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Towards low-carbon mobility: Tackling road transport emissions

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The ever-increasing trend to greater mobility has brought about a situation in which considerations of sustainable development might call for restrictions on the continued growth of the global mobility of people and goods. The transport sector is not the biggest contributor to greenhouse gas emissions, but accounts for a constant part in them and heavily depends on non-renewable fossil fuel. The prevalence of road transport in the sector's emissions makes it a priority in this necessary effort to move away from a carbon-intensive mobility.

This study gives an overview of the options for progressing towards a low-carbon road transport. The solutions include necessary technological advances, and behavioural and organizational changes without which the benefits from these advances would be reduced. Economic instruments and public policies are needed to provide a vital support to this transition. In this regard, although emission abatements in the sector are generally considered to be costly, setting a price to CO_2 emissions can prove an efficient way of adjusting relative prices according to comparative environmental benefits, thus favouring lower-carbon solutions. The options already experimented and the most credible ways forward give a glimpse of mobility's future, and food for thought to make it even better.

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Introduction

In post Industrial Revolution societies, mobility has acquired such a determining role, as a key driver of individual achievements and an enabler of social progress, that it has been recognized as one of the universally acknowledged human rights. However, the ever-increasing trend to greater mobility has brought about a situation in which considerations of sustainable development might call for restrictions on the continued growth of the global mobility of people and goods.

According to IPCC, the transport sector accounted for 13.1% of worldwide greenhouse gas emissions in 2004 (IPCC, 2007a). It also represented 22% of CO_2 emissions from fuel combustion in 2008 (IEA, 2010b). When projecting the mobility habits of industrialized economies onto developing economies, it is easy to understand the shortcomings of our present mobility patterns and means, mainly stemming from the sector's almost complete reliance upon physically finite and economically volatile fossil resources. With international action on climate change aiming at significant emissions abatement in order to prevent the Earth's surface temperature from increasing by more than 2°C, the long-spared transport sector will have to be placed alongside primarily targeted energy-intensive sectors such as power generation. The prevalence of road transport in the sector's emissions makes it a critical point in this action.

Not only will reducing transport-related environmental impact require technological options able to improve energy efficiency and to lower emissions, it will also require simultaneous changes in users behaviours and public policies to foster the implementation of these potential solutions. Advances need support and incentives to balance the competitive edge of widespread, profitable technologies and services. In this regard, setting a price to CO_2 emissions can prove an efficient way of adjusting relative prices according to comparative environmental benefits, thus favouring lower-carbon options.

Yet, the design of carbon pricing instruments in the transport sector is an difficult task, for this sector holds much specificity, including the fact that emissions proceed from diffuse, mobile sources and that emissions abatement are believed to be more costly than in other, more energy-intensive industries.

This article gives an overview of the necessary measures for progressing towards a low-carbon mobility. After exposing the role that transportation plays in current climate change trends in the first section, the focus is put exclusively on the necessary advances in road transportation. The second section outlines the most credible technological solutions for a transition to the use of cleaner energy, without which no improvement can be expected. The third section gives some details about behavioural and organizational changes that can foster the implementation of these new technologies. Finally the fourth section addresses the economic instruments and public policies needed to provide a vital support to all these changes.

1. Transport and climate change

1.1. The growing need for mobility

Mobility has continuously evolved over time. Mankind has successively resorted to its own physical strength, animal traction, river currents and maritime winds to facilitate the movement of people and goods. With industrialization, steam-powered machinery and the internal combustion engine* profoundly changed transport in terms of performance (speed, range), resources and uses. The dramatic expansion of motor vehicles in western societies during the 20th century emblemizes this revolution.

Over the last few decades, a coupling between economic growth and transport development has emerged. With a freight-GDP elasticity of around 1.1 and a passenger transport-GDP elasticity of approximately 0.6, the 50% increase in the OECD's GDP over the 1990-2007 period led to substantial rises in goods and passenger transport, to respectively 10,043.1 billion tonne-kilometres and 12,693.3 billion passenger-kilometres (ITF, 2010a).

This spectacular growth in traffic increased transport's energy consumption at an average annual rate of 1.8% in OECD countries over the 1990-2006 period. The trend is broadly similar in non-OECD countries, with an even higher rate of increase of 2.8% (IEA, 2009).

Ever since industrialization, the development of transport has widely relied on oil. Its high energy content and stable liquid state make it an easily storable and transportable fuel – which is the reason why internal combustion engines are able to provide vehicles with an extensive range. More than 100 years after cars began to be mass-produced, modern means of transport are 95% dependent on oil products (IEA, 2009): gasoline, diesel and LPG (Liquefied Petroleum Gas) on roads, kerosene in the air, fuel oil on the seas. Only rail transport is less vulnerable to this oil dependency, with coal having been replaced more by electricity than fuel oil.

However, transport's high dependency on oil raises two crucial issues for its sustainability: the security of fossil fuel supply and the reduction of the sector's carbon footprint.

1.2. One fossil fuel, two pitfalls

The first challenge facing the transport sector is fuel supply security. Oil is not a renewable resource on the timescale of human civilization (since its natural formation process requires at least tens of millions of years). Yet in little more than a century, we have probably burned more than a thousand billion barrels of oil. In other words, depending on the estimate, between one third and one half of the world's available oil has already been burned, even taking account of upcoming discoveries (BP, 2011). The rocketing world population, which will soon reach 7 billion against 1.2 billion a century and a half ago, combined with increasing average living standards (especially in some large emerging countries), puts further strain on the remaining reserves.

According to the IEA, global primary oil demand on a 2035 horizon would reach 107.4 million barrels per day in a business-as-usual scenario, compared with 84 million in 2009. If environmental objectives are to be achieved, this demand needs to be closer to 80 million barrels per day by 2035 (IEA, 2010a).

The declining rate of new conventional oilfield discoveries and falling production in the largest fields being exploited seem to support the theory, initially known as "peak oil*", which predicts a peak or a plateau in conventional crude oil production in the coming decade, followed by a progressive decrease. Leaving aside environmental concerns, the development of unconventional resources (such as tar sands from Athabasca) might, however, alleviate the pressure on supplies expected by this above scenario.

AN UNSUSTAINABLE TREND IN OIL CONSUMPTION

OIL CONSUMPTION AND GLOBAL DISPARITY

Average demand by inhabitant (tonnes)		Total demand (2008) 4 billion tonnes of oil	A bit of science fiction…
India	0.1	i.e. **0.6 tonnes of oil** consumed on average per inhabitant in the world but 18% of the world's population represents 55% of global oil demand	And if tomorrow… …1 Chinese used on average as much oil as 1 American… … then… … global oil consumption would quite simply **double**.
China	0.3		
Brazil	0.5		
EU27	1.4		
Japan	1.7		
United States	2.9		

Source: IEA, BP

Key point: There are major oil consumption disparities between developing and industrialized countries. The consumption models of the latter are not sustainable on a global scale.

Action in the face of climate change is the second challenge that the transport sector has to address. Its heavy dependency on fossil fuel with high carbon content makes it the biggest contributor to the acceleration of anthropogenic GHG emissions. Global anthropogenic emissions, taking all GHGs into account, amounted to 45 billion tonnes of CO_2 equivalent (tCO_2e) in 2005 (IEA, 2010b), i.e. a 7 tCO_2e world average per capita, with striking discrepancies between regions. The aforementioned demographic and socio-economic trends underline the urgency of moving towards sustainability.

Fuel supply security and environmental concerns must be addressed together, since it is necessary to combat transport's dependency on fossil fuel and especially oil in order to reduce emission levels. Other co-benefits of action in this respect would include the easing of geopolitical tension about supply security and reducing the environmental threat posed by the extraction of unconventional fossil resources. For CO_2 emissions from transport reflect both its environmental impact and the extent to which it relies on oil.

1.3. Assessing transport's carbon footprint

Taking appropriate action requires good knowledge of the relevant facts. CO_2 emissions from transport, although diffuse, can be measured quite precisely by multiplying the quantity of fossil fuel used (in tonnes of oil equivalent, or "toe") by the corresponding emission factor (for example, 2.9 for gasoline, 3.0 for kerosene, and 3.1 for diesel) (IPCC, 2006). Nevertheless, this calculation does not provide a comprehensive assessment of transport emissions. To the CO_2 emissions that result from fuel burned during vehicle use, one must add:

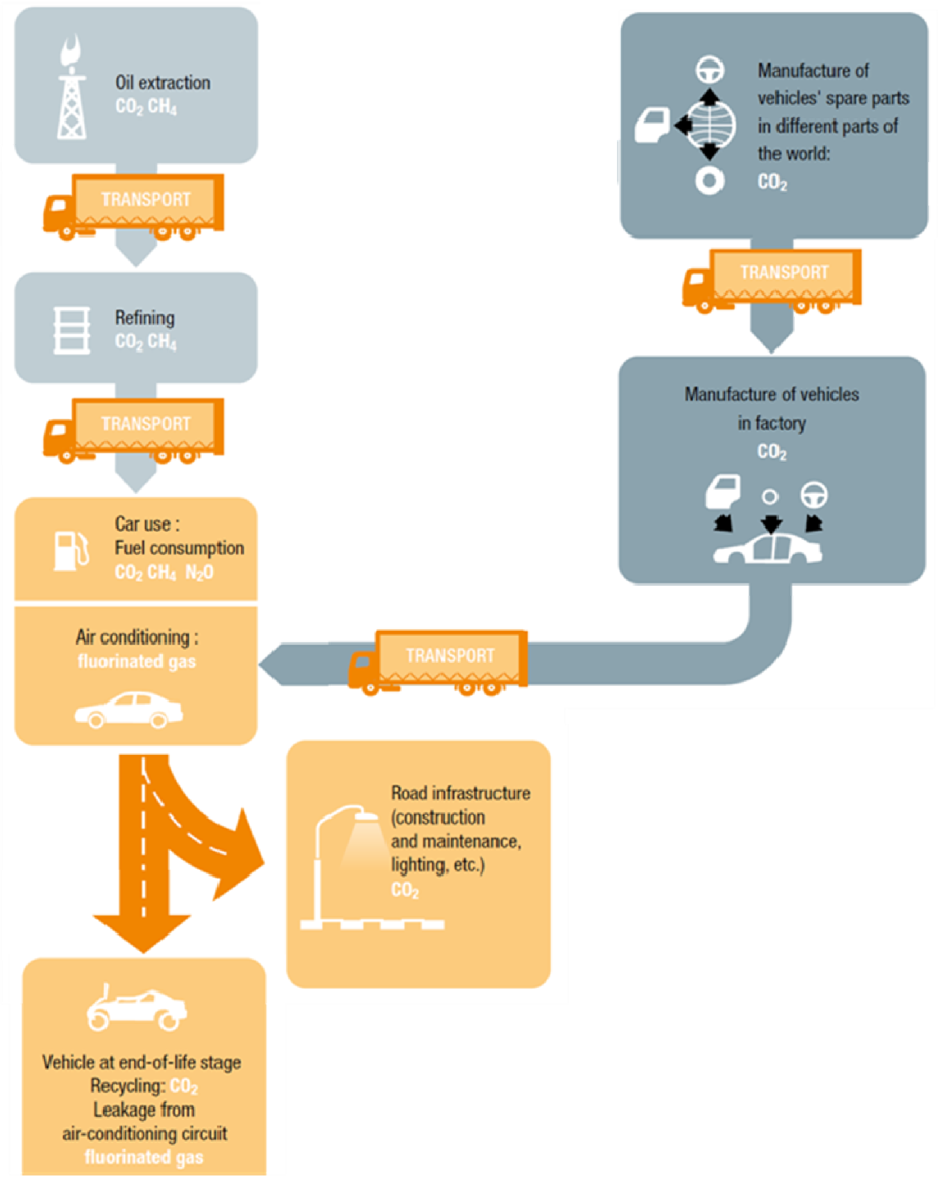
- A small but fast-growing quantity of other greenhouse gases that arises from transport. In particular, the sector is responsible for almost a third of hydrofluorocarbon (HFC) gas emissions (IPCC, 2007b), the significant growth of which since 1990 reflects the development of vehicle air conditioning, especially in passenger cars, but also in trains and refrigerated vehicles. This increasing use of HFC is also a consequence of the Montreal Protocol, which phased out chlorofluorocarbons (CFC) to protect the ozone layer and authorized HFC as a transitional substitute.

- The impact of transport-related emissions, which is even worse if the emissions of the entire "transport system" are taken into account, i.e. the emissions from the vehicle and infrastructure over their complete lifecycle*. Modern industrial processes have led to a clear increase in unitary emissions related to the car manufacturing phase, which add to the industry's greenhouse gases. The same goes for construction and maintenance of transport infrastructure, which must be included in efforts to reduce the industry's emissions.

For an internal combustion engine car, CO_2 emissions during use account for 75 to 80% of total GHG emissions over the complete lifecycle, according to French environment and energy management agency (ADEME). The emergence of new technologies such as electric drives will redefine this proportion, emphasizing the need for improvements at every level, from manufacturing and energy production to disposal and recycling. Carbon pricing mechanisms implemented in the road transport sector might be sensitive to this shift in the terms of the lifecycle emissions equation.

A CAR'S GREENHOUSE GAS EMISSIONS

Emissions during a car's entire lifecycle



Source: ADEME

Key point: A car's usage phase accounts for 75% to 80% of the greenhouse gas emissions throughout its lifecycle.

1.4. Unsustainable trends calling for action

In the fight against climate change, the transport sector is a particularly sensitive issue, due to the rapid growth of traffic and the strong dependency on fossil energies.

Fossil fuel combustion during a vehicle's use is responsible for the release of greenhouse gases. The transport sector's share in global CO_2 emissions from energy combustion has been stable at around 22% over recent decades, for an amount of approximately 6.7Gt in 2008 (IEA, 2010a).

THE INTERNATIONAL ENERGY AGENCY'S SCENARIOS

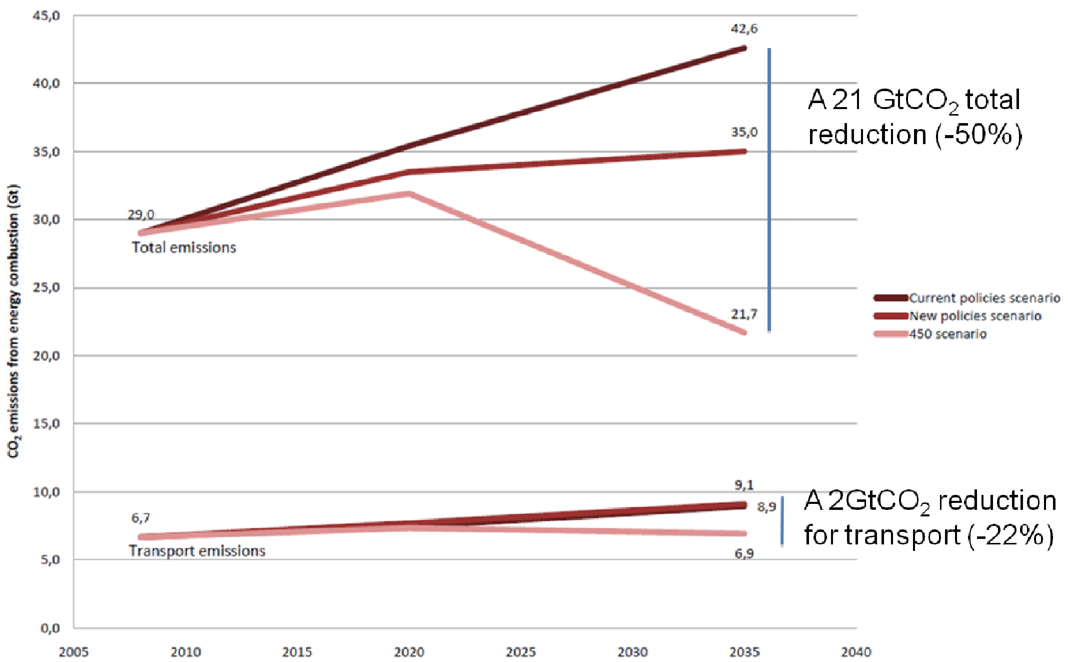
In the *World Energy Outlook 2010*, the International Energy Agency (IEA) defines three scenarios for future trends in CO_2 emissions from fossil fuel combustion, with a 2035 time horizon.

The Current Policies Scenario is a baseline scenario. It assesses the growth in CO_2 emissions if no new measures to mitigate climate change are implemented.

The New Policies Scenario is a more detailed assessment. Based upon the Current Policies Scenario, it takes into account the expected impact of measures already in the pipeline and likely to be implemented.

The 450 Scenario stems from a different approach. Using a backcasting method, it gives a picture of what the emission outline has to be to ensure a 450 ppm CO_2 concentration in the atmosphere, a condition that the IPCC deems probably necessary to keep the temperature from rising by more than 2°C.

Energy-related CO_2 emissions by sector and scenario



Source: IEA

Key point: The transport sector will have to contribute to the general effort towards emissions reduction if international environmental objectives are to be achieved. A 2GtCO_2 cut compared with business-as-usual scenarios, by 2035, will probably be needed.

In the IEA's Current Policies Scenario, transport's emission share reaches 9.1Gt by 2035, out of 42.6Gt total emissions (IEA, 2010a). In this scenario, the environmental targets aimed at by the international community are far from reached. Nor are they in the New Policies Scenario, in which total emissions are lower, but the effort expected from the transport sector is the same. Nevertheless, in the latter scenario, incremental progress, i.e. the continuous development of technologies with no emergence of any disruptive innovation, would limit emissions to an annual increase rate of 1.14% per year, in a nonetheless rapidly growing market.

In the 450 Scenario, the transport sector accounts for 6.9Gt of the 21.7Gt total by 2035 (IEA, 2010a). The effort expected from the sector is proportionally less than what is needed from most other sectors. All the same, it calls for a 2Gt cut (22%) compared with the Current Policies Scenario; it also requires limiting emissions to the 2008 level.

In the Roadmap for moving to a competitive low carbon economy in 2050, the European Commission analyzes pathways to achieve an 80% reduction in global greenhouse gas emissions in the EU by that date, and gives milestones for each sector's expected contribution. In 2005, transport emissions were 30% higher than their 1990 level. Still compared to 1990, they will need to come to between +20% and -9% by 2030, and between -54% and -67% by 2050 (EC, 2011a).

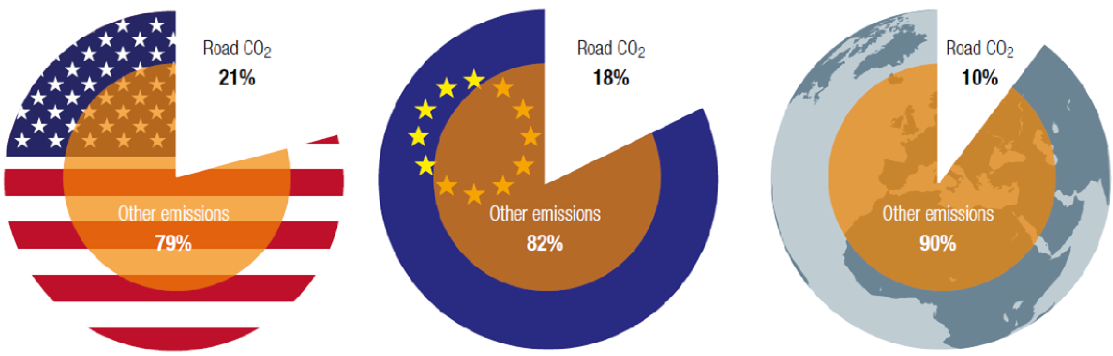
Under these constraints, what might appear as an unwelcome development in an economically sensitive sector could actually be an occasion to stimulate innovation, and might generate substantial opportunities. It is likely that incremental progress will not be enough to achieve this objective without reducing the pace of mobility growth, and that a real breakthrough will be needed for the sector to hit the target.

1.5. Why focusing on road transport?

Road transportation is responsible for a large part of global greenhouse gas emissions. It accounted for 73% of the CO_2 released by fossil fuel combustion in the transport sector in 2008 (ITF, 2010b), and is therefore a priority in the effort needed to reduce the transport sector's emissions.

GREENHOUSE GAS EMISSIONS FROM ROAD TRANSPORT

Road transport CO_2 share in total greenhouse gas emissions in 2005



Source: ITF

Key point: On a global scale, CO_2 emitted by road transportation accounts for 10% of total greenhouse gas emissions (in CO_2 equivalent), with an even larger proportion in developed countries.

Even though greenhouse gas emissions are not the main negative externality of road transport (congestion, accidents, noise and local pollutants emissions are currently deemed to have a higher impact on GDP) (EC, 2011b), endeavours to tackle these emissions often provide co-benefits in some other fields (for instance, electric motors eliminate noise and particulate matters emissions as well as greenhouse gases emissions during use).

Although increasing at a slower pace than emissions from air transport or maritime transport, road transport emissions account for the greatest rise in volume. This growth stems from both the soaring number of cars in the world and the average increase in the length of journeys. The positive effects of efficiency improvements in internal combustion engines and the modernization of fleets are not sufficient to offset the negative effects of the increase in road traffic on the sector's emissions.

A GROWING GLOBAL CAR FLEET

Trend in the rate of motor vehicles ownership worldwide (World Bank / motor vehicles per 1,000 inhabitants)

2003		2007	
China	15	China	32
Brazil	164	Brazil	198
EU27	491	EU27	566
United States	796	United States	820

Source: World Bank

Key point: The global car fleet grew by more than 50% in 5 years. Propelled by large emerging countries, it increased from 560 to 875 million vehicles between 2002 and 2007.

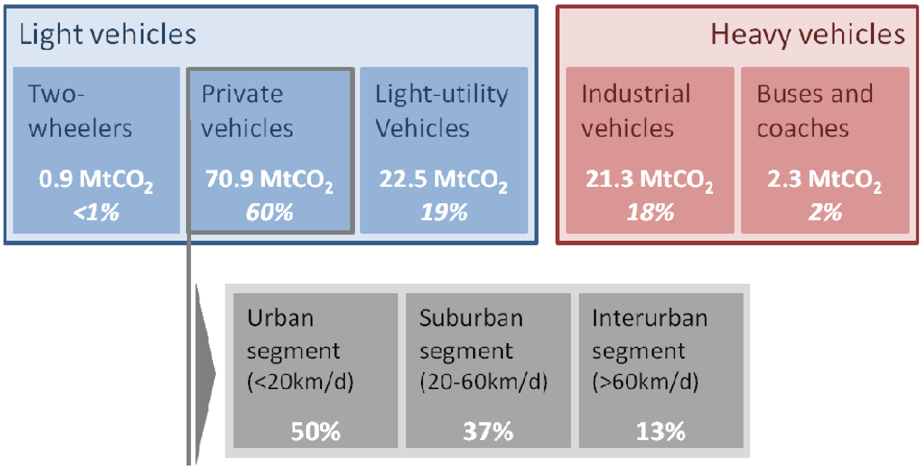
The transportation industry seems to be on the brink of major changes in terms of energy sources, vehicles and the design of mobility services. This threefold change is an opportunity to promote the inclusion of both fuel supply security and climate change issues in development strategies for the sector. Because of its volume, its growth trend, and its relatively quick fleet renewal (that can, moreover, be speeded up), it is a sector in which additional efforts could produce significant results.

Nevertheless, road transportation is a complex sector. It comprises various market segments, the key characteristics of which are the typical ranges and payloads of the vehicles. Distinctions are commonly made between urban and interurban distance classes, and between light and heavy vehicles*.

Another way of breaking the sector down into more specific segments is to separate passenger transport from freight. For instance, in France in 2005, passenger transport accounted for 66% as against 34% for freight (ITF, 2010b). While changing the former appears to be faster in terms of fleet renewal and technological lead time, the actors and decision-makers in the latter are more aggregated, thus allowing an easier implementation of policies. In addition, measures applied to freight generally have greater leverage because their impact does not depend on individual users' behaviour.

A SEGMENTED SECTOR CALLING FOR A PORTFOLIO OF SOLUTIONS

CO_2 emissions from road transportation in France in 2009



Source: CEC from Union Routière de France

Key point: Road transportation is a highly segmented sector, for which different technologies and measures are relevant for reducing emissions, depending on the segment. Due to their relative weight in overall emissions, some segments, such as urban passenger mobility, offer greater leverage.

Vehicle features and journey characteristics are fundamentally different from one segment to another. No silver bullet solution can therefore be expected, and a basket of multiple solutions might be needed to properly address the emissions issue in the road transportation sector.

Different types of solution will be needed to tackle road transport emissions and the sector's correlated oil dependency. A combination of technological advances with organizational and behavioural changes, fostered by relevant economic incentives and public policies, is needed.

2. Technological options for emissions reduction in road transport

Technological incremental advances can improve energy efficiency, and thus help relieve the pressure on both oil supply and the environment. By way of example, incremental improvements in truck design, such as better aerodynamics or the use of single tyres instead of twin tyres, could result in significant emission reductions, up to 4% (DSLV, 2011). Further emission reductions could be achieved by increasing the legal maximum size and weight of trucks, though issues of security and infrastructure needs are impeding the acceptance of this proposal. The measure is controversial: its advocates believe that it would make road freight more energy-efficient by using fewer vehicles; its detractors claim that the number of trucks would stay the same, with the improvement in efficiency encouraging the use of this form of transport and thereby creating a rebound effect* on emissions despite a marginal improvement.

Yet, the most powerful technological option in terms of impact seems to be a broad shift from oil to other power sources and energy carriers. Various promising technologies are already available, or close to being developed, with large-scale potential for a real breakthrough in emissions reduction in road transport. Some of these are particularly appropriate for a given segment, while the others have broader applications.

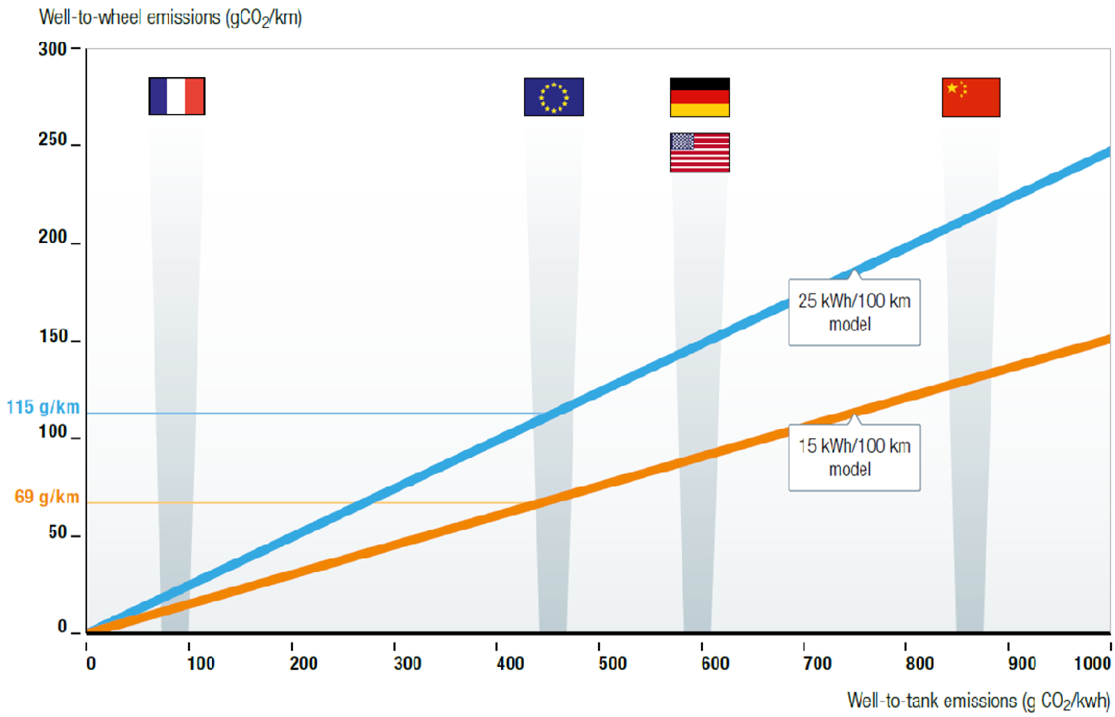
2.1. The long-awaited blossoming of vehicle electrification

The electric car* was created in the late 19th century. It subsequently gave way to internal combustion engine vehicles, as a result of falling fossil fuel prices and the development of suitable infrastructure such as filling stations. Since the early 1990s, electric-drive vehicles have made something of a comeback and are increasing their market share, starting with industrial fleets (power lift trucks, for example) and vehicles with limited range requirements (golf carts, low-speed city cars, postal vehicles, etc.).

Using electricity is a way of limiting the transportation’s sector dependency on fossil fuels and reducing its greenhouse gas emissions as well as local pollutants emissions. First, the efficiency of electric motors – defined as the ratio of recovered mechanical energy to consumed energy– is over 90%, compared to, at best, 35% for gasoline engines and 40% for diesel engines (Michelin, 2011a). Next, unlike internal combustion engines, electricity-powered engines produce no emissions when in use (tank-to-wheel emissions*). Nevertheless, upstream emissions do occur, due to power generation processes (well-to-tank emissions*). Consequently, the environmental benefits of electric vehicles, from the greenhouse gas emissions standpoint, largely depend on how electricity is generated. The move towards low carbon power generation, with the development of renewable energies and nuclear power, the implementation of new processes such as cogeneration*, or the development of carbon capture and storage* technologies as well as storage and smart grid* technologies (for peak-load management), makes electric vehicles a credible option.

CO$_2$ EMISSIONS OF ELECTRIC DRIVE CARS BY COUNTRY

Breakdown of the well-to-wheel emissions of electric drive cars



Source: Michelin

Key point: With the current average carbon content of European electricity, the emissions of an electric drive car (similar to a current ICE vehicle in every other respect) burning 25kWh/100km are 115g/km well-to-wheel*. Without making any modifications to the electric power generation mix, these emissions fall to 70g/km for a car burning 15kWh/100km. This is an improvement of about 35% as compared to an ICE vehicle model that would meet the European Union threshold for 2020 (95g/km tank to wheel).

There are several levels of electrification for a vehicle.

- The first levels involve various hybrid vehicles* combining an electric motor and a main internal combustion engine.
  - Micro-hybridization, also known as the stop-start system, allows the engine to stop when the vehicle comes to a standstill, and automatically restarts it when the driver presses the accelerator. This system can save up to 15% fuel in an urban environment.
  - More advanced hybridization technologies allow regenerative braking, electrically assisted acceleration at low engine speeds, and even a zero-emission mode over a range of a few kilometres, with disconnection of the internal combustion engine.
  - Plug-in hybrid vehicles and range-extender hybrid vehicles are the most electrified hybrid vehicles: their larger batteries can be charged (by connecting to the grid) and make it possible to run on electricity for several tens of kilometres.
- The battery electric vehicle, or 100% rechargeable electric vehicle (sometimes referred to as the “full-electric vehicle”), has only one engine, running on the electricity provided by batteries recharged by connecting to the grid.

The implementation of advances in this area is most likely to be gradual, as the past years have already shown. Electrification should be progressive, for example impelled by the development of stop-start systems, then by the large-scale adoption of hybrid cars, and finally the emergence of fully electric car fleets. However, not all electrification levels are as yet suited to all market segments.

- Vehicles intended for urban use will probably incorporate all electrification levels. Regenerative braking systems and zero energy-consumption when idle provide energy savings particularly for urban use, where maximum speed and range are low but acceleration and stops are frequent. Another benefit of electric engines is their low noise level, as well as the total absence of local pollutants emissions (including nitrous oxides and particles).
- In regard to vehicles intended for longer distances, the weight/energy ratio of batteries currently gives hybrid vehicles better long-term prospects. These can take advantage of the benefits of electrification in urban use, and have a range comparable to that of conventional internal combustion engine cars.

2.2. The challenges of hydrogen and fuel cells

The electric energy necessary to power an electric motor can either be drawn from a battery (storage device) or be generated by a fuel cell, and the dual mode is possible. A fuel cell produces electricity from hydrogen and oxygen, with water as the only discharge, and answers to oil dependency and environmental concerns when in use. Moreover, hydrogen is a good energy carrier. Its use as fuel thus extends vehicle ranges in comparison with battery vehicles.

While battery technologies, i.e. plug-in hybrids and fully battery-powered electric vehicles, deeply redefine the way users buy the energy their vehicle will consume, the use of hydrogen technologies has more similarities with that of traditional thermal vehicles: cars would have a tank that would be refilled at hydrogen stations, thereby obviating the need to be plugged into a power source for longish periods (or to have their battery swapped). However, large-scale development of hydrogen in the transport sector would require the deployment of a sizable infrastructure, from production facilities to fuel transport and delivery.

Furthermore, since hydrogen does not exist naturally, its production requires a significant amount of energy, thus giving rise to environmental efficiency concerns. Its transportation and storage are major technical issues, and the economic benefits of the whole process are yet not proven.

2.3. Different situations for different biofuels' patterns

Because they are renewable liquid fuels, biofuels* could be a way to continue using traditional-design engines while instantly reducing their dependency on fossil fuels. Moreover, the carbon content of biofuels, released during combustion, is extracted from the atmosphere by photosynthesis as the plant grows. Thus in principle the use of biofuels does not cause carbon transfers from subsoil to atmosphere, and is therefore not included in greenhouse gas emissions inventories.

These benefits are real as long as biofuels come from plants that are renewable and do not involve environmentally harmful changes in land-use*. The main negative impacts linked to the development of biofuels concern the deforestation to which they have contributed in certain regions, and the acute problem they pose in terms of competition with food crops. This competition can either be direct (the trade-off in the use of a particular crop between biofuels and food) or indirect (the trade-off between biofuel and food crops on a particular piece of agricultural land). Other adverse effects of biofuel production on a lifecycle assessment basis are the additional emissions produced during the fuel processing and fuel transport phases.

Historically, first-generation biofuels were produced from food crops – sugarcane, sugar beet, soya, rape and palm oil, corn and wheat – allocated to energy use. Their development was aimed at reducing well-to-wheel greenhouse gas emissions from transport as well as reducing dependency on fossil fuels. The potential for emissions reduction using these crops is still difficult to gauge insofar as the figures differ from one plantation to the next.

In optimal conditions, significant gains can be achieved: up to 53% for corn ethanol and 70% for sugarcane ethanol in an urban context (Michelin, 2011b). But taking into account emissions generated upstream can greatly affect these figures and sometimes reverse them: intensive farming prior to the transformation into fuel can generate significant greenhouse gas emissions, and the impact becomes negative when its expansion impinges on forests or carbon sinks more generally (as in Indonesia's peat lands).

New biofuels are currently being developed, and will be produced from lignocellulosic biomass (forest residues, short rotation coppice, stalks and leaves, etc.) or dedicated crops that are not in competition with food crops on agricultural land (photosynthetic algae, for example). In the medium term (2030-50), these are likely to be a complementary source of supply, offering possibilities for reducing well-to-wheel emissions by as much as 90% (Michelin, 2011b), but currently have production costs that prevent large-scale commercial exploitation.

BIOFUEL: HISTORICAL OVERVIEW

The main biofuel producers are Brazil and the USA for ethanol, and Europe for biodiesel.

- Strongly state-supported, Brazilian ethanol has been produced since the 1970s, in order to reduce oil expenditure. Its spread was accompanied by the development of FlexFuel cars, a technology allowing any mix of gasoline and alcohol from 25% ethanol by volume up to 100%, thereby offering Brazilian drivers the possibility of adjusting the mix according to the respective prices of the two fuels. Significant public funds invested in the biofuel industry brought biofuels' share in national vehicle fuel mix over 25%.
- In the United States, between 1978 and 2007, federal tax breaks on fuels containing at least 10% ethanol gave momentum to the industry's development (less than 1 Mtoe in 1980, 23.1 Mtoe in 2009). Ethanol consumption has been increasing at an annual rate of almost 25% since 2000 and several hundred production plants are now in service. In 2005, the US government enacted an objective to incorporate 5.5% bio-ethanol into fossil fuels by 2012.
- In Europe, biofuels underwent a similar development, except that biodiesel is more prominent than ethanol. They represented 4% of motorcar fuels in 2009. With production levels of 7 Mtoe of biodiesel and 1.7 Mtoe of ethanol, the European Union is the third biggest biofuel producer. EU consumption of biofuel has grown at an average annual rate of more than 35% since 2000, and its development plays a part in the roadmap adopted by the European Union to reach 10% of renewable energy in transport by 2020.

In 2009, global first-generation biofuel production stood at 73 million tonnes (52 Mtoe): 58 million tonnes (39 Mtoe) of ethanol for gasoline engines and 15 million tonnes (13 Mtoe) biodiesel. It therefore represented almost 4.5% of the world's consumption of oil refined into gasoline and diesel (1.7 billion toe in 2009).

Source: EPA, EC

More specific solutions tailored to particular contexts can bring significant progress towards emissions reduction. For example, biogas from urban waste can be used as an alternative fuel for fleets such as public transportation and garbage collecting vehicles.

Every technology offers both potential benefits and potential shortcomings. Many options are available, but only a few of them will ever be deployed on a large scale.

2.4. Economic and ecological conditions for success

Ecological concerns arise in relations to some technologies. Their knock-on effects sometimes raise sustainability issues, as in the case of biofuel production, thereby requiring the implementation of sustainability criteria in order to prove truly beneficial in the framework of an overall GHG emissions assessment (including land-use change effects). Other technologies suffer from environmental efficiency uncertainties. For instance, the use of battery-powered electric drives raises the issue of GHG emissions from electricity production, which depend on local or national conditions. Another area for vigilance in regard to batteries concerns their production and end-of-life management.

What is more, the uneven readiness level of many of the technologies currently viewed as reduction sources leaves room for major doubts regarding the future extent of their implementation, and the benefits that can be expected. The question of the timeliness of a technology's development and deployment further complicates the picture.

For example, the development of electric vehicles is unarguably dependent on the implementation of specific private and public infrastructures (e.g. plug-in infrastructure for recharging). In this way, like mobile telephones in the early 1990s, the meshing of networks at local and national levels will affect the rate at which this new mode of transport is taken up. Furthermore, the adaptation of manufacturing capacity to the new architectures (compact passenger compartments, elimination of a chassis, and incorporation of batteries) and technologies (lighter material such as aluminium and carbon-fibre composites) is decisive.

Public backing is vital for the changes called for in manufacturing capacity and in specific infrastructures. The decisive steps of early market formation and progressive upscaling, during which profitability is uncertain or even not expected, are very risky for the actors financially involved. Within this perspective, suitable incentives can make initial underutilization less burdensome.

Finally, competitiveness is a crucial criterion for any technological advance. Car purchase undoubtedly involves economic reasoning, since price is one of the main factors in the decision-making process. To be sold, cars relying on new technologies must still be competitive. €30,000 electric cars could easily be produced, but few would be sold. Similarly, production cost is still a huge obstacle to the development of second generation biofuels (standing, at present, at $100-$300 per barrel for lignocellulosic biomass, and over $800 per barrel for algae) (Michelin, 2010).

The development potential of a technology is closely linked to its cost/benefit ratio. For vehicles, calculations should take the total cost of ownership into account, and not only purchase costs. Energy and CO_2 prices would thus have an increased and explicit leverage on competitiveness. Economic instruments could then help improve a competitive edge that might otherwise remain weak and promote the spread of environmentally favourable options.

3. Behaviours and mobility organization

Technological changes are just one factor in the transition towards the reduction of greenhouse gas emissions without putting the growth of mobility in question. Their maximum efficiency can only be obtained if they are part of a more general effort to improve every aspect of transportation, involving:

- changes in individual behaviour allowing more efficient use of existing means and the elimination of inefficiencies and waste;
- and changes in the organization of mobility service, as regards goods transportation, intermodality* and private vehicle ownership.

Most of these changes require decisions to be taken in the choice of transport infrastructures.

3.1. Mobility behaviours and the information challenge

Individuals can have a twofold influence on the energy efficiency of their mobility and the type of fuel it relies on, both as users and as buyers.

A range of diverse factors – such as lifestyle, education, and emotional involvement – influences choices and makes them fundamentally irrational. Being aware of environmental issues and of the environmental qualities of the desired product is a necessary first step when considering buying a green vehicle (assuming it is more expensive than internal combustion engine vehicle). Within the population of passenger car owners or would-be owners, the promotion of environmental performance criteria (lower pollution and greenhouse gas emissions) and comfort criteria (noiselessness, smooth drive experience and reserved parking facilities) can lead to changes in purchasing behaviour.

At the present time, efforts should be focused on making information available and understandable to the buyer. In the absence of an efficient information protocol, car buyers are prone to resort to misleading shortcuts (like looking at the engine size to estimate the environmental qualities of an engine) and rely on common misconceptions. Enhanced vehicle labelling, mentioning both the absolute amount of emissions and a comparison with vehicles from the same market segment, could be a real improvement.

Yet few car buyers consciously choose more environmentally friendly options – only around 5% in the UK (LCVP, 2011). As purchase price is the main criterion (along with vehicle size) taken into account, economic instruments can help redefine purchasers' preferences.

Information about the total cost of ownership is also needed to tackle what is referred to as high time preference or, figuratively, consumer myopia: buyers tend to take into account only the short-term expenditure associated with their purchase, instead of assessing the total cost of ownership. However, such analysis is essential if new technology vehicles, with their high purchase costs, are to be perceived as competitive.

Vehicle purchasers thus have a role to play in energy efficiency and savings, and so do drivers. Auxiliary consumption – air conditioning accounts for most of it – and driving style influence the overall energy consumption of vehicles, and the high sensitivity of electric vehicles to these factors will amplify their impact in the future. Improvements in this area can be quite simple, and immediately translate into savings. Practical experimentation may be an effective way to demonstrate the feasibility of most changes, through programmes such as eco-driving lessons.

More generally, the behaviour of transport users has a direct influence on transport emissions, starting with the choice of transportation for each mobility need. Especially in urban contexts, where various modes of transportation are often available, the search for sustainable mobility ought to lead users to consider the whole spectrum of options: walking, cycling, public transport, vehicles on a time-sharing basis, and, where applicable, passenger cars, possibly with car-sharing. This rationalization of existing modes of transport can help reduce congestion by better traffic control, staggering daily journeys to work when possible, and ensuring a better use of public transport. It constitutes a good source of emissions reduction that can be obtained within the framework of existing techniques and infrastructures.

URBAN GROWTH

In 2005, UN figures showed 20 cities of more than 10 million inhabitants, compared to only two in 1950. 10% of the world's urban population (which, since 2007, is larger than the rural population) is concentrated in these megacities.

In this regard, urban mobility will be an increasingly prominent and critical issue, in terms of quality of life as well as from an environmental standpoint.

Source: UN

The increasing scarcity of oil resources and the persistent shortfall in regard to objectives to reduce greenhouse gas emissions call for a radical change in the conception and practice of urban mobility. Nonetheless, the current number of cars running on fossil fuel and the fact that cars play a large part in people's transportation habits mean that we can only hope for a gradual transition towards a low carbon mobility. This transition will probably require new mobility options to be made available.

3.2. Towards a service economy

The transition to low carbon urban mobility can, in the medium term, bring about changes in modes of vehicle ownership, and a concomitant need for new business models. Like automated bicycle rental schemes, which are springing up in more and more major cities (mainly in Europe, and more recently in North America), time-share car networks* are now appearing. These operate by enabling users to borrow a car at one terminal and return it at another when they have completed their journey, for a subscription and a mileage fee.

This type of service redefines the relationships between the different actors. The driver would no longer be the consumer of a product, but would become the user of a new service offered by a new type of operator, an intermediary between the car manufacturer and the user. This new agent, which would become the car buyer, would have considerable optimization possibilities in terms of fleet management and energy consumption. Being able to place large orders for new cars, it could also have a significant influence on carmakers in regard to vehicle design.

Subscription to this type of service could be combined with the traditional public transport pass or travel card, and possibly entitle subscription-holders to hire other types of vehicle occasionally (family cars, utility vehicles). A study by the European Environmental Agency shows that purchasers choose their car according to their occasional, exceptional needs, and more generally that people are more willing to change their daily commuting habits than their occasional long-distance trips (EEA, 2010). Unfortunately, there are few environmentally clean vehicles that meet the specific needs of long road journeys. In future, the combination of local-range clean mobility solutions with an intermodal set of choices for long-distance journeys is crucial if demand is to be oriented towards greener services, adapted to the most frequent need, namely daily commuting. We would shift from an economy of individual vehicle ownership to an economy of functionality.

TIME-SHARE CAR NETWORKS

After the bike-sharing boom of the late 2000s, the provision of time-share car services is now growing rapidly. In 2006, approximately 11,700 cars were available around the world, through programmes such as Zipcar (the largest of them), which at that time was available in 67 cities in the USA, Canada and the UK. The start of Autobleue in Nice in early 2011, and the upcoming launching of Autolib' in Paris, with its 3,000 battery electric cars and 1,000 stations, are the latest signs of this take-off.

In addition to centralized fleet management, which can provide substantial improvements (especially for maintenance, scrapping and recycling procedures), these schemes make high car-occupancy rates achievable – the average American car remains unused for 22 hours a day – and decrease public parking congestion.

The programme operators may variously be carmakers, leasing or rental companies, existing mobility service providers, new specific actors, or a combination of these. They make use of business models created for bike-sharing, adapted to the specificities of cars. In the most usual arrangement, the operator makes the initial investment and pays the operating costs (including a public space usage fee), and keeps a proportion of the revenues generated by urban advertising hoardings; many projects use PPP as well.

Furthermore, time-share vehicles demonstrate the viability of mobility as a service, in which users no longer have to own their means of transportation. It can be seen as the transportation component of a more general trend in developed economies, namely the shift from ownership to a service economy.

Sources: Kriston et al., Mairie de Paris, USA Today

As far as freight is concerned, changes in the way the supply chain is organized can be used to reduce greenhouse gas emissions. Given the proportion of freight in transport as a whole and the notable shortcomings of this sector (empty trucks in transit, failed delivery attempts), there is room for significant action to be taken.

A great number of potential improvements have already been identified. These may be classified at three different levels, depending on the environmental benefits expected: optimization of traditional freight business (e.g. bundling, capacity, and route optimization), the targeted reduction of some of its negative effects (for example, through modal shift*), and finally the transition to a truly green service.

Behavioural changes are dependent on the availability of solutions offering real choice latitude. The viability of this provision requires that suitable infrastructure is in place.

3.3. Infrastructure & Information Technologies shaping tomorrow's transport

The interconnection of the various transportation modes is central to these new developments. The availability of public transport lines that function efficiently and safely is essential. Achieving an efficient intermodal transport system would require major investment upstream. In particular, action with the highest cost/benefit ratio could focus on a number of critical bottlenecks that undermine the efficiency of the entire transportation system.

Similarly, the popularization of electric vehicles or time-share car services cannot be dissociated from the infrastructural component (implementation of a closely integrated network, facilitated connectivity with the rest of the multimodal network). Again, since road transport will be part of the future of freight, probably with a 30% to 60% share depending on the scale of the modal shift towards other transportation solutions (EC, 2011b), investment in infrastructure in this segment cannot be ignored.

Information technology could also contribute to this effort to develop the convenience and the interconnection of mobility services. The Internet's ubiquity, associated with the massive increase in intelligent portable devices such as smart phones, make new mobility practices possible, with the various modes of transport integrated into intelligent transportation systems.

3.4. *The need for incentives*

Combined changes in behaviour and the provision of mobility, fostered by appropriate investment in infrastructure and information technology, are needed for the transition to low carbon mobility that takes full advantage of technological improvements. Such changes, however, need to be incentivized.

- Information is an enabler of behavioural change, but may not be sufficient. The creation of "best-in-class" certification could have brought a 20% to 40% greater emissions reduction among new cars in the UK if every customer had chosen the cleanest car in the segment (King, 2011). Here, the implementation of regulatory measures for carmakers, or fiscal incentives for car buyers, could redefine the range and the order of buyers' choices.
- The optimization of traditional freight business directly results in benefits for operators and emissions reduction, since it brings immediate fuel savings. Conversely, modal shift or offsetting carbon emissions give rise to additional costs that no customer wants to pay. Such measures could provide substantial further improvements, but can only be implemented if customer-driven incentives make them affordable.
- Infrastructure and urban planning* are key drivers of mobility choices and supply chain organization. Nevertheless, urban sprawl seems to be the prevalent pattern in the expansion of cities, leading in particular to worse congestion. Appropriate economic and urban planning policies could curb this trend.

Economic instruments and public policies can thus have a positive and much needed impact on changes in behaviour, organization and infrastructure, as well as on the development of technological solutions.

URBAN SPRAWL

In industrialized countries, soaring housing prices in city centres lead to the construction of new residential areas on the outskirts of towns. In the absence of suitable public transport options, this pushes people towards passenger cars. In developing countries, the rural exodus is at the root of unchecked urban growth.

The expansion of cities increasingly entails urban sprawl, which exacerbates congestion in major urban centres, leads to an increase in the distances covered on a daily basis, and proportionally contributes to the rise in greenhouse gas emissions.

The attractiveness of city centres such as those of New York, London, Tokyo and Paris demonstrate the possibility of turning to dense areas with efficient public transportation to tackle transportation-related emissions. On the other hand, there appears to be a density threshold for cities (50-150 inhabitants/ha) below which mass transportation systems are not economically feasible. For fast-growing mega-cities in emerging countries, the issue of transportation-related emissions is a major challenge in the course of their development. Keeping city areas compact and investing in efficient mass transportation networks will be essential for limiting the increasing use of personal cars.

Source: World Energy Council

4. Economic incentives and public policies

The public authorities can influence research, development and deployment through the use of different instruments. A normative framework set by emission standards is one option. Resorting to economic leverage on carbon emissions, through tax systems or market mechanisms, is another. A broader set of indirect measures can complement these.

4.1. Setting emission standards for carmakers

A regulatory approach, with the introduction of emission standards*, is an effective way of fighting certain types of pollution. For example, the 1987 Montreal Protocol, which gradually banned the use of certain fluorinated gases in the CFC and HCFC families, halted the thinning of the ozone layer.

Emission standards are difficult instruments to handle when it comes to diffuse emissions such as greenhouse gases generated by the transport industry. One difficulty stems from the need to define normative levels for very varied sources (passenger cars, light utility vehicles, trucks, etc). Moreover, these levels have to be consistent with state-of-the-art technologies if they are to be complied with. A second difficulty comes from the cost of implementing strict compliance and monitoring procedures to deter potential cheating.

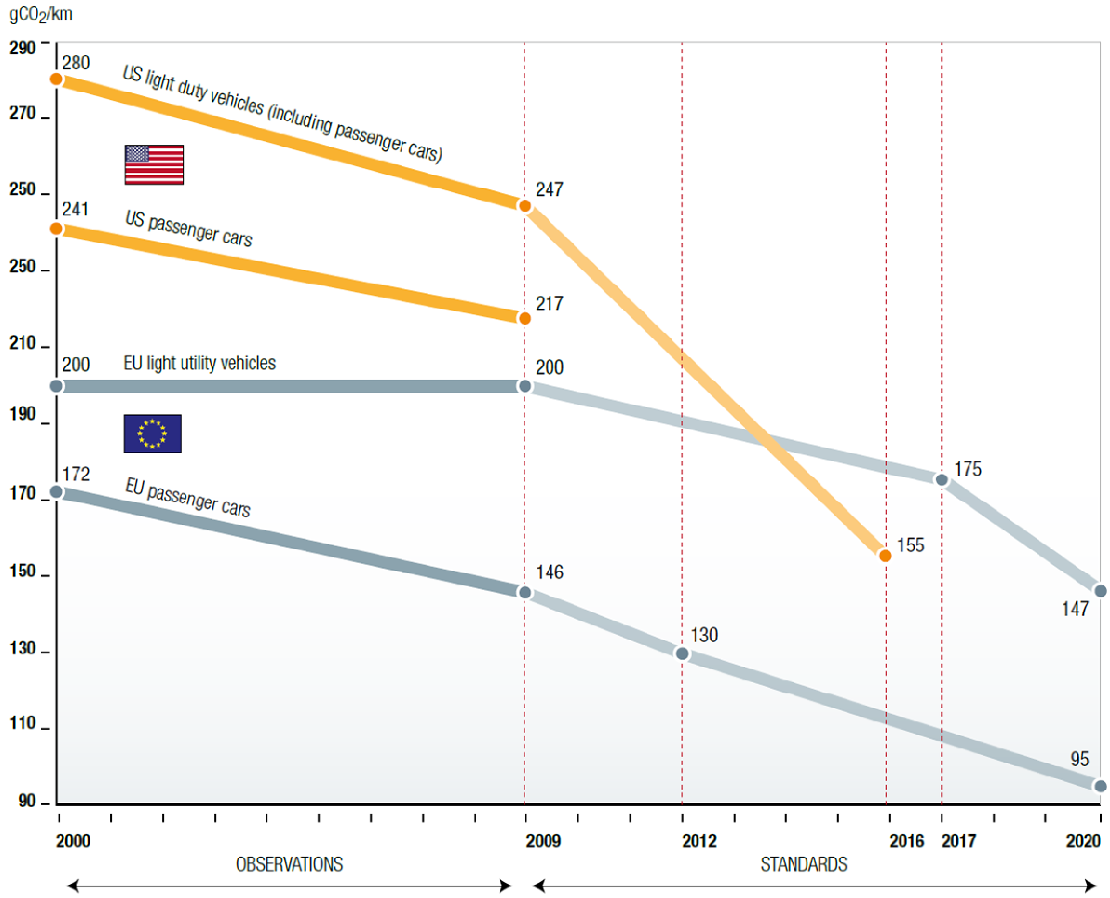
The European Union initially relied on negotiating voluntary agreements with the car industry to promote reductions in road transport emissions. These agreements, signed in 1998 and 1999, set a 140gCO_2/km objective to be achieved by 2008 or 2009. They led to a downward trend in car emissions, although the targets were not met (EC, 2007). In 2009, the EU introduced a mandatory standard on emissions from new passenger cars to speed up the improvements. EC Regulation 443 (EC, 2011c) sets 120gCO_2/km and 95gCO_2/km targets to be reached respectively by 2012 and 2020, which should enable CO_2 emissions to be reduced by 200 million tonnes over the 2010-20 period (EEA, 2011). An additional standard for light utility vehicles was introduced in 2011 by EC Regulation 510 (EC, 2011d), with a 175gCO_2/km target level for 2017 and 147g/CO_2 for 2020.

In 2010 the United States implemented its first Federal standard to limit CO_2 emissions from light vehicles. This norm should lead to a reduction of 960 million tonnes of CO_2 emissions over the life-span of passenger cars and light utility vehicles sold in the 2012-16 time period (EPA, 2011).

As regards European and American regulations on new vehicle CO_2 emissions, the introduction of standards is proving to be appropriate because of its relatively limited scope and cost: only new vehicles are targeted by the EU and US CO_2 standards, in such a way that CO_2 emissions only need to be measured by vehicle model and not for each individual vehicle.

EMISSION STANDARDS FOR NEW CARS IN EUROPE AND THE UNITED STATES

Observed CO_2 emissions of new vehicles and standards



Source: EC, EPA

Key point: The European Union and the United States have recently adopted standards setting maximum levels of CO_2 emissions for new cars: respectively 95 and 147 grams of CO_2 per kilometre for passenger cars and light utility vehicles by 2020 for the EU; 155 grams of CO_2 per kilometre for light vehicles (private and commercial) by 2016 in the United States.

To be fully effective, the regulatory approach must provide long-term visibility, so that the industry clearly knows which direction to take and that the required efforts may be gauged some way ahead. It requires relevant metrics, upon which standards and other regulations are based. It also needs careful scrutiny to ensure that apparent emission reductions do not come from a better response to specific testing procedures only, but from improvements under real-life conditions.

BETTER METRICS FOR MORE APPROPRIATE REGULATION

Existing test procedures such as NEDC (New European Driving Cycle) that are used to measure tank-to-wheel emissions (regulated through so-called "tailpipe emission standards"), could evolve towards an NEDC+ procedure that would include real-life cycles or, more generally, would better reflect the effective usage of vehicles. Furthermore, manufacturers are calling for the design of procedures that would apply to well-to-wheel emissions. Ultimately, work needs to be done on the estimation of whole lifecycle emissions. Those developments in the metrics reference system are required all the more with the advent of a more diversified technology mix in the sector, including electric drive and biofuels.

Nonetheless, regulation by standard comes up against many limitations in terms of managing greenhouse gas emissions from transport. CO_2 emission norms do not guarantee that the environmental objective is met: the prospects of reducing the industry's emissions can be compromised by a sharp increase in congestion or by an aging fleet, even if new vehicles comply with emission norms. Furthermore, emission standards do not encourage behavioural changes in the vehicle usage phase. Similarly, standards do not create any incentive to make an effort to reduce emissions beyond the level required by the standard. Hence the point of also using economic instruments that offer the further advantage of minimizing the cost of meeting targets.

4.2. Why introducing a price for carbon in the road transport sector?

Setting a carbon price stems from the idea that one can influence the choices made by the sector's agents in favour of solutions with low greenhouse gas emissions, by making it less expensive to use goods and services that are the source of relatively low emissions.

In the absence of a carbon price, the atmosphere is exposed to the "tragedy of the commons", to use the well-know phrase introduced by the American researcher Garrett Hardin in 1968 (Hardin, 1968). According to Hardin, in line with economic principles, unlimited access to a limited resource leads to a conflict between individual interest (to consume as much as possible of the resource) and common interest (to preserve the resource). This conflict can result in the overexploitation and disappearance of the resource. Intensive fishing of certain endangered fish species or overgrazing in nomad areas such as the Sahel are contemporary illustrations of the "tragedy of the commons".

Since the Industrial Revolution, the development of the world's economy has relied on free use of the atmosphere's capacity to store greenhouse gases. Economic agents have viewed it as an infinite reservoir, able to absorb all emissions. This state of affairs has led to emissions accumulating in such proportions that today the stability of the climate is under threat.

Setting a carbon price in the economy generates two types of incentives. The first is to rationalize the use of products that emit large quantities of greenhouse gases within the framework of existing technologies: better adjustment of heating, the adoption of slower and smoother driving styles, the reduction of congestion by spacing out journeys or car pooling, etc. The second is to accelerate investment in research and development in new low carbon technologies: developing renewable energies, investing in biofuels, developing electric vehicles, etc.

PAYING FOR CARBON EMISSIONS

Applying a price to primary energies of €20 per tonne of CO_2 emitted would raise the price of a barrel of crude oil by €8.60, i.e. a surcharge of between 5% and 22% (for a barrel priced between €40 and €150). At a price of €20 per tonne of CO_2, the average European would have to spend €160 a year if he were to pay for all the direct and indirect CO_2 emissions produced for his energy needs. The same budget for Americans would be €400 a year per capita and €80 a year for the Chinese.

Source: CEC

There are three types of instrument for introducing a carbon price into the economy: taxes, emissions trading and project-based mechanisms.

4.3. Carbon taxation on fuels, vehicles, or infrastructure

A carbon tax* is a tax that sets a price for CO_2 emissions: its rate is expressed in euros per tonne of CO_2 emitted. A carbon tax adjusts the relative prices of assets (e.g. vehicles, infrastructure) or energy sources (fuels) according to their respective carbon intensity*. When this fiscal instrument is used, the public authorities set the carbon price, and the effects on emissions will depend on the reactions of the sector's agents.

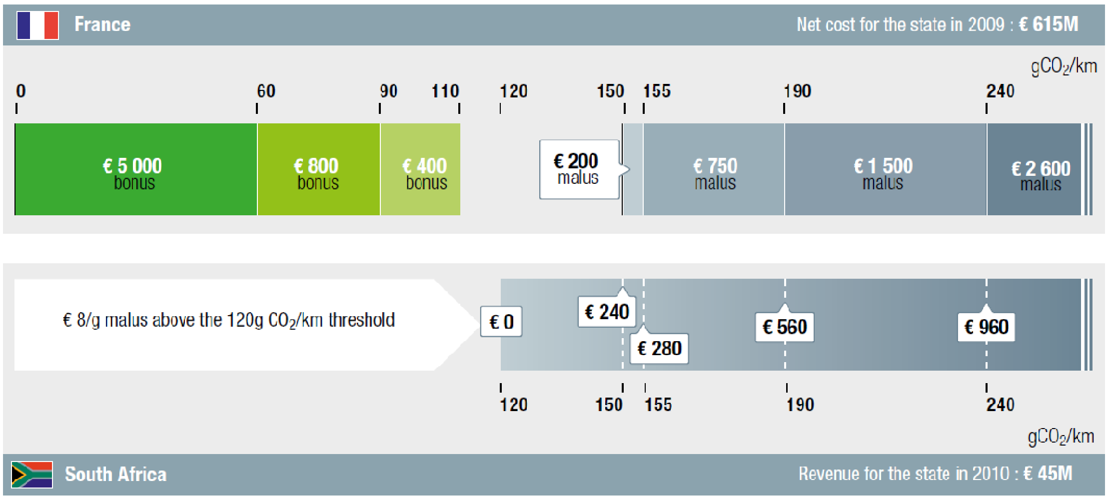
A carbon tax encourages emission reductions where they are the least expensive: if a manufacturer has to pay a tax of €20 per tonne of CO_2 emitted, it is in his interests to carry out all emission-reducing investments costing less than €20 per tonne of CO_2 avoided. In this way he saves the difference between the tax he would have had to pay without making any investment and the cost of the investment. A tax therefore means that the overall cost of abating emissions is reduced compared to the introduction of a standards-based policy.

Moreover, the reinvestment of the revenue from the carbon tax can make the fiscal measure more efficient. Supporting R&D or funding critical infrastructure could be a way to boost the sector's advances towards low-carbon technologies, and therefore generate what economists call a double dividend*.

Road transportation is traditionally taxed at several levels: infrastructure (e.g. tolls), vehicles (e.g. taxation of heavy goods vehicles, the bonus-malus system) and fuel. Transportation taxation developed in most industrialized countries in the middle of the 20th century, to fund road infrastructure and augment national budgets.

THE BONUS/MALUS SYSTEM: A CARBON TAX AT PURCHASE?

Two examples of bonus/malus systems for passenger cars



Source: CEC

Key point: In a broad sense, malus or bonus-malus systems applicable to motor vehicles at purchase can be seen as a form of carbon tax, based on a vehicle's emissions per kilometre and giving consumers an incentive to buy lower-carbon vehicles.

The main levy is generally on fuel. By altering the prices, taxes can have an effect both on overall fuel demand and on the relative market shares of different fuels. Up until the 1990s, taxation was not viewed as a way of orienting buyers towards vehicles using the lowest-carbon fuels. Since then, the emergence of environmental concerns has tended to reorient existing taxation in favour of a stronger incentive to cut emissions. A carbon tax applied to the transport industry can make the highest-carbon fuels more expensive, thus favouring fuels that emit less or no CO_2; it can also make it more economical to purchase vehicles with low emissions and/or encourage the industry to produce lower-carbon, more energy efficient vehicles. The contrasted evolutions of the US and European markets, regarding in particular SUVs' development, can be seen as an effect of the implementation of differentiated taxation policies.

The environmental efficiency of carbon taxation relies on its explicit link to CO_2 emissions. However, in many countries, taxes already represent a significant portion of fuel prices (for example, around 50% to 60% on gasoline and from 45% to 55% on diesel in Europe, and 40% on gasoline and 22% on diesel in Brazil), and in some places amount to an equivalent of €200/tonne of CO_2 emitted. These existing fuel taxes could be considered *de facto* carbon taxes; they in fact blur the relationship between the fuel price and its carbon content, so long as the carbon tax rate is not high enough in comparison. In addition, certain countries have implemented systems of subsidies for fuels or fossil fuels that function like "negative carbon taxes": they encourage the use of fossil energies.

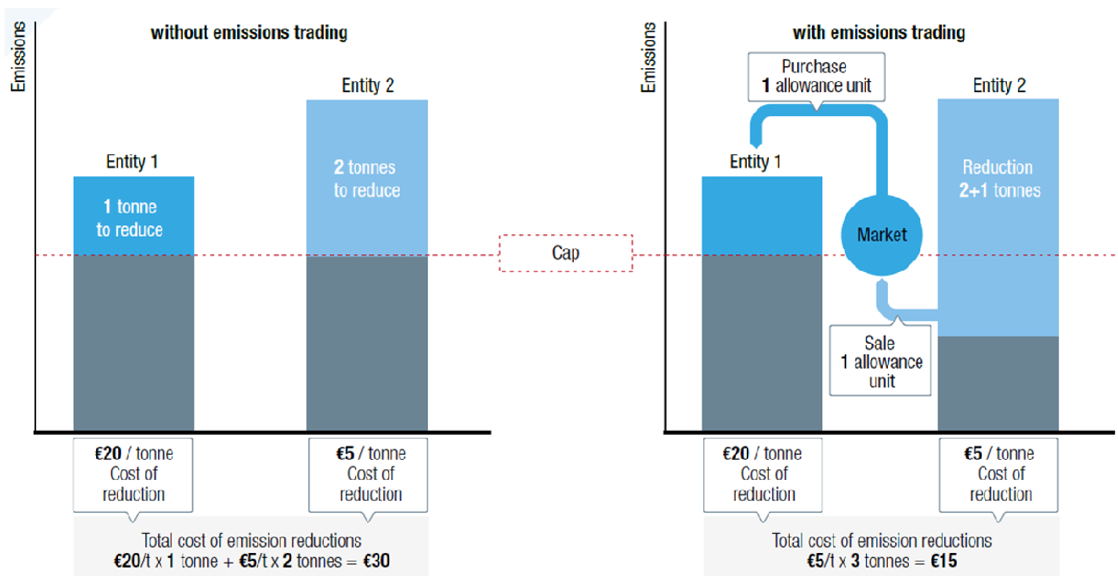
Finally, the harmonization of tax regulation design across borders would improve the comprehensibility of environmental policies and lessen market distortions.

4.4. *The pros and cons of cap and trade for road transport*

In a greenhouse gas emissions allowance trading system*, or "carbon trading", the public authority sets a quantitative emissions reduction objective and the market then sets the price of the emission allowance. The global emissions cap ensures that the environmental objective is met. The authorities set the total volume of emissions authorized by distributing or selling a limited number of allowances (1 allowance = the right to emit 1 tonne of CO_2); in this case we refer to regulation by quantities (as opposed to regulation by prices via a tax). The allowances are shared between participants, who can trade these rights among themselves.

THE PRINCIPLE OF EMISSIONS TRADING

Cap and Trade



Source: CEC

Key point: In the absence of emissions trading, compliance with an emissions cap requires each entity to reduce its emissions, whatever the cost may be. Emissions trading gives more flexibility to entities with an emissions cap, each being able to choose to reduce its emissions or to purchase an allowance from an entity that has reduced its emissions. Emissions trading is economically efficient: it minimizes the total cost of hitting the environmental target.

Emission trading attaches a price to the release of greenhouse gases and enables the environmental objective to be achieved at a lower cost. To comply with the environmental restriction applied to them, actors can choose between reducing their emissions and purchasing allowance units in the market. In this way, agents whose marginal costs for emissions reduction are lowest have an incentive to further reduce their emissions so as to sell their excess credits to agents with higher costs. As a result, emissions are cut first in those entities where it costs least to implement the reduction.

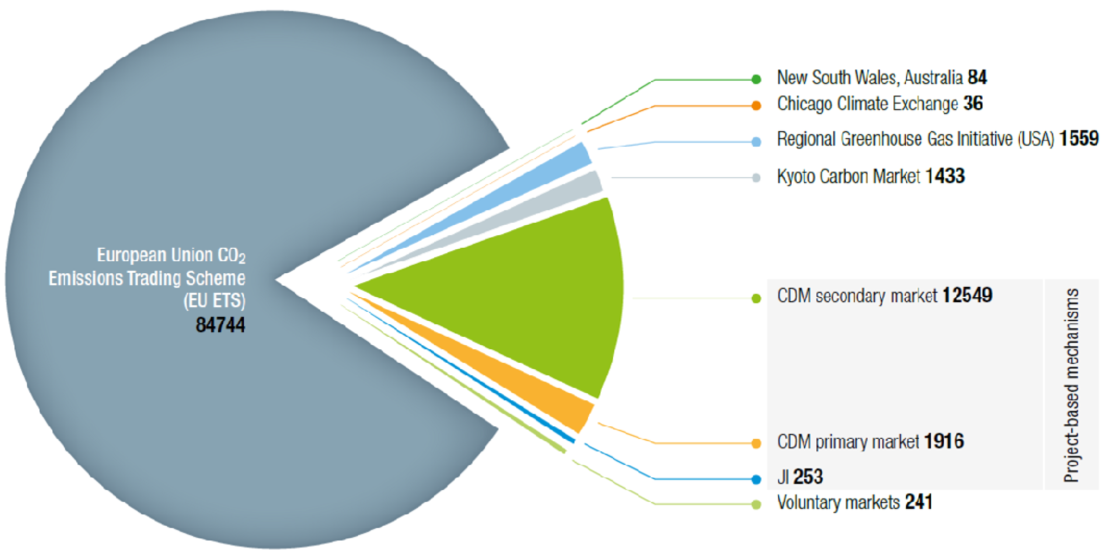
In a similar way to a carbon tax, emissions trading can generate a double dividend. If some or all of the allowances are auctioned, the appropriate reinvestment of the revenue (support to R&D or critical infrastructure financing) can help trigger further progress in the fight against climate change.

The United States pioneered the implementation of emissions trading, which has proved effective in the fight against acid rain caused by sulphur dioxide (SO_2) emissions from power production plants. SO_2 emissions trading was introduced in 1995 and has made it possible to achieve the initial objective of halving SO_2 emissions as compared to their 1980 level (67% effective reduction) several years ahead of schedule and at less cost (De Perthuis, 2010).

The European Union is the first group of countries to have put in place an emissions cap-and-trade system to help reach their objectives under the Kyoto Protocol. The EU Emissions Trading Scheme (ETS) came into effect in January 2005. It covers emissions from almost 12,000 specified industrial plants in seven major sectors: power and heat generation, refining, cement, glass, paper, iron and steel and coke ovens. Half of the EU's CO_2 emissions are covered, amounting to around 2 billion tonnes of CO_2 per year. In 2010, 5.2 billion allowances were traded in the European emissions marketplace, for an average price per unit of around €14 over the year (World Bank, 2011). A little more than a fifth of these transactions were spot deals, while the rest were exchanged through derivatives contracts (forward, futures and options).

EUROPEAN EMISSIONS TRADING AT THE HEART OF WORLDWIDE CARBON FINANCE

Carbon assets transactions in 2009 (M€)



Source: Michelin and CEC from World Bank, Bloomberg New Energy Finance and Ecosystem Marketplace

Key point: The EU ETS represents 82% of global emissions trading; with 14% of transactions, the Kyoto Protocol's project-based mechanisms are the second pillar of global carbon finance. These two large markets are directly linked, with European manufacturers accounting for a large proportion of global demand for CDM and JI credits.

Other countries and regions have developed or are developing similar systems that will enable the geographical scope of economic agents working with a carbon price to be extended in future: ten north-eastern states and California in the USA, the state of New South Wales in

Australia, New Zealand, Japan and soon South Korea. The new carbon economy is made up of all these systems that interact in a complex way and were set up in the wake of international negotiations under the aegis of the United Nations.

Existing emissions trading systems have so far been applied to fixed installations, on the grounds that emissions at consumer level (from mobile sources) are much harder to measure than at producer level (from stationary sources). This situation can change, though. The European carbon market, for example, is going to include air transport as of 2012. Discussions are also under way to incorporate maritime transport in a cap-and-trade emissions system, whether at a European or international level. The inclusion of the road transport sector, however, does not currently appear to be on the agenda for the European Union Emissions Trading Scheme (which currently covers 45% of all EU greenhouse gases emissions), or any other scheme.

The carbon price in the European market is rather low compared to implicit carbon taxation by means of fuel taxes. This potential price gap would significantly undermine incentives to reduce emissions in the sector, but it would allow actors to contribute to reductions at the lowest possible cost (whatever sector they occur in) and would be consistent with the intention of having a single robust price signal for carbon in the EU.

Two types of option for the inclusion of road transport in such a scheme can be envisaged. The first consists of an upstream approach, through which the ETS burden would fall on fuel suppliers, in a limited number of facilities. For instance, refineries already covered by the EU ETS (around 170) for emissions related to fuel production, would also have to own quotas corresponding to the CO_2 subsequently released from the combustion of the fuel they sell. This does not mean that they would have to bear the cost of the fuel's carbon content, as they can pass it on to consumers. The second option would involve a downstream approach. Here, the ETS burden would fall directly on fuel consumers. The result would be equivalent to that of upstream implementation with full cost pass-through to consumers. The implementation of the downstream option would be easier on selected fleets, e.g. captive fleets, because of their centralized management, thereby reducing the number of actors to be monitored.

4.5. Towards a better use of project-based mechanisms

An additional way of integrating carbon value into the transport economy lies in project-based mechanisms*. The Kyoto Protocol linked the introduction of commitments by industrialized countries to cut emissions with "flexibility mechanisms". In particular, the two project-based mechanisms introduced by the Protocol, the Clean Development Mechanism* (CDM) and Joint Implementation* (JI), are the second main pillar of worldwide carbon finance after the EU ETS. Following the strict rules laid down and monitored by the UNFCCC Secretariat, these two tools fund emission-cutting projects through carbon credits issuance.

The mechanism works as follows. To be eligible for the Kyoto Protocol project-based mechanisms, a project must demonstrate that it engenders an "additional" reduction in emissions as compared to a reference scenario, defined as the most probable scenario if the project did not exist. Once the project has been approved and implemented, those behind the project receive the number of carbon credits corresponding to the emissions reductions achieved in comparison to the reference scenario. These credits are called Certified Emission Reductions (CER) or Emission Reduction Units (ERU). They can be sold, either to parties who will be able to use them in order to be in compliance – typically a European manufacturer subject to a cap – or for "voluntary compensation".

The exploration of project-based mechanisms in the transport industry was hindered by problems of measuring and monitoring cuts in emissions. Moreover, the low carbon price levels allowed little by way of action, given that abatement in the transport sector is acknowledged to be more costly than in many other sectors. Out of 2,900 projects registered in early 2011 under the Clean Development Mechanism, only six come from the transport industry (of which 80% of allowances were emitted for the Bogotá bus rapid transit system project alone); and out of 432 projects registered under JI, none was a transport project (UNFCCC, 2011). The withdrawal before registration of the JI project of urban buses running on biomethane in Lille, France, illustrates the lack of adequate methodologies that would facilitate the implementation of project-based mechanisms to the transportation sector.

THE DOMESTIC PROJECTS SYSTEM

The European domestic projects* systems are local applications of the Joint Implementation (JI) mechanism. Actors who are not covered by the European trading scheme are given the possibility of being remunerated for the voluntary implementation of emission reduction projects, in the form of ERU credits.

This system enables sectors such as transportation, agriculture, construction and waste processing to contribute to the decarbonisation of the economy at the lowest cost for society.

In France, a range of methodologies has been developed to specify the characteristics of eligible projects. In regard to transportation, one methodology concerns the use of biomethane from waste rather than natural gas as a fuel; another concerns the organization of dynamic carpooling.

However, consideration is being given, at an international level, to changing to a new generation of project-based mechanisms, crediting a number of basic emission reduction actions. One such is Nationally Appropriate Mitigation Actions (NAMAs). Introduced by the Copenhagen accord, NAMAs consist of voluntary emission reduction measures undertaken by developing countries that are reported by national governments to the UNFCCC. Transportation would seem to be an appropriate future candidate here if the measuring and monitoring emissions from mobile sources can be dealt with more efficiently, and if carbon finance instruments lead to an adequate carbon price.

4.6. Choosing the right instruments

Although often viewed as very different, theoretically taxes and trading schemes have more similarities than differences. Incentive taxes and negotiable allowances depend on an equivalent price mechanism, in theory, from the point of view of its economic effects: with perfectly informed agents, these two instruments enable emission reduction efforts to be made at the lowest cost for the community. If introduced correctly, they can help make substantial savings compared to public actions conducted on the basis of mandatory standards. However, the two instruments achieve a balance in different ways: in the case of a tax, the initial uncertainty concerns the amount of emissions reduction, while in the case of a trading system the uncertainty applies to their price. Another difference lies in the implementation and transaction costs, which are higher in the case of an emissions trading scheme. Furthermore, trading may not be affordable for small agents whose business often has no connection with financial activities. In the real world, the climate policies introduced are generally a combination of several instruments.

Indeed, a growing number of European countries have national carbon taxes co-existing with the European carbon market, each sector being covered by the instrument deemed most relevant. Faced with the need to take further action to combat climate change, it makes sense to combine the various instruments as far as possible so as not to neglect any potential source of emission reductions. Taxation measures seem to be best suited to the diffuse emissions of road transportation, except for specific cases such as commercial fleets that could be placed under an ETS cap. Flexibility mechanisms such as domestic projects provide an additional framework so that the scope of carbon pricing is as broad as possible.

The setting of emission standards also has a part to play. Setting standards gives the industry the overall direction to follow, and therefore makes the messages sent by the economic instruments all the more understandable. When combined with an emissions cap, standard levels can be used to set the baselines for sectoral crediting, with the possibility of trading then providing an incentive to outperform the standard-related emissions reduction.

These measures need to be supported by the implementation of a number of other public policies indirectly influencing greenhouse gas emissions, such as:

- support for research and development to foster promising technologies and reduce their lead times;
- congestion charging to deter private vehicle use in specific sectors, and to tackle congestion and air quality problems;
- reserved lanes for public transport in order to enhance its efficiency and reliability;
- lower speed limits to minimize congestion and reduce overall emissions.

The instruments must be used with caution, for otherwise they can give misleading signals. For instance, subsidies must be time-limited if they are to be perceived as an R&D boost, and not as compensation for the setting of a carbon price. Other points of vigilance in regard to medium- to long-term comprehensibility (for coherent industrial decision-making) or policy flexibility (to avoid technological lock-ins*) can go a long way towards maximizing the effectiveness of these policies.

4.7. Feedback on existing carbon pricing experience in road transport in Europe

A broad range of carbon pricing instruments have already been tried out to combat CO_2 emissions from road transport in Europe.

Several European Union Member States have introduced carbon taxation on fuels. Finland (1990), Norway and Sweden (1991), Denmark (1992), and more recently Ireland (2010), have introduced national carbon taxes on fuels, with respective standard rates of €20, €43, €108, €13 and €15 per tonne of CO_2 as of 1 January 2010 (Elbeze and De Perthuis, 2011). These carbon taxes generally provide for a differentiated treatment of passenger transport and goods transport, the latter being systematically exempted or compensated to limit the impact on the actors' international competitiveness.

CARBON TAX – SPEEDING UP THE TRANSFORMATION OF SWEDEN'S CARS

The carbon tax brought in by Sweden was at the heart of its 1991 fiscal reform. The tax played a central role in the 9% reduction in CO_2 emissions that occurred between 1990 and 2007, even though GDP rose by 48% over the same period (i.e. an emission level 20% to 25% lower compared to a "business-as-usual" scenario). In the transport industry, this carbon tax promoted the development of and demand for low-carbon cars. In 2008, a third of new cars sold in Sweden were FlexFuel*.

Source: CEC

Annual ownership taxes, sometimes called vehicle excise duty, increasingly take into account the vehicle's emission level. For instance, since March 2001 in the UK, the more emissions the car produces, the higher the charge. Cars emitting less than 100gCO_2/km are exempt from vehicle excise duty, whereas cars emitting between 121 and 140gCO_2/km are charged £120. The maximum level of £400 per year applies when emissions exceed 226gCO_2/km.

A similar type of instrument consists of subsidies to efficient vehicles, sometimes complemented by scrappage incentives. For example, in 2008 in France, in addition to the bonus-malus system, a €300 "super-bonus" was offered for the scrapping of cars older than 15 years. This premium was eventually raised to €1000, from 2009 until late 2010.

Other schemes have proved useful for encouraging improvements in vehicle use and not only in vehicle purchase. Switzerland's Heavy Vehicle Fee, charging lorries on the basis of their gross weight, kilometres driven and emission category, resulted in a 14% decrease in lorry journeys between 2000 and 2005, while the volume of goods transported increased by 3% over the same period, thus demonstrating a more efficient use of capacity (Santos et al., 2010).

Congestion charges are another way of changing mobility behaviour, applying to both passenger transport and freight. London introduced a trial scheme in 2003, which resulted in approximately a 20% reduction in the number of four(or more)-wheelers in the charging zone, and a subsequent 30% reduction in congestion over the year. It also led to a modal shift, mainly toward the bus network. The first such scheme was tried out in Singapore, with congestion pricing for heavy vehicles since 1975 and for all motor vehicles from 1989 onwards, resulting to a 45% decrease in peak hour traffic volumes. Stockholm introduced a similar congestion charging system in 2007 (Santos et al., 2010).

Conclusion

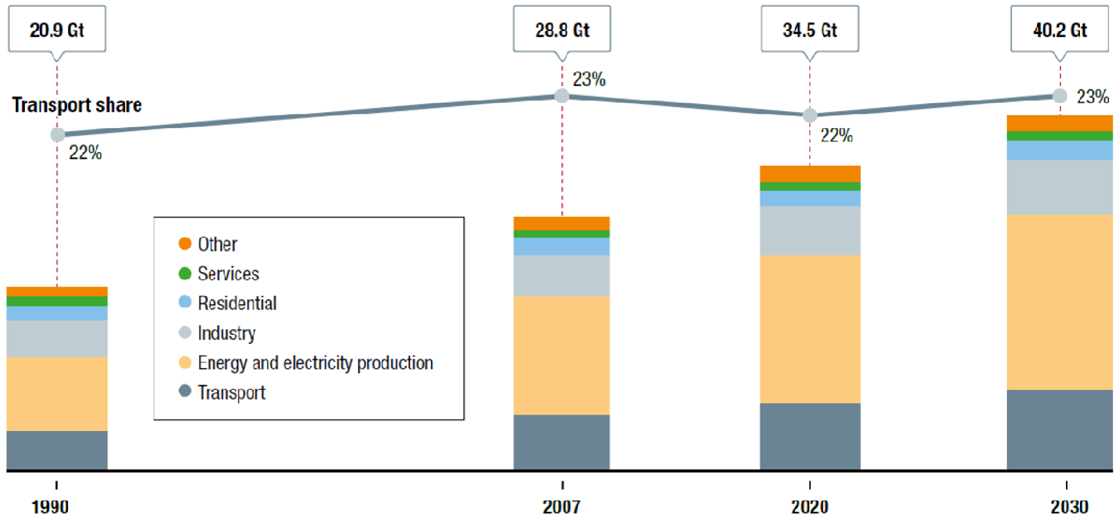
The road transportation economy, largely ignored by carbon pricing mechanisms, is still a long way from taking account of the climate change issue, along with its challenges and opportunities. As seen in sectors covered by the ETS, however, it is probable that if a price on CO_2 emissions were gradually incorporated into decision-making of the actors concerned, it would prove to be a powerful tool for triggering the changes most needed.

Although neither of the main two carbon pricing instruments – emission trading schemes and carbon taxation – perfectly matches the specificities of this complex sector as a whole, they are both relevant to some of its segments, and largely equivalent in their potential effects. In particular, while carbon taxation appears to be easier to implement for tackling diffuse emissions from private cars for instance, cap-and-trade systems seem appropriate when dealing with emissions from commercial fleets. Flexibility mechanisms such as domestic projects provide an additional framework for making the scope of carbon pricing as broad as possible.

More generally, in a sector where there is no silver bullet for achieving significant emissions reduction, due to its complex, multi-segmented character, carbon pricing, in whatever form it may take, is a useful complement to regulatory and other public policies designed to encourage technological, behavioural and organizational innovation.

Appendix: Facts and figures

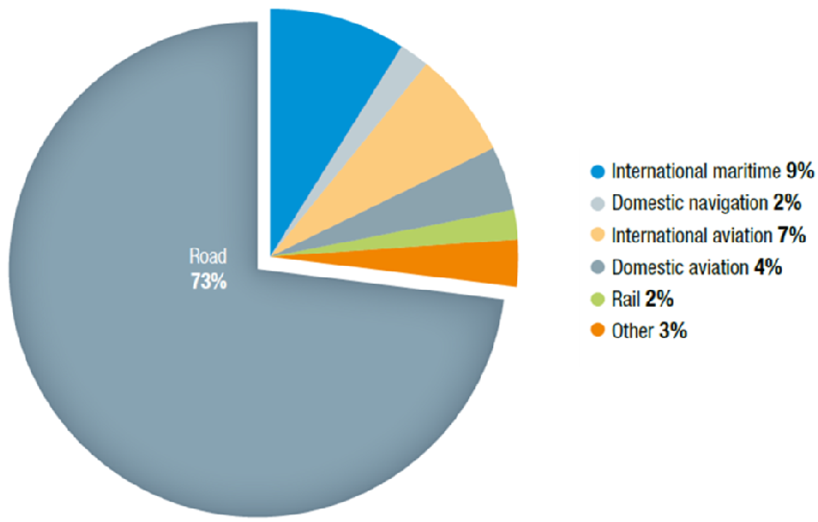
CO_2 FROM ENERGY: TRANSPORT SHARE IN WORLD TOTAL EMISSIONS
IEA's 'business-as-usual' case scenario



Source: IEA, ITF

Transport's share in global CO_2 emissions from fuel combustion has been constantly close to 22% over the last decades. Nevertheless, the proportions are far from being even between industrialized and developing countries: transport has persistently accounted for approximately 30% of CO_2 emissions from fuel combustion in OECD countries as against 16% in non-OECD countries.

CO_2 EMISSIONS FROM TRANSPORT WORLDWIDE
Distribution of emissions by transport mode



Source: IEA

The situation is similar in road transport, which has constantly accounted for 24% of OECD countries' total CO_2 emissions as against 11% in non-OECD countries over the last decades.

WHAT JOURNEY FOR ONE TONNE OF CO_2?

1 tonne of CO_2 per passenger: different distances for different transport modes		
Private car (driver alone)	Plane	French high-speed TGV train
3 one-way journeys between New York and San Francisco	1 round trip between Berlin and Shanghai	5 years of weekly Paris-Marseille-Paris
3 x 5,000 = **15,000km**	2 x 8,500 = **17,000km**	5 x 52 x 2 x 800 = **416,000km**

Source: ADEME's Carbon Footprint calculator

ENERGY AND CARBON CONTENTS

		Gasoline	**Gas oil (Diesel)**
Energy content per tonne		0.995 toe	0.964 toe
Carbon content per tonne		2.88 tCO_2	2.99 tCO_2
Additional cost (in €) from a carbon price of	15 €/tCO_2	3 cents/litre	4 cents/litre
	30 €/tCO_2	6 cents/litre	8 cents/litre
	100 €/tCO_2	21 cents/litre	25 cents/litre

Source: CEC, IPCC, IEA

WORLD TRANSPORT CO_2 EMISSIONS OVER THE LAST TWO DECADES

	World CO_2 emissions from fuel combustion (Mt)											Evolution	Emissions per capita (t)
	1990	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	Change 1990-2008	2008
Total	20,964.85	21,793.68	23,496.55	23,674.57	24,069.94	25,110.5	26,357.32	27,129.14	28,023.96	28,945.33	29,381.43	40%	4.39
Transport *share of total*	**4,583.67** *21.9%*	**5,014.53** *23.0%*	**5,659.04** *24.1%*	**5,684.06** *24.0%*	**5,797.84** *24.1%*	**5,922.84** *23.6%*	**6,172.89** *23.4%*	**6,285.03** *23.2%*	**6,434.74** *23.0%*	**6,614.87** *22.9%*	**6,604.66** *22.5%*	**44%**	**0.99**
Road	3,286.73	3,680.66	4,143.25	4,208.74	4,305.86	4,402.69	4,553.77	4,614.72	4,708.4	4,824.29	4,848.42	48%	0.72
Rail	146.66	110.75	117.27	114.25	116.91	123.07	115.04	123.38	126.6	130.61	107.65	-27%	-
Domestic aviation	280.81	278.39	320.27	309.69	292.69	291.3	306.67	310.95	304.75	310.85	297.34	6%	0.11
International aviation	258.22	287.81	354.42	347.13	365.61	366.79	393.4	421.57	436.25	446.59	454.85	76%	
Domestic navigation	97.68	92.75	107.49	108.75	107.46	116.69	112.77	118.84	122.58	126.36	128.39	31%	0.11
International shipping	354.77	408.72	468.61	446.70	462.25	470.45	523.39	522.28	556.62	589.09	578.20	63%	
Other transport	158.79	155.45	147.73	148.82	147.06	151.86	167.83	173.29	177.53	187.08	189.81	20%	-

Source: ITF from IEA

Glossary

Biofuels: liquid fuels produced from organic matter. Unlike second generation biofuels (largely produced from biomass excluding useful feedstock, such as lignocellulosic biomass) and third generation biofuels (from algae), first generation biofuels like *bioethanol* from corn and *biodiesel* from sugar cane are mainly derived from conventional crops.

Carbon capture and storage (CCS): this process, also known as *Carbon capture and sequestration*, consists in not letting CO_2 emissions (generally from large sources) go back into the atmosphere. The most favoured storage options are currently injection in deep geological formations (notably exhausted gas fields), in deep ocean masses, or in the form of mineral carbonates.

Carbon intensity: the amount of carbon emitted per unit of energy. The carbon intensity of a fuel depends on its energy content, whereas that of an asset depends on all the energy used for its production or construction.

Carbon tax: a fiscal measure whose principle is to give a price to the CO_2 emissions (or greenhouse gas emissions, expressed in the equivalent amount of CO_2) related to an activity. Taxes can be implemented at several levels: for instance, infrastructure, vehicles, and fuels are different options for a carbon tax in road transportation.

Clean development mechanism (CDM): one of the two project-based mechanisms defined under the Kyoto protocol. This flexibility mechanism allows Annex B countries (with mandatory reductions to be carried out) to implement emission reduction projects in non-Annex B countries, in exchange of *Certified emission reductions (CER)*, a type of tradable carbon credits.

Cogeneration: the capture, for heating purposes, of the by-product heat from electricity generation in order to maximize energy efficiency of a power plant, also known as *Combined heat and power*.

Congestion charging: a pricing measure aiming at traffic reduction in a particular area and/or in peak demand periods. London, Stockholm, Singapore and other cities have implemented charging for city centre access, addressing noise and local pollutant issues as well as CO_2 emissions.

Domestic project: the application of the *Joint implementation (JI)* flexibility mechanism in the European Union Member States. In domestic project schemes, the public authority offers *Emission Reduction Units (ERU)* carbon credits as a reward for the implementation of voluntary emission reductions in sectors with no cap on emissions.

Double dividend: the possible cumulative effect of emissions abatement and fund raising allowed by a carbon pricing measure. The first dividend consists in emission reductions directly triggered by the measure itself, while the second dividend comes from the reinvestment of the revenue generated by the measure's implementation (for further environmental actions or other economic or social purposes).

Electric vehicle (EV): a vehicle running on electricity exclusively, also known as *Fully Electric Vehicle (FEV)*. Currently, the energy is stored either in batteries (*Battery Electric Vehicles, BEV*) or in hydrogen for ulterior release by fuel cells (*Fuel Cell Electric Vehicles, FCEV*). Unlike internal combustion engines (ICE), electric motors are reversible: they can recuperate energy to reload a battery. In addition, they can provide much higher energy efficiency, as well as lower maintenance costs thanks to their simpler design.

Emission standards: a specification set by the public authority for a category of vehicles. In practice, emissions standards often set maximum emission levels for new vehicles, and are based on emission averages expressed in gCO_2/km and measured on standardized driving cycles.

Emissions allowance trading system: the possibility for agents constrained by a cap on emission levels to trade their emission allowances, also known as *cap & trade* mechanism. An emission allowance trading system is a flexibility mechanism enabling the necessary reductions at a lower cost.

FlexFuel: a vehicle with an internal combustion engine designed to run on more than one fuel. The two fuels, usually gasoline blended with either ethanol or methanol fuel, are stored in the same common tank. Flex-fuel engines are capable of burning variable proportions of the resulting blend, automatically adjusting their combustion characteristics.

Heavy vehicle: the class of vehicles exceeding a particular weight (generally 3.5t), also called *industrial vehicles (IV)*.

Hybrid vehicle (HV): a vehicle running on both conventional fuel and electricity. Several hybridization levels are developed, with the common feature of combining an internal combustion engine and an electric one.

Intermodality: the interconnection and the easiness of switch between transportation modes.

Internal combustion engine (ICE): by far the most widespread motor technology in road transportation. Its spectacular development is strongly linked to the simultaneous rocketing of oil fuel production and oil distribution infrastructure deployment in the 20th century. Its cycles result in energy generation and exhaust gas emission releasing CO_2 and particulate matter among other compounds.

Joint implementation (JI): one of the two project-based mechanisms defined under the Kyoto protocol. This flexibility mechanism allows Annex B countries (with mandatory reductions to be carried out) to fund emission reduction projects in other Annex B countries, in exchange for *Emission Reduction Units (ERU)*, a type of tradable carbon credits.

Land-use change: a significant factor in greenhouse gas release in the atmosphere, as a result of changes in carbon stocks induced by modifications of the type of activity being carried out on a unit of land (forestland, cropland, grassland, wetland, settlements or other). Sustainability criteria used to assess overall GHG emission reduction performance of biofuels pathways scrutinize both direct land-use change (when feedstock for biofuel purposes replaces a prior land-use of that land) and indirect land-use change (when displacement of a previous activity or use of biomass induces land-use changes on other lands).

Lifecycle: the period comprising a product's manufacturing, use and disposal. Lifecycle analysis is indispensable to assess the total greenhouse gas emissions related to a product. Recycling starts a new lifecycle.

Light vehicle: the class of vehicles not exceeding a particular weight (generally 3.5t). A distinction is generally made between *private vehicles (PV)* and *light-duty vehicles (LDV)* on the grounds of their typical usage.

Modal shift: a change in transportation modes' choice. When resorting to cleaner transportation means, modal shift can provide substantial emission reductions.

Peak oil: a theory which predicts the advent of a peak or plateau in world crude oil production between 2010 and 2020, before a progressive decline. The global production curve would be similar to those of countries whose national production has already declined, driven by the depletion of the biggest fields in activity.

Project-based mechanisms: the two flexibility mechanisms introduced by the Kyoto protocol, namely *Clean development mechanism* and *Joint implementation*. They give agents under an emission cap the opportunity to offset their own emissions by contributing to reductions in other countries or sectors.

Rebound effect: the difference between the intended and final effects of a measure. The intended impact (e.g. in terms of emission reduction through fuel efficiency of vehicles) can even be overtaken by its knock-on effects (e.g. increased traffic induced by higher competitiveness).

Smart grids: a set of technologies aiming at optimizing the power transmission and distribution system. Smart grids can help increase the coordination between suppliers, consumers and networks in order to better deal with peak loads and, more generally, perform real-time management of power flows.

Tank-to-wheel (TTW): related to fuel consumption when using a vehicle. It does not take the energy used for fuel production into account. For road transportation, *tailpipe emissions* is a synonym.

Technological lock-in: a situation in which the market configuration impairs technological diversification. The dominant position of an actor or the broad diffusion of a standard can result in the inability for other technologies, though possibly more efficient, to develop. The advantage to the first entrant on a market, or the favouring of a specific actor or process through subsidies can lead to such a lock-in.

Time-share car networks: transportation services enabling short rental of self-service vehicles. Their design is based on automated bicycle rental schemes. They spearhead the transition towards a *functionality economy* in mobility, service-centred, where the ownership of its transportation means is superseded. Time-share car networks also tackle the low car-occupancy rate issue.

Urban planning: a set of policies related to the spatial organization design. They play a significant role in lifestyles and habits' formation, and thus have a real impact on environmental issues.

Well-to-tank (WTT): related to fuel production. Electric energy's well-to-tank emissions depend on the energy mix of the production area.

Well-to-wheel (WTW): taking fuel production as well as fuel consumption into account. Well-to-wheel assessment is essential to compare the real environmental impacts of different technologies, especially electric vehicles (free from tank-to-wheel emissions).

Acronyms

ADEME: Agence de l'Environnement et de la Maîtrise de l'Energie (French Environment and Energy Management Agency)

CDM: Clean Development Mechanism

CEC: Climate Economics Chair

CER: Certified Emission Reductions

CFC: Chlorofluorocarbons

CH_4: Methane

CO_2: Carbon dioxide

EC: European Commission

EEA: European Environment Agency

EPA: Environmental Protection Agency

ERU: Emission Reduction Unit

ETS: Emission Trading Scheme

EU: European Union

GDP: Gross Domestic Product

GHG: Greenhouse Gas

HCFC: Hydrochlorofluorocarbons

HFC: Hydrofluorocarbons

ICE: Internal Combustion Engine

IEA: International Energy Agency

IPCC: Intergovernmental Panel on Climate Change

IT: Information Technologies

ITF: International Transport Forum

JI: Joint Implementation

LPG: Liquefied Petroleum Gas

NAMA: Nationally Appropriate Mitigation Action

NEDC: New European Driving Cycle

NO_2: nitrogen dioxide

ppm: parts per million

PPP: Public-Private Partnership

R&D: Research & Development

SO_2: sulfur dioxide

SUV: Sport Utility Vehicle

tCO_2e: ton of CO_2 equivalent

toe: ton of oil equivalent

UN: United Nations

UNFCCC: United Nations Framework Convention on Climate Change

References

BP, 2011, *Statistical Review of World Energy*.

De Perthuis, C., 2010, *Economic Choices in a Warming World*, Cambridge University Press.

Deutscher Speditions- und Logistikverband e.V., 2011, *Presentation for the Challenge Bibendum 2011 Workshop 1-5, May 18th 2011, Berlin*.

Elbeze, J., and De Perthuis, C., 2011, *Twenty years of carbon taxation in Europe: some lessons learned*, Les Cahiers de la Chaire Economie du Climat, Information and debates Series.

EC, 2007, *COM(2007) 19 final. Results of the review of the Community Strategy to reduce CO2 emissions from passenger cars and light-commercial vehicles*.

EC, 2011a, *COM(2011) 112. A Roadmap for moving to a competitive low carbon economy in 2050*.

EC, 2011b, *Presentation of the DG Move for the Challenge Bibendum 2011 Workshop 1-5, May 18th 2011, Berlin*.

EC, 2011c, *Regulation (EC) No 443/2009 of the European Parliament and of the Council of 23 April 2009 setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO_2 emissions from light-duty vehicles*

EC, 2011d, *Regulation (EU) No 510/2011 of the European Parliament and of the Council of 11 May 2011 setting emission performance standards for new light commercial vehicles as part of the Union's integrated approach to reduce CO_2 emissions from light-duty vehicles*.

EEA, 2010, *Working Paper - Images of low-carbon transport in 2050: an end-users perspective*.

EEA, 2011, *website <http://www.eea.europa.eu>*, accessed July 2011.

EPA, 2011, *website <http://www.epa.gov>*, accessed July 2011.

Hardin, G., 1968, *The Tragedy of the Commons*, Science, vol. 162.

IEA, 2009, *Transport, Energy and CO_2*.

IEA, 2010a, *World Energy Outlook*.

IEA, 2010b, *CO_2 Emissions from Fuel Combustion*.

ITF, 2010a, *Trends in the transport sector*.

ITF, 2010b, *Reducing Transport Greenhouse Gas Emissions. Trends & Data*.

IPCC, 2006, *Guidelines for National Greenhouse Gas Inventories*.

IPCC, 2007a, *Fourth Assessment Report of Working Group III. Technical Summary*, Cambridge University Press.

IPCC, 2007b, *Fourth Assessment Report of Working Group I*, Cambridge University Press.

King, J., 2011, *Presentation for the Challenge Bibendum 2011 Leaders' Forum - 20.05.2011 - Berlin*.

Kriston, A., Szabo, T., Inzelt, G., 2010, *The marriage of car sharing and hydrogen economy: A possible solution to the main problems of urban living,* International journal of hydrogen energy, vol. 35.

Mairie de Paris, 2011, *BLEU Climat*.

Ministère de l'Écologie, de l'Énergie, du Développement durable et de la Mer, Mission Climat, 2010, *Chiffres Clés du Climat. France et Monde,* Repères.

Michelin, 2010, *Biofuel Summary*.

Michelin and CEC, 2011, *More Air! Reduce CO_2 Emissions in Road Transport*, Challenge Bibendum Booklets.

Michelin, 2011a, *Let's drive electric! Electric and Hybrid Vehicles*, Challenge Bibendum Booklets.

Michelin, 2011b, *Let's drive bio! What biofuels for what uses tomorrow?*, Challenge Bibendum Booklets.

UNFCCC, 2011, *CDM and JI pipelines <http://cdm.unfccc.int> and <http://ji.unfccc.int>*.

World Energy Council, 2010, *Energy and Urban Innovation*.

World Bank, 2011, *Internet Data Catalog <http://data.worldbank.org>*.

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