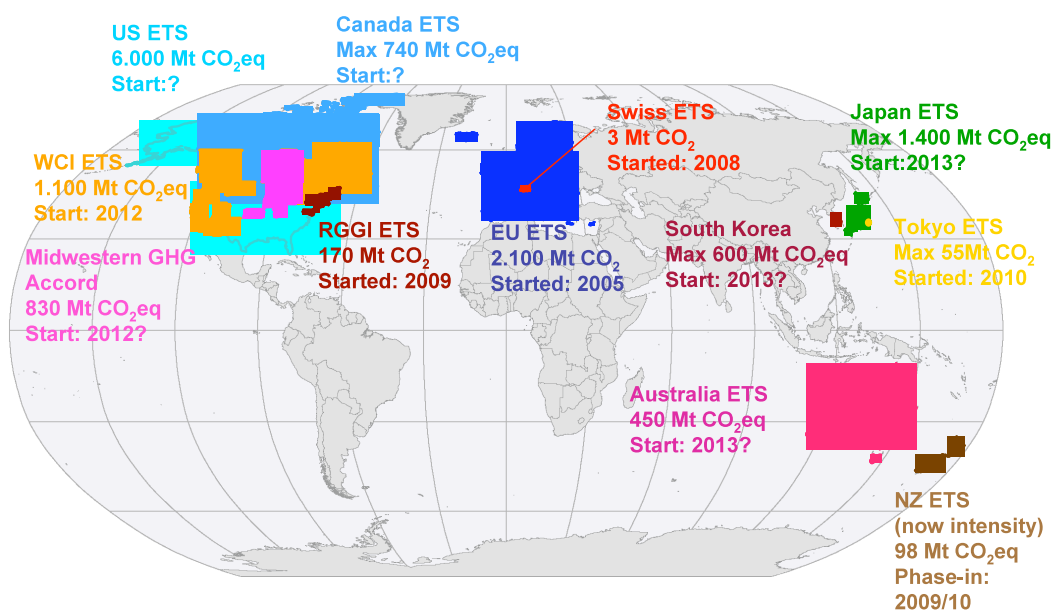


Figure 18: Regional cap-and-trade systems in preparation or operation.

The European Union has proposed the creation of an OECD-wide cap-and-trade system by 2015 (EC 2009c).¹² A system of regional trading systems is envisaged linking domestic initiatives in OECD countries. Major developing countries could implement sector intensity-based crediting or trading systems with

¹² For a discussion of future international carbon market architectures and linking of regional trading systems, see Flachsland et al. (2009a, b) and Tuerk et al. (2009).

absolute caps and sell allowances to the OECD markets. This would constitute an intermediate step before adopting comprehensive cap-and-trade later on.

The most obvious benefits from linking e.g. a US system and the EU ETS would be enhanced efficiency in achieving domestic abatement targets. Harmonized carbon prices across regions imply the creation of a level playing field across the capped industries, which can be expected to underpin political stability of climate policy. Another benefit of a harmonized carbon price is facilitation of RD&D planning in international markets that expect identical GHG prices, e.g. markets for road transport vehicles. Also, independent regional carbon markets are likely to be linked indirectly via world credit (e.g. CDM) markets in any case, so direct linkage will facilitate coordinated governance of international carbon markets.

Potential caveats to linking regional cap-and-trade systems are that a shared understanding of optimal policy implementation is required insofar as system design touches upon critical issues. This concerns additionality of credits (Chapter 6.1) or the implementation of market control devices such as price floors or ceilings. Note that the method of allocation is largely irrelevant in the context of linking since related issues (e.g. the subsidy it entails under free allocation) will arise also in absence of linking. Another potential caveat is that linking may not entail significant welfare gains if pre-link allowance prices are rather similar. This is not unlikely, especially if the systems are already linked indirectly via third markets, e.g. if they both enable access to credits on the international CDM market (see Flachsland et al. 2009a). Finally, linking requires that the partners recognize the level of ambition of the linked trading system: as an illustration, it is unlikely that policymakers would link the EU ETS to a system that is prone to overallocation (e.g. RGGI). Insofar as linking can involve international financial transfers, the burden-sharing implied by regional abatement targets requires endorsement prior to linking.

Against the background of these considerations, well-designed and well-governed trading system links offer a number of benefits. Still, the more relevant step for GHG regulation of road transport emissions is likely to be inception of cap-and-trade in the first place, with linking as an important option for further enhancement of policy design.

7. Towards GHG pricing instruments

What is the optimal climate policy portfolio for road transport? In chapter 2-4, we analyzed existing policy instruments in a *bottom-up* perspective. Chapter 5-6, derived the rationale of cap-and-trade in a *top-down* manner. This section develops a synthesis that features a cap-and-trade system at the core of road transport climate policy, with properly designed regulatory instruments as complements that cure GHG pricing market failures.

Current regulation of GHG emissions in the transport sector heavily relies on non-market standards that have only limited coverage. While fuel efficiency standards and low carbon fuel standards can be effective and efficient policy instruments in their particular context, they lack comprehensive scope and fail in setting optimal incentives due to both generic inconsistencies and specific design.

Fuel efficiency standards address car manufacturers and incentivize them to improve the efficiency of their product. Current regulation is effective and efficient in doing so. However, with diversification of fuel supply chains, fuel efficiency standards must be specified to address car manufacturer's responsibilities, by strictly regulating tank-to-wheel efficiency, and - in the long run - by focusing on energy metrics.

Fuel efficiency standards are subject to two rebound effects. First, increased market shares of more efficient cars are partially offset by greater demand for road transport. Second, car manufacturers can react to standards through technology and innovation, shifting their automobile portfolio, but also by pushing additional fuel efficient cars into the market (e.g. by offering discounts). As such, fuel efficiency standards set perverse incentives. Additionally, fuel efficiency standards – targeting car manufacturers - are set in CO₂e/km in California, capturing emissions from well-to-wheel. However, car manufacturers can only influence tank-to-wheel efficiency and/or emissions, and thus these policies do not provide proper incentives for fuel producers. Emission trading can then be a suitable instrument to address GHG emission across all fuels and technologies, and hence, providing a level playing field.

Low carbon fuel standards address fuel producers and favor low-carbon fuels but can incentivize increased production of low carbon fuels without lowering the production of high carbon fuels. In its current implementation, the Californian LCFS disproportionately favors electricity (counting only a third of average Californian GHG emissions from power generation). The burden of emission responsibility is shifted to car manufacturer whereas utilities can influence life cycle emissions of BEVs, and thus, are the appropriate actor to be regulated. The upstream GHG emissions (from power generation) of electric cars are not strictly accounted for. A reform proposal is to use LCFS for regulating the carbon intensity

of liquid fuels only. This would incentivize a low-carbon biofuel infrastructure and inhibit the use of high-carbon unconventional oils.

Crucially, both fuel efficiency standards and low carbon fuel standards leave transport demand mostly unregulated. In fact, transport volumes may even increase above business-as-usual due to rebound effects.

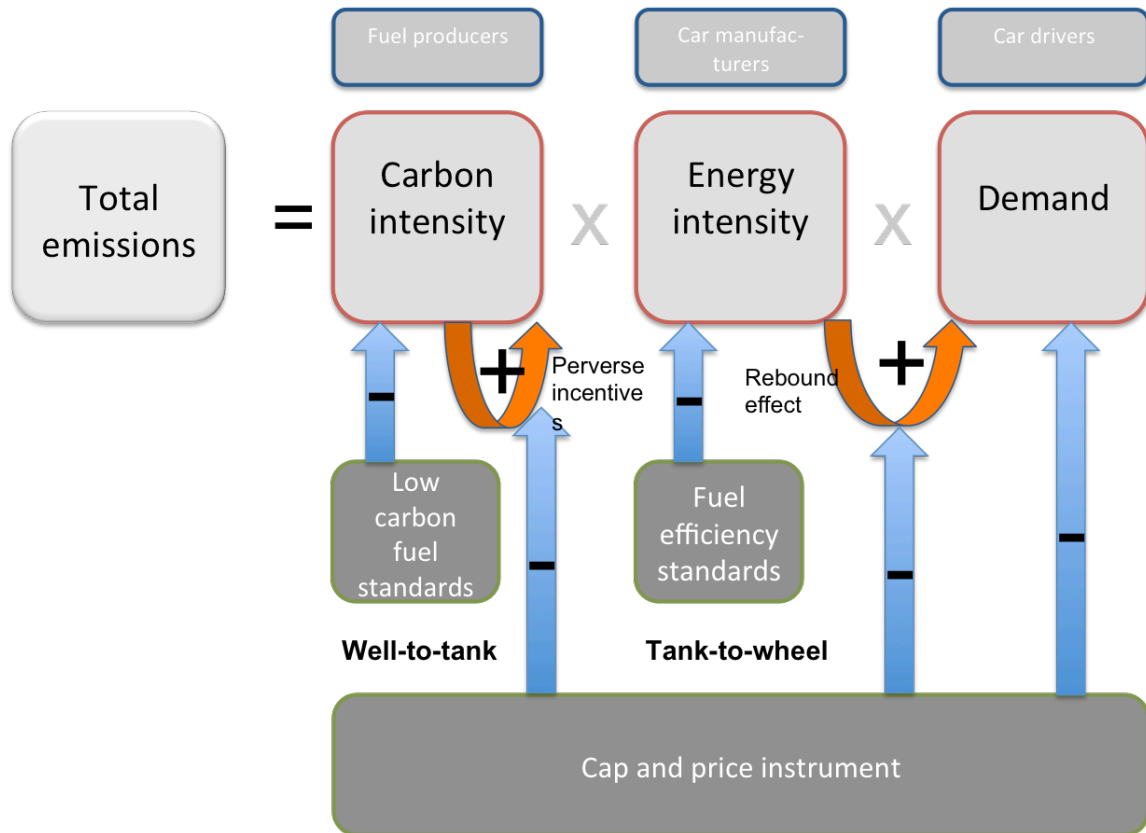


Figure 19. Closing the policy gap with a cap and price instrument. A quantity target and the corresponding GHG price alleviate rebound effects and perverse incentives of fuel efficiency standards and LCFSs. Emission trading would also provide a level playing field across all fuels enabling fuel efficiency standard to focus on tank-to-wheel efficiency – where they are truly effective. The crossregulation of carbon intensity by GHG standards for vehicles (red arrow) becomes unnecessary. Non-price instruments are valuable in addressing specific market failures, especially in a dynamic setting. However, non-price instruments need to accurately address actors according to their capabilities and incentive structures. Hence, LCFS should focus solely on liquid fuel providers and can be phased out with successful implementation of a cap and price signal. Fuel efficiency standards should reflect car manufacturers’ responsibility in terms of tank-to-wheel energy-based metrics.

Some failures can be alleviated by better design, e.g. switching to energy-based efficiency measures for fuel efficiency standards. However, for rebound effects, perverse incentives, and overall regulation of GHG emissions in the road transport sector, other instruments are required. Here we argue for quantity instruments, regulating absolute emissions, and an associated price signal. This can be, for example, a cap and trade scheme. The effects of such an instrument would be as follows:

- A transport-sector or economy-wide cap and with a corresponding price on GHG emissions ensures efficiency, environmental effectiveness and provides a level playing field across all fuels.
- Low carbon fuels are systematically incentivized. As such, a cap and associated price signal perfectly complements fuel efficiency standards measured in tank-to-wheel efficiency.
- A cap eliminates the perverse incentive effects of LCFS.
- An economy-wide cap makes inefficient cross-sectoral regulation (e.g. the LCFS regulation of electricity with respect to BEVs) unnecessary. LCFS can focus on regulation of fossil fuels and biofuels, and possibly be phased out with emission trading in place.
- Possible rebound effects of fuel efficiency standards (higher transport demand) are avoided.
- Transport demand is subject to an economy-wide efficient price signal and becomes part of the overall mitigation effort.

The main effects are summarized in Figure 19. Existing instruments, such as fuel efficiency standards and LCFSs, may still have an important role in a cap and price signal world. For example, efficiency standards are needed to achieve economy-wide dynamic efficiency and counter loss aversion bias of consumers. LCFSs can be phased out as a stringent cap and credible enforcement is implemented. However, the accounting framework of LCFS is a crucial precondition for region-wide cap and trade that unsufficiently covers world-wide emissions (arising from agricultural production). As such, the Californian LCFS and the European FQD can be understood as ancillary steps to an economy-wide cap in these world regions. Finally, a price signal of cap-and-trade is unlikely to spur sufficient large-scale investments in new fuels technology if price signal is relatively low and cross-sector only incentivizes reductions from stationary sources in the near term. This is only a problem if relevant learning curve effects are expected for low-carbon biofuels, i.e. if current high costs of biofuel infrastructure are justified by future gains. Under these circumstances even a efficient cap and trade system should be complemented by supporting learning-technologies. If learning technologies are not supported there is a remarkable risk that the transport system will be locked-in in a high cost-equilibrium. However, as long as an economy-wide cap and price instrument is not in place, a low carbon fuel standard is a reasonable second-best policy for local regulators. However, both fuel efficiency standards and LCFS can be needed to be adapted to achieve their primary objectives, and leave static efficiency of abatement to a cap and associated price signal.

Similar to our conclusions, DeCicco (2010) asks for aligning incentives and actors when regulating GHG emissions in the transport sector, specifically emphasizing the need for a energy-based metric for new vehicles. Yeh and Sperling (2010) review existing LCFS schemes and point out the need to properly align LCFSs with existing or envisaged cap and trade schemes.

Altogether, a cap and trade system with an associated price signal would disincentivize the increased production of low-carbon fuels that would be optimal under LCFS alone and counteract the rebound effect of fuel efficiency standards. An associated price signal will reduce transport demand to welfare enhancing levels. Hence, quantity instruments and the corresponding price signal can help to remedy some weaknesses of current standards.

Cap-and-trade is, however, more than a patch for the weaknesses of the current policy framework. In contrast, a binding economy-wide cap is a necessary condition to achieve an ambitious emission mitigation target. The associated price signal provides harmonized incentivizes across the economy, and hence, is effective and efficient in incentivizing all available mitigation options that respond to price signals. Carbon taxation of road transport fuels is an alternative market-based instrument, but attaining mitigation targets in an efficient manner requires more regulatory adjustments than a cap-and-trade system. Cap-and-trade, hence, is desirable also from a top-down perspective. More specific non-market policy instruments are relevant in so far as they address market failures, i.e. they intervene where price signals are not fully effective. The flow of this argument is visualized in Figure 20.

Any instrument is only as good as its design. For cap-and-trade, critical design issues include auctioning of allowances. The point of regulation should be upstream, e.g. at refineries, to limit transaction costs and to coherently capture all emissions. A cap-and-trade scheme needs to set credible long-term reduction targets and enforcement mechanism to be dynamically efficient and make more specific instruments such as LCFS or FQD obsolete.

With current reduction goals of major world economies till 2020 and existing transport policies in place, an inclusion of the road transport sector will not increase allowance prices and, hence, won't put further burden on other sectors. Fuel providers will be incentivized to shift to low-carbon fuels, most likely low-carbon biofuels. R&D in these fuels will be further promoted. High-carbon fuels, e.g. from Canadian tar sands, will not be economically viable. A small price increase in fuels will incentivize ecodriving and consumer's purchase decisions. Hence, car manufacturers will have an additional incentive to shift production to fuel efficient cars. However, here the driving force of the fuel efficiency standard is stronger. Altogether, factoring in the emission reductions of the 2008/2009 recession, 2020 targets will most likely be overachieved and more ambitious emission reduction targets are plausible.

Ignoring challenges in the transport sector, and leaving regulation in its current framework is both environmentally harmful and economically inefficient. Specific regulation must correctly address responsibilities while not confounding separate goals in one instruments. In particular, fuel efficiency standards need to address the responsibility of car manufacturers in terms of tank-to-wheel efficiency only, leaving the regulation of GHG content to cap-and-trade or temporarily to low carbon fuels standards. A cap on emissions from the transport sector is paramount to reign in emissions from the transport sector and avoid rebound effects.

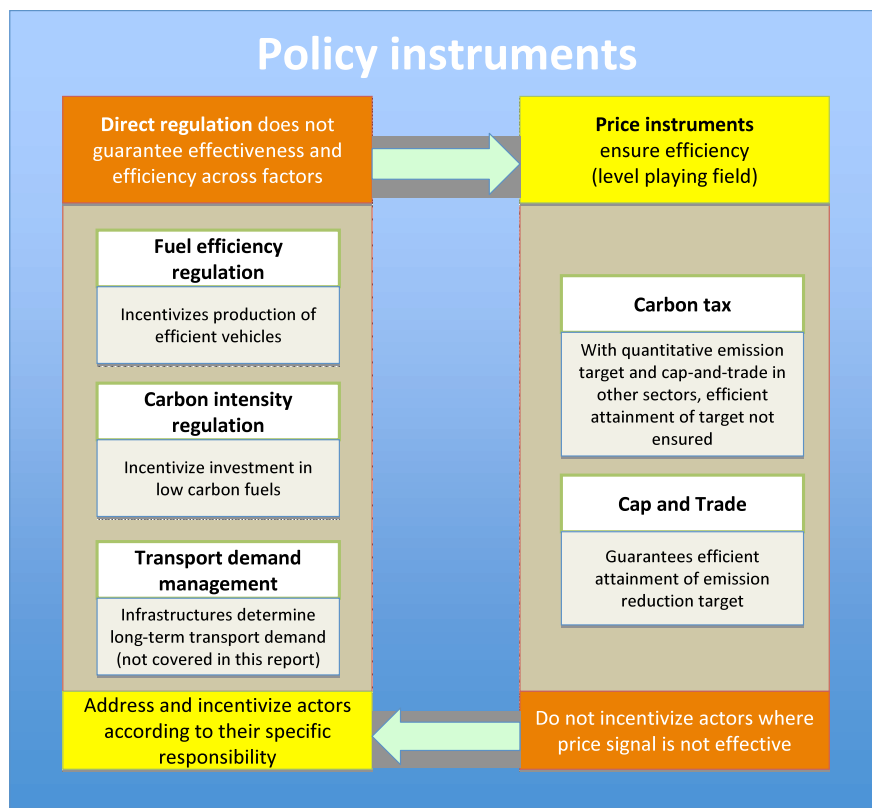


Figure 7: Rationale of policy instruments in a climate mitigation framework for road transportation.

8. Conclusions

This study thoroughly combined an empirical and systematic perspective on road transport GHG emission regulation. Part I reviewed existing policy instruments in the framework of a road transport emission decomposition analysis that identifies carbon intensity, energy intensity and travel demand as major emission drivers. Fuel producers, car manufacturers and consumers are the actor groups corresponding to these drivers, and direct regulation needs to set appropriate incentives for these actors to yield effective and efficient outcomes. With the rise of alternative fuels and vehicles, fuel supply chains diversify and emissions tend to occur further upstream. Hence, the responsibility of car manufacturers should shift to maximizing tank-to-wheel efficiency exclusively. In the short-to-medium term tank-to-wheel efficiency can be converted to equivalents of current measures, such as l/100km. In the long term, and with significant market shares of alternative vehicles, fuel efficiency is best measured in energy metrics, providing a neutral measure across all vehicle technologies. In contrast, well-to-tank emissions of fuels become increasingly relevant with alternative fuels. The capability to reduce emissions, and hence, responsibility shifts from car manufacturers to fuel suppliers – including refineries and utilities – and these actors are accountable for the carbon content of their respective fuels. Cap and trade is a flexible and comprehensive solution to regulate all GHG emissions and providing a level playing field across all fuels and technologies.

As a necessary complement, carbon content of all fuels must be comprehensively regulated. Currently, most fuel producers are only subjected to renewable fuel standards. These fuel standards suffer from ignoring or insufficiently addressing the GHG content of biofuels. Low carbon fuel standards, as explored in California, remedy this situation – at least when they account for all life cycle emission. Still they provide perverse incentives as intensity-based standards and, more specifically, give credits to utilities for BEVs – mixing up responsibility of fuel producers and car manufacturers, and hence, setting ineffective incentives.

As standards and policies target only specific emission drivers and actor groups, they fail to set harmonized abatement incentives across all drivers, actors and fuel chains that are relevant in road transport. Regulators would require perfect information on every aspect of the transport system to efficiently implement a set of direct regulatory instruments that achieves emission reduction targets at minimum costs. By contrast, carbon pricing instruments such as GHG trading and taxation theoretically incentivize implementation of all abatement options in a cost efficient manner. Corresponding to this concept of economic efficiency, carbon pricing also ensures a level competitive playing field across fuels and technologies. In reality there are often market failures that prevent harnessing the theoretical abatement potentials to their optimal extent. This is where traditional - and possibly innovative

- direct regulatory instruments have an important role to play even in presence of GHG pricing instruments, and even if they may not deliver perfect efficiency and effectiveness (Figure 20).

Against this background, part II of the study examined the rationale for carbon pricing in the road transport sector and reviewed prominent objections to this approach. No concern justifies non-adoption of carbon pricing. The empirical policy context is characterized by quantitative emissions targets (as documented in country submissions to the Copenhagen Accord, and the 2°C objective endorsed by the Accord), and the presence or expectation of emission trading in other sectors of the economy. Hence, economy-wide cap-and-trade is the more suitable than carbon taxation to ensure economically efficient attainment of quantitative policy objectives. Also, under uncertainty, taxes would require politically costly adjustments not only within but across sectors to guarantee efficiency.

Some observers have cautioned that transaction costs could be very high, or that inclusion of road transportation would lead to carbon leakage. With suitable design of road transport of emission trading, in particular by choosing the point of regulation upstream at refineries, the transaction costs of emission trading will be contained. In fact even carbon taxation requires emission monitoring, reporting and verification (MRV) regimes. Carbon leakage concerns arise because it is feared that the relatively steep abatement cost curve of road transportation will lead to increased allowance prices in an ETS, thereby intensifying concerns over carbon leakage in trade-exposed industries. However, applying four marginal abatement cost curves for European road transport this study demonstrates that carbon prices would not increase if EU road transport were included to the EU ETS by 2020. Even when increasing the economy-wide level of effort to 30% below 2005 emissions in 2020, three out of four cost curves indicate constant certificate prices. Reasons are (i) non-trivial abatement potentials in the road transport sector, (ii) access to international credit markets adds abatement options, and (iii) the 2020 transport sector abatement target envisaged by EU policy makers (7% below 2005 levels in 2020) which will probably be achieved easily with existing non-price regulation. Indeed, factoring the Great Recession into emission trajectories, the 30% reduction target will not cause high certificate prices and can be recommended to the EU.

Including the transport sector in the Californian (Western States) emission trading scheme seems particularly useful, as the demand side in the transport sector dominates GHG emission trends and existing non-price policies are hence insufficient to achieve the reduction targets set out in AB32. Emission trading would be the most flexible instrument to attain the goal of limiting 2020 emissions to the 1990 level, incentivizing all available abatement options in the transport sector and suitably complementing existing transport regulation (i.e. Parvley I, LCFS, SB 375). In addition, transsectoral upstream emission trading would allow a level playing field across all fuels, rendering cumbersome end-of-pipe carbon accounting unnecessary.

The prospect of linking regional emission trading systems as envisaged by the European Union promises gradual improvement of the policy instrument by addressing concerns over carbon leakage, competitiveness, and efficiency of international climate policy. Challenges of international policy coordination need to be resolved and domestic trading systems need to be implemented in the first place to make this a viable policy option. This study concludes that road transport fuel inclusion to cap-and-trade, complemented by appropriate regulatory policies to cure specific market failures, is the most promising policy option for future climate policy regulation of the European, Californian and US road transport sector.

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Glossary

Additionality: Requires that carbon credit-generating projects (e.g. reforestation) be in addition to such projects that would have happened without the existence of an emissions trading scheme

All Electric Range (AER): The maximum distance a Plug-In Hybrid Electric Vehicle can travel using only stored electricity as the power source

Alternative fuel vehicles: Comprise battery electric vehicles (BEVs), plug-in hybrid vehicles (PHEVs), hydrogen fuel vehicles and in a broad sense also flex-fuel vehicles that enable driving on biofuels

Anaerobic digestion: Decomposition of organic material facilitated by bacteria which produces methane, carbon dioxide and water, a mixture which is commonly called “biogas”

Baseline-and-credit: A type of emissions trading scheme where regulated entities are incentivized to reduce greenhouse gas emissions below a projected 'business as usual' baseline. An entity can generate carbon credits that can be sold by reducing below the baseline

Battery Electric Vehicle (BEV): An alternative fuel vehicle that is powered entirely by battery-stored electricity

Bioelectricity: Electricity produced from biomass feedstocks; this has been proposed as one way to decarbonize electricity generation

Bioenergy: Energy derived from any biomass (e.g. biofuels, bioelectricity, bioheat).

Biofuels: Any solid, liquid or gaseous fuel derived from biomass that can be directly combusted in vehicles.

Biomass: Material of organic origin, in non-fossilized form (e.g. agricultural crops, forestry waste or by-products, microbial matter, household organic waste)

Cap-and-Trade: A type of emissions trading scheme where regulated entities are required to emit GHGs under a specified emission level, or cap; if an entity emits under the cap, it made sell excess carbon allowances to other firms; if the entity's emissions exceed the cap, it must purchase allowances from other firms in order to surrender a proportionate amount of carbon allowances to the program Administrator

Carbon content: The amount of carbon contained in a unit of a particular fuel, such as gasoline or electricity, usually measured in grams of CO₂-equivalent per megajoule (gCO₂e/MJ)

Carbon leakage: The possibility that unilateral carbon pricing could lead trade-exposed, GHG-intensive industries to replace domestic production by imports or to relocate production to foreign countries with lower or no carbon constraints.

Clean Development Mechanism (CDM): An emissions trading mechanism outlined in the Kyoto Protocol which allows Annex I countries to purchase emissions credits from carbon sequestration or emissions reduction projects carried out in non-Annex I countries.

Corporate Average Fleet Economy (CAFE): Vehicle fuel economy standards propagated by the US federal government; requires manufacturers of passenger cars and light trucks to produce vehicle fleets with a maximum average mpg

Downstream: Usually a comparative term; in a fuel production and consumption life cycle pathway, a point in the pathway which is closer to the end of the fuel's life cycle (e.g. distribution and consumption stages)

Dynamic efficiency: Long-term economic efficiency, usually taking into account predicted trends in demand and supply (as compared to static efficiency)

Electrolysis: A hydrogen production method in which an electrical current is passed through water to split H₂O into H₂ and O₂ gases

EUA: EU Emission Allowance. Name of allowances in EU ETS.

European Union Emissions Trading Scheme (EU ETS): The largest multinational emissions trading scheme in the world as of 2010 that began in 2005. Regulated entities are the following industrial sectors: iron and steel; cement, glass, and ceramics; pulp and paper; electric-power generation; and refineries. This accounts for approximately 46% of EU GHG emissions.

Global Warming Potential (GWP): The measure of how much a particular GHG molecule will contribute to global warming over a given period of time once emitted into the atmosphere, which depends on its atmospheric lifetime and

infrared absorption capacity; measured in carbon dioxide-equivalents (CO_{2e}), where the GWP of CO₂ is 1

Grandfathering: A method of calculating initial carbon credit distribution to entities regulated under an emissions trading scheme in which credits are allocated according to each entity's historical emissions

Greenhouse gas (GHG): a molecule that contributes to trapping heat in Earth's atmosphere (i.e. the greenhouse effect) by absorbing infrared radiation

Intergovernmental Panel on Climate Change (IPCC): Scientific intergovernmental body that reviews and assesses the most recent scientific, technical and socio-economic research related to climate change; does not conduct research but prepares policy-neutral papers and reports, including periodical Assessment Reports on the state of climate change research

Lifecycle Analysis (LCA): A method of evaluating GHG or other parameter performance by assessing the inputs and outputs within the product system starting with resource extraction, tracking the various stages of production, distribution and use and ending with the disposal of the product

Low Carbon Fuel Standard (LCFS): A policy option for reducing carbon intensity of transportation fuels which requires transport fuel producers to lower the average carbon intensity of their products to meet a standard (measured in gCO_{2e}/MJ) which declines over time

MACC: Marginal abatement cost curve

Plug-in Hybrid Electric Vehicle (PHEV): An alternative fuel vehicle that is capable of utilizing stored-battery power for the duration of its AER and gasoline when the battery charge is exhausted

Regulated Entity: In an emissions trading scheme, a firm whose emissions meet a specified emissions cap or baseline and which is responsible for emissions credit surrender to the scheme's administrator

Renewable Fuel Standard (RFS) [RFS1, RFS 2]: A public policy which requires a certain proportion of an economy's fuels to come from approved renewable sources and/or sources alternative to fossil fuels; the policy may also incentivize greater production of alternative/renewable fuels through tax incentives, loans and grants to fuel producers and consumers, which is the case in the US

Steam Methane Reformation (SMR): The most common method of producing hydrogen from fossil fuels in which natural gas or other methane-based fuel is reacted with steam at high temperatures to produce H₂ and CO gases

Tank-to-Wheel (TTW): Describes a portion of a transportation fuel's life cycle, including only the consumption of fuel during vehicle operation

Uncertainty Loss Aversion Bias (ULAB): a psychological characteristic of consumers in which the uncertainty over future savings from energy efficiency and the greater weight of consideration given to present losses results in choosing sub-optimal energy efficiency options

Upstream: Usually a comparative term; in a fuel production and consumption life cycle pathway, a point in the pathway which is closer to the beginning of the fuel's life cycle (e.g. extraction, production and refining stages)

Well-to-Tank (WTT): Describes a portion of a transportation fuel's life cycle which extends from original feedstock extraction to vehicle fuel tank or battery

Well-to-Wheel (WTW): Describes the entirety of a transportation fuel's life cycle (the sum of Well-to-Tank and Tank-to-Wheel)

Zero Emission Vehicle (ZEV): A vehicle that emits no tailpipe pollutants, including particulate matter, carbon dioxide, nitrogen oxides, and volatile organic compounds (e.g. bicycles, some electric vehicles, some fuel cell vehicles)

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List of Figures

Figure 1: Change in transport sector CO₂ emissions by mode and region in a business-as-usual scenario, 2006-2030, including passenger and good transport.No table of figures entries found.

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Table 1: Overview on fuel efficiency standards in some world regions.	26
Table 2: Year 2005 reference emissions, baseline emission projections, policy targets under the 20% EU-wide reduction target, and corresponding abatement target for the EU ETS and transport MACCs under consideration (in MtCO ₂ e) (Sources: Year 2005 emissions EEA 2010; for MACCs see Figure 11).	59

Annex A: Scenarios for future market shares of electric vehicles

The global market share of electric vehicles (BEV, PHEV, BEV with range extender) is unanimously projected to grow. However, the extent and pace of growth is uncertain and dependent on various factors. Figure 3 below summarizes the growth scenarios of different studies on the matter. Projected market shares in the total of the vehicle fleet in 2020 range between 1% (Minimal Scenario) and 13% (Optimistic Scenario). The Base Scenario estimates a penetration of 7% by 2020. In the long term, the IEA (2009b) forecasts a 50% market share in 2050 (BLUE Map scenario). The question is not so much whether the electrification of the transport sector will take place but rather at what pace. The near-term economic potential of electric vehicles is dependent on various uncertain factors including energy prices (oil, electricity), battery technology and cost, economies of scale, recharging infrastructure, regulatory requirements and fiscal incentives. A model-based study of the German Aerospace Centre (Mock et al. 2009) investigates different scenarios of future market prospects. Assuming a moderately increasing crude oil price, electricity and hydrogen from fossil energy sources as well as an average CO₂ target value of 113 g/km for the German new vehicle fleet in 2030, electric vehicles (BEV with and without range extender) could achieve market shares of approx. 40% on the German new passenger car market by 2030. Under different constraints, with a stricter CO₂ target value of 75 g/km and higher penalty fines as well as electricity and hydrogen being produced from renewable sources, electric vehicles could achieve market shares as high as 95%, including a 35% proportion of fuel cell hybrid electric vehicles.

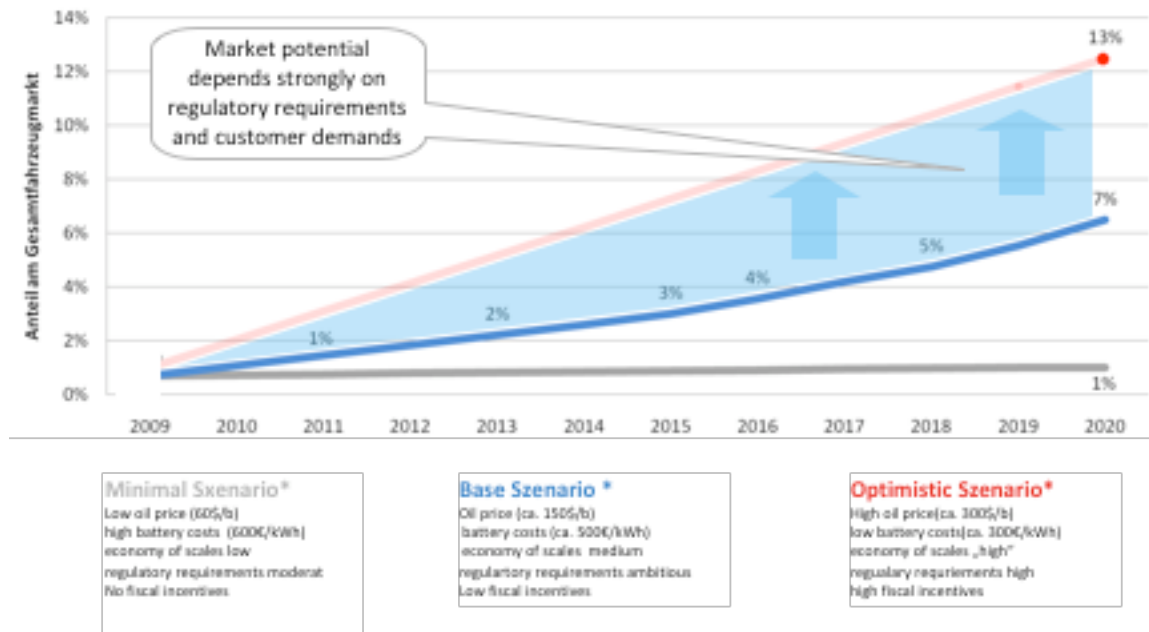


Figure A. 1: Scenarios for market shares of electric vehicles (Sources: BCG 2009, MCK, Dt. Bank, Bain, R. Berger, PA Consulting)

Boston Consulting Group, a consulting firm, estimates the market penetration of different vehicle technologies in 2020 (BCG 2009). In their medium growth scenario (Scenario 2 in Figure 3) electric vehicles (BEV, PHEV, BEV with range extender) will account for 26% of global new-car sales in 2020. In their view, this is the most likely scenario. However, under all scenarios and in all world regions, the internal combustion engine will continue to dominate the market for new passenger cars until 2020.

Annex B: Fuel pathways – data and sources

<i>Fuel pathway</i>	Feedstock	Production	Distribution and Storage	Vehicle	Total
<i>Emissions (gCO_{2e}/MJ)</i>					
<i>Efficiency Loss (%)</i>					
Gasoline (conv.) [1]	28	55	6	292	381
	6	13	2	59 [2]	80
Gasoline (uncov.) [3]	86	39	4	304	433
	15	13	1	53 [2]	82
Diesel (conv.) [1]	24	34	1	220	279
	9	13	0	51 [4]	73
Diesel (unconv.) [3]	55	37	2	221	315
	15	7	2	51 [4]	74
Hybrid (gasoline) [1]	24	27	3	217	270
	6	13	2	51 [5]	72
Hybrid (diesel) [1]	21	23	2	190	236
	9	13	0		68
Natural Gas [1]	11	12	8	182	213
	3	3	23	48 [7]	77
PHEV AER (Coal) [8]	22	410	0	0	432
	2	65	5	13 [9]	85
PHEV AER (Renew) [10]	17	0	0	0	17
	0	0	14	39 [9]	53
BEV (Coal) [8]	18	331	0	0	349
	2	65	5	7 [11]	79
BEV (Renewables) [10]	13	0	0	0	13
	0	0	14	22 [11]	36
H2 FC Hybrid onsite [1]	14	135	15	0	164
	7	28	13	21 [12]	69
H2 FC Hybrid offsite [1]	14	150	1	0	165
	7	28	37	11 [12]	83
H2 FC Hybrid elec [10]	16	0	0	0	16
	0	28	16	23 [12]	67
H2 FC (onsite) [1]	18	180	20	0	218
	7	28	13	28 [13]	76
H2 FC (offsite) [1]	18	200	2	0	220
	7	28	37	15 [13]	87
H2 FC (Electr.) [10]	21	0	0	0	21
	0	28	16	31 [13]	75
H2 ICE (onsite) [1]	24	238	27	0	289

	7	28	13	33 [14]	81
H2 ICE (offsite) [1]	23	257	2	0	283
	7	28	36	18 [14]	89
H2 ICE (Electr.) [10]	27	0	0	0	27
	0	28	16	37 [14]	81

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[4] Diesel ICE thermal efficiency (0.34) sources:

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[5] Hybrid gasoline engine thermal efficiency (0.35) sources:

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[7] Natural gas ICE thermal efficiency (0.33) source:

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[9] PHEV efficiency (0.55): Assuming 50% driving with hybrid gasoline efficiency (0.35) and 50% with all-electric (0.74)

[10] Evans, A., Strezov, V., Evans, T., 2009. Assessment of sustainability indicators for renewable energy technologies. *Renewable and Sustainable Energy Reviews*, 13:1082-1088.

[11] BEV thermal efficiency (0.74) source: Page, S., Krumdieck, S. 2009. System-level energy efficiency is the greatest barrier to development of the hydrogen economy. *Energy Policy*, 37:3325-3335.

[12] H2 FC hybrid thermal efficiency: Assumption (no literature on this)

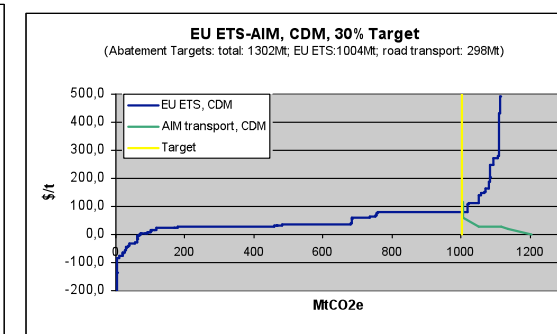
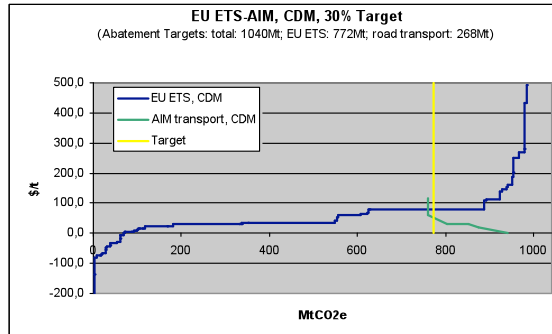
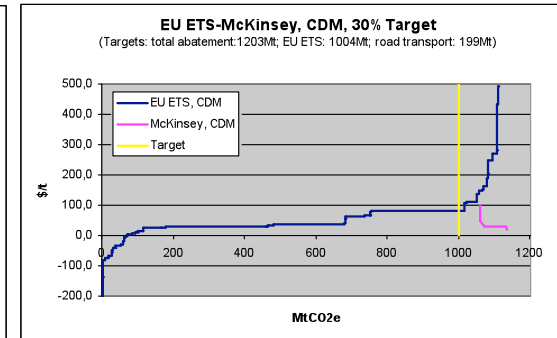
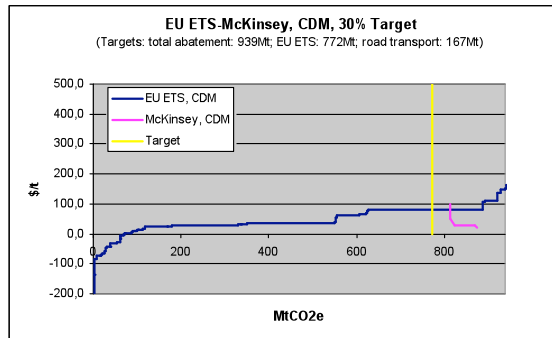
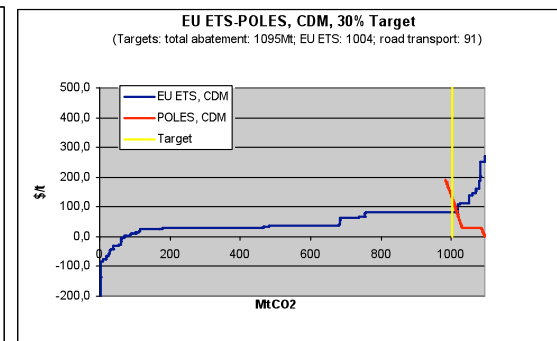
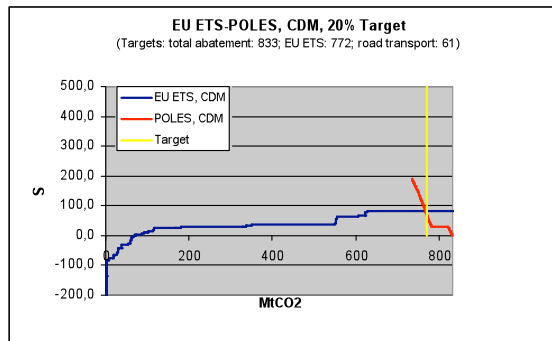
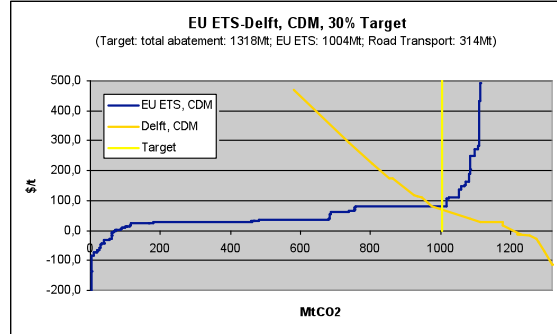
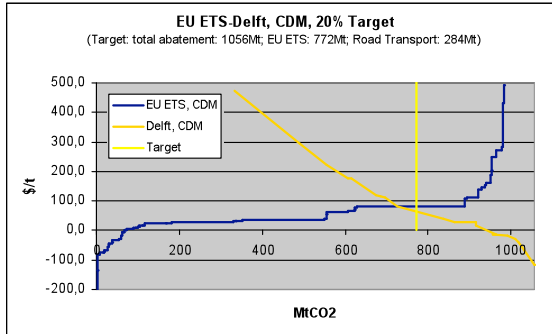
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Annex C.1: Linking MACCs overview, 20% and 30% reduction cases



Annex C.2: Linking MACCs overview, 20% reduction case without CDM access

