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Market Development for Green Cars

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FOREWORD

This report presents and analyses policies, programmes and approaches for the development, market introduction and diffusion of green cars. It reviews government policies in a number of OECD countries as well as a selection of non-OECD economies. The report attempts to provide: *i)* a better understanding of the growing market for green vehicles; *ii)* new analytical instruments to identify policies and approaches that could be designed and put in place, notably with the aim of fostering the uptake of green cars; and *iii)* to the extent possible, insights into the efficiency and effectiveness of existing policies, as well as guidance on how to assess the impact of future measures.

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The report integrates the outcomes of the workshop "The Green Road Ahead – What Role for Government Policy in Fostering Clean Vehicle Markets?" that was held in Paris on 16 April 2012. It also benefitted from additional discussions at the "2012 OECD Green Car Workshop" that was hosted by the Ministry of Knowledge Economy in Seoul on 28 June 2012.

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ABSTRACT

Alternative fuel vehicles, or green cars, can potentially make an important contribution to greening the economy. They can help reduce greenhouse gas emissions and threats to air quality and human health. They can enhance the energy security of countries. And they can provide governments with new sources of economic growth and competitiveness. Although green cars are generating increasing interest among policy makers, businesses and consumers, their economic and environmental benefits are still uncertain. Several factors are slowing the development of the market, such as: the high price of green cars relative to conventional petrol- and diesel-fuelled vehicles; the lack of refuelling/charging infrastructure; the restricted driving range compared to conventional vehicles, and the perceived distance needs of consumers, which often do not correspond to their regular driving habits; as well as refuelling times that are longer than what consumers are accustomed to. In addition, high entry barriers favour incumbent firms and technologies over newcomers. Nonetheless, innovative business models are emerging, and play a fundamental role in determining the success of green vehicles. Given these specific barriers, there is a role for government to support the development and diffusion of green vehicles, including through policies to strengthen the markets for green cars. However, the use of targeted policy intervention to foster markets for green cars raises a number of challenges related to the timing and level of support, the choice of appropriate policies and fuels/technologies that should be supported, and the inherent risks. Appropriate policy design and evaluation are critical in this respect, as is the development of good policy practices.

RÉSUMÉ

Les véhicules à carburants alternatifs, ou voitures vertes, peuvent contribuer de manière importante à rendre l'économie plus verte. Ils peuvent aider à réduire les émissions de gaz à effet de serre et les menaces à la qualité de l'air et à la santé humaine. Ils peuvent améliorer la sécurité énergétique des pays. Ils peuvent aussi fournir aux gouvernements de nouvelles sources de croissance économique et de compétitivité. Mais bien que les voitures vertes suscitent un intérêt croissant parmi les décideurs politiques, les entreprises et les consommateurs, leurs avantages économiques et environnementaux sont encore incertains. Plusieurs facteurs freinent le développement du marché, y compris : le prix élevé des voitures vertes par rapport à celui des véhicules à moteur à essence et à moteur diesel; le manque d'infrastructures de ravitaillement en carburants ou de recharge de batteries; une autonomie limitée par rapport à celle des véhicules conventionnels; et la perception qu’ont les consommateurs de leurs besoins en terme d'autonomie de leurs voitures, qui pourtant ne correspondent souvent pas à leurs habitudes régulières de conduite; ainsi que les temps de ravitaillement/rechargement qui sont plus longs que ceux auxquels les consommateurs sont habitués. En outre, des barrières à l'entrée élevées favorisent les entreprises et les technologies en place par rapport aux nouveaux entrants. Néanmoins, des modèles d'entreprises innovants voient le jour, et jouent un rôle fondamental dans la réussite des véhicules verts. Compte tenu de ces obstacles, les gouvernements ont un rôle à jouer pour soutenir le développement et la diffusion de véhicules verts, notamment par le biais de politiques visant à renforcer la demande. Cependant, l'intervention politique ciblée pour favoriser la demande de voitures vertes soulève un certain nombre de défis liés au calendrier des mesures et au niveau de soutien, aux choix de politiques et de combustibles et technologies devant être soutenus, et aux risques inhérents. La conception des politiques et une évaluation appropriée sont essentiels à cet égard, tout comme une bonne mise en œuvre de ces politiques.

EXECUTIVE SUMMARY

Developing a greener economy is a key policy imperative in many OECD countries and also beyond the OECD membership. Alternative fuel vehicles (AFVs) can potentially provide an important contribution to this objective. They can help reduce greenhouse gas (GHG) emissions and threats to air quality and human health, enhance the energy security of countries, and provide governments with new sources of economic growth and competitiveness.

Although green cars are generating increasing interest among policy makers, businesses and consumers, their economic and environmental benefits are still uncertain. Several factors are slowing the development of the market, especially of the more radical alternatives such as battery electric vehicles (BEVs). These include: the high price of green cars relative to conventional petrol- and diesel-fuelled vehicles; the lack of refuelling/charging infrastructure; the restricted driving range compared to conventional vehicles, and the perceived distance needs of consumers, which often do not correspond to their regular driving habits; as well as refuelling times that are longer than what consumers are accustomed to. In addition, high entry barriers favour incumbent firms and technologies over newcomers. Nonetheless, innovative business models are emerging, and play a fundamental role in determining the success of green vehicles.

Given these specific barriers, there is a role for government to support the development and diffusion of green vehicles, including through policies to strengthen the markets for green cars. However, the use of targeted policy intervention raises a number of challenges related to the timing and level of support, the choice of appropriate policies and fuels/technologies that should be supported, and the inherent risks. Appropriate policy design and evaluation are critical in this respect, as is the development of good policy practices.

Policy efforts should focus on putting transport on a more sustainable path

OECD and non-OECD countries are increasingly facing serious environmental challenges. Among these, governments are confronted with the need to reduce GHG emissions as well as threats to air quality and human health posed by local pollutants. In addition to these environmental issues, significant concerns in many OECD countries over energy security and dependence on foreign oil supplies have prompted governments to search for alternative sources of energy. Finally, "green growth" is increasingly seen by governments as a promising avenue in their exploration of new sources of growth, including in the transport sector.

It is clear that a "business as usual" approach will be unsustainable: at current trends, the contribution of the transport sector to carbon emissions and environmental degradation is bound to increase. Policy makers in both OECD and non-OECD countries can consider different options to put transport, both of passengers and freight, on a more sustainable path. For example, vehicle kilometres travelled (VKTs) can be reduced by supporting alternatives to the car, *e.g.* putting a higher price on driving; limiting urban sprawl through effective land-use policies; strengthening public transport; and supporting the introduction of innovative car-sharing and carpooling schemes. Negative environmental impacts of road transport can also be reduced through a better use of vehicles, for instance by promoting eco-driving and applying information and communication technologies in transportation ("intelligent transportation systems"). Finally, road transport can be made sustainable over the long term by improving the energy efficiency of vehicles.

When considering the different policy options, policy makers should bear in mind that there is no silver bullet. Different measures are not necessarily exclusive, and may work best when implemented in a complementary fashion. However, there are also potential unintended consequences: for example, gains in energy efficiency may not result in CO_2 emission reductions, since improved efficiency can lead to more driving.

Although incumbent technologies offer some potential for further improvements in environmental performance, new solutions will have to be developed and enter the mass market. Innovation will play an important role; it will lead to new ideas and technologies, but also to new entrepreneurs and business models, thus contributing to the establishment of new markets.

The global recession has hit the automotive industry heavily

Demand for motor vehicles is highly correlated with the general business cycle, but the amplitude of the cycle is actually higher in the automotive industry. Even before the economic crisis, the automotive industry was mature and had been characterised by slow growth. It was one of the most heavily hit sectors in the global recession, as demand for cars plummeted.

Many OECD and non-OECD governments put in place measures both to support the industry directly and to encourage car sales. In a number of cases, governments made their support conditional on the production of more energy-efficient cars, or provided direct incentives to consumers to purchase green cars, through car scrapping and replacement schemes.

Although the main objective of public support during the crisis was arguably to provide a stimulus to the car industry and to the broader economy, these schemes also contributed indirectly to improving the energy efficiency of vehicles. While the economic efficiency of these schemes is questionable, they have underscored market trends that had already emerged, such as: increasing environmental awareness of car buyers; and the growing importance assigned by consumers to a vehicle's total cost of ownership (TCO) relative to the upfront purchase price. Nevertheless, households typically wish to recover the investments made in better fuel economy in a far shorter period than the expected lifetime of a vehicle.

The market outlook for green cars is uncertain

Identifying a market for green cars and analysing its developments present some daunting challenges. First, the very concept of a market for green cars is difficult to pin down, due to the existence of separate and competing technology trajectories. Second, the economic and environmental benefits of green vehicles are still very uncertain, and this leads to difficulties in appraising the potential market outlook. Several factors are slowing down the development of the market, and the deployment of green vehicles currently seems to be following the more conservative estimates.

Although they started to garner significant attention starting from the oil shocks of the 1970s, the history of green cars is as old as that of petrol-powered engines. Eco-innovations to improve the energy efficiency of vehicles and reduce their environmental impact have taken two main approaches. After the first failed experimentations with electric vehicles (EVs) at the turn of the 20^{th} century, early efforts were concentrated on improving the design of the conventional internal combustion engine (ICE), and subsequently on improving the design of vehicle characteristics that improve fuel consumption, other than the engine. More recently, eco-innovations of a more radical nature have enabled the emergence of entirely new types of propulsion and fuels that in some cases allow the combination of conventional and alternative technologies.

"Green cars" can be defined as vehicles that use alternative fuels (other than petrol or diesel) and/or alternative types of propulsion (other than the conventional ICE). Alternative fuels include biofuels, natural gas, hydrogen and electricity from the grid. Alternative propulsion systems include hybrid and electric engines.

It would be misleading, however, to include only hybrid and electric vehicles in the "green car" category. Petrol- and diesel-fuelled vehicles are becoming much more efficient, to the point that the gap between CO_2 emissions from ICE vehicles and those from hybrid and plug-in hybrid electric vehicles is forecast to be closing quite quickly. This makes it more complicated to predict future technology trajectories, and has important implications for carmakers' strategies and government policies.

Green cars are generating increasing interest among policy makers, carmakers and users. Although their diffusion is slowly increasing, they will likely command only a small share of the automotive market in the coming years, relative to total worldwide vehicle sales. It appears that the current outlook for the development of green vehicle markets is following a conservative scenario, rather than a more optimistic one. A number of factors may explain the slow development, both on the demand side (the high price of AFVs relative to conventional ICE vehicles; the lack of refuelling/charging infrastructure; the restricted driving range compared to conventional ICE vehicles, and the perceived distance needs of consumers, which often do not correspond to their regular driving habits; and refuelling times that are longer than what consumers are accustomed to) and on the supply side (limited economies of scale; high initial capital investment and low returns to R&D). In addition, a high degree of uncertainty surrounds market developments for different products and technologies, particularly with respect to which product or technology will emerge as the most widespread.

An important trend for the coming decades is the increasing importance of emerging countries as automotive markets, especially in Asia. Their demographic profiles and urban environments are likely to shape market developments significantly. E-mobility is already popular in China in the form of e-bikes, and inexpensive two-wheelers are popular in India. However, it is still unclear if this trend will also translate into a more widespread diffusion of green vehicles in those markets. For example, the potential of electric cars in large economies such as China and India still seems quite limited, at least as a means to cutting transport emissions.

New innovative business models are emerging

Green cars are likely to disrupt the automotive value chain both on the demand and on the supply side, and it is expected that this will lead to significant innovations. Innovative business models may play a fundamental role in determining the success of green vehicles, by bringing them to the market and promoting their dissemination. In terms of the sales business models of carmakers, two main approaches are emerging as the preferred options: outright (direct) sale to consumers and leasing of the vehicle.

New business models are also emerging around the battery itself, as the battery represents a high share of the final electric vehicle price. For example, battery leasing makes the vehicle more affordable to consumers and removes a significant element of financial risk. A variation of this business model adds the feature of battery swapping to battery leasing, and can be seen as a "mobile-phone-style transportation contract".

Charging infrastructure is another area where innovative business models are being developed and tested. For example, an EV can be changed at different locations, public or private. Several players can provide these different charging solutions, and the landscape for infrastructure is still very much evolving. The issue of refuelling infrastructure also applies to other alternative fuels, for example in the case of natural gas stations and hydrogen stations.

Car-sharing is also increasingly seen as a business model that can facilitate the diffusion and adoption of green vehicles, especially plug-in hybrid electric vehicles and pure battery electric vehicles, as it may facilitate the shift in consumers' minds from thinking of the car as a product to thinking of it as a service. In the last decade, car-sharing companies have started to integrate green vehicles in their fleets.

In recent years most automotive manufacturers have made announcements that they will introduce some type of green vehicles in their fleets, most of them already in 2011-12. However, corporate strategies with respect to green cars differ significantly in terms of technological choices. At the same time, most carmakers have taken the approach of not putting all their bets on one technology, but rather diversifying their offerings to customers.

This variety makes it difficult for carmakers to fully utilise economies of scale, which is one of the reasons why green cars are still expensive and thus less acceptable for consumers. Interoperability of the recharging infrastructure can reduce the level of uncertainty about the development of the market, thus enhancing incentives for carmakers to introduce green vehicles at an earlier stage. Reducing market uncertainty and utilising economies of scale as early as possible will help reduce the price of green cars, especially battery electric vehicles, thus accelerating market development.

The energy efficiency of green vehicles should be assessed taking into account the full product life cycle and performing a "well-to-wheel" calculation of how they perform in comparison with traditional ICE vehicles. This is important to ensure that low- or zero-emission vehicles do not in fact represent "displaced emissions", *e.g.* emissions from carbon-intensive electricity generation. There are also some important environmental issues with regard to the batteries used in EVs.

Another word of caution concerns the inevitable trade-offs that emerge from a government decision to pursue the greening of road transport. This issue has been discussed at length with regard to taxes, but also applies to other demand-side instruments such as regulations and standards. Policy makers should also consider that the impact of a wider deployment of green cars on climate change and the environment depends not only on the number of vehicles purchased and driven, but also on what transport mode people were using before buying a green car. Overall, it appears that the societal costs of reducing CO_2 emissions by promoting electric cars, even with low carbon electricity, remain high at present.

Specific industrial and competition issues surround green vehicles. The green car industry is characterised by a proliferation of technological trajectories, which leads to market segments that are not fully substitutable. In addition, they depend on different critical elements with little or no R&D scope economies, and little or no spillovers between them. The infrastructure needed for the deployment of the vehicles is also not the same for the different technologies. At the same time, there are also some complementarities between the different trajectories. For example, FCEVs, BEVs and PHEVs are likely to benefit from each other's mass deployment.

An analysis of trajectories for green vehicles has important public policy implications. Although policy makers should generally favour technological neutrality, governments at the same time have a role in overcoming some of the failures and barriers that prevent the adoption and diffusion of green vehicles.

Systemic barriers and market failures prevent the development and diffusion of green cars

The transition to a more sustainable transport system is hampered by the existence of market and systemic failures which prevent the development and diffusion of green cars. The main barriers to the diffusion of green vehicles can be ascribed to inertia, inadequate infrastructure, government failures and market failures.

Inertia can be defined as a resistance to change or tendency of economic, human and physical systems to change very slowly. It can be a major obstacle to the development and diffusion of green cars. Elements of inertia include low returns on R&D, network effects, barriers to competition and slowly changing norms and habits.

For example, as the market for the more disruptive AFV technologies is still relatively limited, the *returns on R&D investments* may not be high enough to encourage the necessary private sector investment. This adds to the riskiness of R&D investment in this area: the uncertainty surrounding the development of the market for green cars means that companies may gain a return only after a very long payback period, and it is unclear if they will be able to gain sufficiently large market shares to recover their R&D costs.

Network externalities can also cause inertia in the development and diffusion of green cars. Barriers to entry can arise from increasing returns to scale in networks and contribute to creating a bias in the market towards existing technologies. Consumers may be reluctant to purchase a green vehicle if they are uncertain that a network of refuelling/charging infrastructure will be extended far enough to cover their needs. Instead, they will tend to favour the incumbent ICE technologies for which gasoline and diesel refuelling stations abound.

The development of markets for clean vehicles is also hampered by *high entry barriers* that tend to favour incumbent firms and technologies and hamper entry by potential competitors. For instance, path dependence may lead to lock-in failures and dominance of existent designs in systems and technologies. High entry costs may exist for new technologies, and therefore lead to high cost of switching to these new technologies for users.

Many barriers to entry and competition are of a technical nature. For example, one factor that is holding back purchases of electric vehicles in particular is the limited driving range. Another technical shortcoming linked to the limited range of EVs is the long time required for charging. Significant technical entry barriers also exist on the supply side, in particular for battery manufacturers.

Slowly changing norms and habits of consumers have been identified as another potential source of barriers to the diffusion of green cars. One of the main psychological factors impinging on consumer adoption of hybrid and electric propulsion systems (especially the latter) is "range anxiety", *i.e*. the fear that the vehicle will not have sufficient power to take the driver to his or her final destination. At the same time, psychological and behavioural factors may also play in favour of consumer uptake of green vehicles.

A high level of uncertainty about the prospects of success of green vehicles and the long timescale for setting up the *charging infrastructure* may deter firms from investing in the necessary technologies. This market failure is made more acute by timing: the private sector may eventually invest in charging infrastructure, but will probably not do so until sufficient demand generates a revenue stream to earn a reasonable return on investment.

The role of the government involves not only removing factors of inertia and failures in the market, but also tackling barriers to the development and diffusion of green vehicles created by its own institutional and regulatory systems. For example, *perverse subsidies and preferences to incumbents* (*i.e*. to conventional fuels and ICE vehicles) represent a key disincentive for manufacturers to develop green vehicles and for consumers to adopt them. *Policy unpredictability and regulatory uncertainty* can also have a significant impact on manufacturers' decisions as regards the production and commercialisation of green cars as well as on adoption by consumers.

Finally, a number of market failures potentially impinge on the diffusion of clean vehicle technologies. *Information externalities* occur in clean vehicle markets, as consumers do not always act rationally in terms of incorporating fuel savings into their purchasing decisions. In addition, if *negative environmental externalities* (*i.e*. unpriced environmental costs related to GHG emissions and air pollution) are not internalised by firms and households, there will be little demand for AFVs.

There is a role for government policies to foster markets for green cars

To help overcome these barriers and market failures, governments in OECD and non-OECD countries have implemented several types of policy instruments, and thus promote the diffusion and adoption of green vehicles. The policy initiatives reviewed and analysed in this report show that AFVs are being deployed with diverging sets of standards, incentives, business models and degrees of government involvement. In particular, the following elements may explain the sheer variety of initiatives and paths followed in different countries: *i*) industrial structure and presence of incumbent firms; *ii*) national policy priorities to improve environmental performance; and *iii*) distance from the technological frontier and size of the market.

One overarching observation emerging from policy development in OECD and also non-OECD countries is that many initiatives to promote the adoption of green vehicles are taking place at the level of cities, as part of strategies to improve air quality and reduce congestion and noise.

The analysis in this report focuses specifically on policies that act on the demand (pull) side. Of course, supply-side (or technology-push) measures, such as direct public support to R&D, demonstration and verification also play an important role in fostering the development of alternative fuels and alternative propulsion technologies. The following demand-side policies play a particularly important role.

Public procurement

Public procurement can tackle many of the factors of inertia that impinge on the diffusion of green vehicles. For example, automobile manufacturers have a greater incentive to develop and produce AFVs if procurement helps them recuperate (some of) the sunk costs of large and risky investment over a pre-determined period of time. Public procurement programmes to purchase a fleet of green cars (or in public transport) can also promote the adoption by private motorists thanks to network effects. By creating a signalling effect as lead users, governments can create and/or expand the network that is needed for early adopters and then encourage private firms and consumers to take up green vehicles.

Green public fleets can also play an important demonstration effect in the commercialisation phase of AFVs, as they enable potential users to witness how green cars compare with conventional petrol- and diesel-powered vehicles in terms of performance, reliability and other characteristics. Thus, public procurement may contribute to breaking some of the psychological biases against green vehicles. It can help to overcome information asymmetries, and provide consumers with the basic building blocks of knowledge that they need when they make their purchasing decisions.

At the same time, using public procurement to foster consumer uptake of green vehicles can also be a double-edged sword; a failed demonstration programme may well provoke a backlash against green vehicles. The risks inherent in using public procurement as a demonstration tool call for thorough evaluations of the impacts of these programmes on consumer confidence vis-à-vis green vehicles and the resulting uptake. However, currently such evaluations are largely absent across OECD countries.

Although public procurement has significant potential for fostering the development and deployment of green vehicles, there are also some important challenges. For example, the public sector often lacks the capacity to design and implement purchasing programmes that are oriented to stimulating eco-innovations in the transportation sector. Moreover, using public procurement to support market development of green cars runs the risk of creating inefficient policies and of introducing distortions to the competitive process, including in the international context.

Performance-based regulations and standards

Performance-based regulations and standards can be designed to foster improvements in the environmental performance of motor vehicles. Governments can design fuel economy regulations so that they are technology neutral, and that they foster continuous innovation by allowing flexibility in achieving the outcomes rather than supporting specific solutions. However, when a technology is already locked in, performance regulations and standards may not be sufficient to bring about more radical innovations. In some cases, this has led regulators to turn performance regulations and standards into *de facto* technology mandates.

Performance-based regulations and standards can also help to change consumers' norms and habits vis-à-vis green cars as well as overcome information asymmetries, by highlighting the improved fuel economy and environmental performance of an AFV relative to less efficient and more polluting options.

By setting a performance target, fuel economy or emission reduction standards can enhance regulatory certainty for carmakers and investors, especially if governments commit for a long-term horizon. In addition, the introduction and potential revisions of the regulations should be communicated clearly and transparently to all interested parties.

The policy cases presented and analysed in this report shows that performance-based approaches across OECD and non-OECD countries employ very wide and diverse combinations of mechanisms. They illustrate the importance of designing performance regulations so that they induce continuous efforts and behavioural change amongst carmakers and drivers, without locking them in any particular technological pathway. Given the considerable industry-specific expertise that will be required in public bodies as a pre-requisite to the design and implementation of such instruments, regulators need to consult widely with industry and other stakeholders, as is currently done in many OECD countries. In addition, the governance of setting and administering performance standards can be crucial in determining the effectiveness of the regulation. In particular, vertical co-ordination is important to address excessively complex "nested regulations" between different levels of government.

Challenges also exist in evaluating the cost-effectiveness and specific effects of performance-based approaches, also because it can be difficult to isolate the specific effects of regulation from other influences, including the simultaneous impact of other policies or exogenous factors. Nevertheless, it is important to evaluate the effectiveness of performance-based approaches regularly.

Technology-based standards and regulations

Technology-based standards and regulations affect innovation by setting technical specifications for ensuring interoperability, securing minimum safety and quality, achieving variety reduction and providing common information and measurement. Their use can contribute to redress some of the failures that are preventing green vehicles from being widely adopted by consumers.

Technology-based standards and regulations can enable the emergence of positive network externalities by ensuring interoperability. In addition, standardisation and the resulting interoperability provides private sector operators with a stake in the manufacturing of green vehicles and investment in refuelling infrastructure with long-term certainty and predictability as to the government commitment to sustainable road transport. Technology-based standards and regulations can also contribute to changing the bias of consumers against green vehicles, and overcome information asymmetries.

The reviewed initiatives in the area of standardisation for alternative fuels and propulsion technologies highlight two important challenges for policy makers: getting the right timing for standardisation and the international dimension of standardisation.

Getting the right timing for standardisation is an important challenge for policy makers and other actors. Standards should be introduced not too early as this could shut out alternative (and potentially better) options, but early enough to create interoperability and positive network effects. Specific barriers in markets for EVs may justify some degree of standardisation at an early stage in order to reduce uncertainty. At the same time, standardisation should not be excessive, and leave room for experimentation that could lead to continued innovation.

Another challenge relates to the international dimension of standardisation. International co-operation can play an important role in diffusing green car technologies across countries, for example by agreeing to uniform standards for connecting vehicles to charging stations. Although standardisation efforts are ongoing at international level and in multilateral fora, different standards are emerging around the world, and this may bring some degree of uncertainty to the deployment of the charging infrastructure. Some efforts are underway to harmonise standards at the regional/continental level.

Price-based measures

Price-based measures can play a fundamental role in tackling one of the main entry barriers for green vehicles, *i.e*. the high cost relative to conventional ICE vehicles. They can address this barrier by raising the price of the most polluting and energy-inefficient vehicles, *e.g.* through taxation, or by lowering the price of cleaner fuels and propulsion technologies, *e.g.* through tax credits and direct subsidies. In so doing, these measures can either be technology neutral, or favour specific fuels or technologies. Price-based measures may also contribute to changing norms and habits of consumers and overcoming information asymmetries, as they can help to put consumers in a better position to make a rational decision. Finally, taxation of relatively more polluting fuels and propulsion technologies can also correct the unpriced negative environmental externalities caused by road transport.

There are two main categories of price-based measures: *i)* fiscal and financial incentives (*e.g.* direct subsidies through financial transfers to buyers or users of green vehicles, or tax incentives); and *ii)* fiscal and financial disincentives (taxes and charges that aim at changing the relative prices of inputs and the price of outputs).

Perhaps unsurprisingly, several studies find that fiscal and financial incentives have had a positive effect on the adoption of green vehicles. However, results are mixed, especially with regards to the cost-effectiveness and budgetary sustainability of the schemes, which tend to be expensive.

Policy experiences from OECD countries also reveal the crucial importance of the timing and sequencing of financial and fiscal incentives. Policy makers should send clear signals about the duration of price incentives, while avoiding exposure to large potential subsidy costs.

Developing instruments based on pricing is a complex task that often requires highly technical knowledge about particular technologies to set the right support level and administrative skills to design incentives and disincentives that lead to a behavioural shift amongst targeted consumers. Another main challenge for pricing instruments is to produce a shift in consumer behaviour by increasing awareness of the long-term benefits of green vehicles.

Price-based measures run some other risks. For example, they may end up focusing AFV innovations along relatively narrow lines, which could result in inefficient decisions of producers, investors and consumers. There is also a risk of "picking the wrong winners and losers" by providing direct or indirect incentives and/or disincentives in sectors or technologies on which policy makers do not have full information. Moreover, there is a danger that providing early financial or fiscal support to a technology might prove highly costly if the technology in question is not yet mature enough. The issue of equity is also important. Tax credits and subsidies may end up being highly regressive, and only reward those who need them the least. In addition, fuel and vehicle taxes may create a disproportionately big burden on poor households, although the evidence does not seem to support this argument.

Price-based measures can play a role in the overall policy mix, but have some limitations in the current context of growing fiscal constraints across OECD countries.

Support for commercialisation

Governments may need to support the commercialisation of innovative fuels and propulsion technologies, to help overcome barriers to innovation, such as high entry costs and lock-in failures. In addition, newcomers and new business models play a crucial role in the development of green vehicles and their diffusion in the market. Therefore, governments may consider introducing initiatives to encourage venture capital investment in the creation and growth of new firms.

Full evaluations of the impact of government support to financing commercialisation of green vehicles are largely lacking, possibly because many of these initiatives are quite recent. Therefore, it is not fully clear what constitutes best practice in this area. Generally, evaluations of programmes in support of commercialisation of eco-innovations highlighted positive outcomes in terms of mobilisation of private funds as well as employment creation. However, concerns over the management and effectiveness of these programmes have been raised in several countries.

Infrastructure provision

By supporting the provision of refuelling infrastructure, governments can tackle the important network externalities that prevent the creation of markets for green cars, as well as provide private operators with an incentive to invest.

The timing and sequencing of infrastructure deployment is crucial. Sufficient recharging infrastructure should be in place not only for the initial wave of vehicles, but also for the second phase of the market ramp-up. In addition, it may be appropriate to support the installation of refuelling/charging infrastructure in advance of AFV deployment, in order to avoid a potential "chicken-and-egg" problem. Well-designed public-private partnerships may provide the most promising approach to developing the necessary infrastructure.

Information-based measures

In order to overcome information asymmetries, governments can also implement measures aimed at enabling individuals to make more informed choices, such as labelling and consumer education and awareness-raising.

In isolation, labelling schemes are unlikely to lead to significant fuel efficiency improvements, but they can be tied effectively to other instruments, such as tax incentives and subsidies. In fact, some evaluations show that consumers put a high value on fuel economy.

Education plays an important role in steering users' behaviour towards sustainable consumption and raise awareness of what consumers can do to reduce the negative environmental impact of their car purchase and usage patterns. In addition, the benefits of an EV need to be clearly communicated to the potential purchaser, also since the high initial price of the battery requires a longer-term perspective about the associated expenses.

Networks and partnerships

Transaction costs and co-ordination failures are particularly acute in the development of green vehicles, as there are a large number of alternative technological trajectories. Networks and partnerships can facilitate co-operation and optimise the use of resources (*e.g.* knowledge, finance) among a variety of actors.

Networks and partnerships to foster the development and diffusion of green vehicles in OECD countries have different structures and modus operandi (*e.g.* multi-stakeholders platforms; knowledge networks; high-level working groups; operational and technical task forces). Their outputs range from producing strategic visions for the decarbonisation of transport to solving operational and technical issues in putting in place the right framework conditions and infrastructure required for AFVs deployment.

Formal evaluations of the impact of networks and partnerships on the market development of green vehicles are generally lacking. However, anecdotal evidence emerging from the experience in OECD countries seems to suggest that they have often provided key governance structures for co-ordinating diverse actors in a complex environment.

In an uncertain market, policy design and evaluation are key

The choice of instruments to support green cars depends on what systemic barriers and market failures need to be addressed. It is likely that the most appropriate policy response will be a mix of instruments, because of the presence of several interacting and interdependent systemic and market failures.

At the same time, the use of targeted policy intervention to foster markets for green cars raises a number of challenges related to the timing and level of support, the choice of appropriate policies and fuels/technologies that should be supported, and the inherent risks. Because AFV technologies are still characterised by a high degree of uncertainty as regards the net benefits they bring to the environment, the society and the economy, policy makers should pay particular attention to issues of policy design and evaluation.

In particular, the following aspects should be considered:

- The government is not the only player in addressing market and systemic failures preventing the development of markets for green cars, and it should assess the **appropriateness of intervention** on a case-by-case basis. Especially in times of tight public budgets, limited resources may restrict the government's ability to deal with policy concerns on its own. For example, different actors can provide private or public charging solutions. In this case, policy makers should consider carefully whether to address the market failure directly or to develop the right framework conditions and a sound business environment, which could enable private operators to overcome the barriers instead.
- When determining the degree and modalities of their involvement, governments should assess carefully the best incentives to promote green transportation on the basis of **country-specific regulatory frameworks, experiences and policy goals**. They can play different roles in fostering the development of green vehicle markets: either as facilitators or as leaders with a more proactive, top-down approach.
- As for other policies that aim at inducing environmental innovations, policy makers should consider the **stringency, predictability and flexibility** of the instruments' design to encourage the development and diffusion of green cars.
- **Stable, consistent and long-term policy signals** are important for manufacturers and consumers of green vehicles. For example, if the stringency of an instrument that aims at improving vehicle fuel economy is in question, the strength of the incentives for manufacturers to develop innovative solutions and promote them will be reduced. Therefore, policy makers should set and announce clear long-term objectives and targets and communicate under which conditions these might need to be subject to revision.
- The **timing and sequencing** of policy implementation is important:
  - Voluntary self-regulation to reduce vehicle CO_2 emissions may be introduced first, but not necessarily be effective. A sequencing arrangement may involve the automatic or non-automatic application of mandatory, more stringent performance standards.
  - Technology-based standards should be introduced not too early, as this would result in lock-in effects, but early enough to promote interoperability and positive network effects. Competition among different product designs, technological solutions and business models during a proliferation period contributes to ensuring that the most efficient and desirable solution will emerge that could later become a standard on the market.

However, the nature of the barriers preventing the development and diffusion of green vehicles may justify a minimum level of standardisation at an early stage.

- As for pricing measures, most OECD countries give consumers a higher level of incentives in the first period of the schemes, while gradually decreasing them in the following years. The arrangement has the objective of providing a strong pull at a stage of market deployment in which costs are high and the technology is still surrounded by uncertainty. Once costs decrease and AFV technologies gain acceptance in the market, subsidies are typically phased out. With regard to vehicle taxation, as automobile manufactures improve the energy efficiency of their vehicles over time and the market evolves accordingly, policy makers may consider tightening the stringency of fiscal disincentives, in order to ensure that the measures continue to contribute to CO_2 emissions reduction. At the same time, pricing measures are quite expensive and are often not cost-effective in meeting their main goals, suggesting that their role in the overall policy mix should not be overstated.
- Policy makers should also encourage that a sufficient recharging infrastructure is put in place not only for the initial wave but also the second phase of the market ramp-up. This should ideally be based on public-private partnerships. In addition, it may be appropriate to support the installation of refuelling/charging infrastructure in advance of AFV deployment, in order to avoid a potential "chicken-and-egg" problem.

- Policy makers should ensure **technological neutrality**, and should ideally support the broadest portfolio of alternatives. When they do implement targeted interventions, these should be carefully designed. Targeted interventions can end up favouring specific technological solutions and create or enhance lock-in, although it is very difficult for policy makers to know in advance which option will be the most efficient and effective. But implementing technology-neutral instruments is not always possible. Public resources are finite, and cannot be spent on all innovations. Policy makers should remain alert to the risk that direct support to AFV technologies becomes captured by vested interests and gives rise to opportunities for rent seeking. Incentives should be limited in time and volume, for example by including a sunset clause.
- **"Picking" AFV technologies,** for example through technology mandates or targeted incentives, is risky. Selective treatment should only be given to technologies that can be reasonably expected to have a steep learning curve and for which costs are expected to come down at a fast pace due to economies of scale and scope.
- **Ongoing monitoring and evaluation** of technologies as well as of technical and commercial challenges can enable flexible and continuous adaptation of policy to current conditions. This can imply the discontinuation of a scheme if the results of evaluation show that a technology is not delivering what was originally expected. At the same time, this can reduce policy predictability and certainty for the private sector. In these cases, policy makers should weigh the cost of reducing predictability and certainty for the industry against the benefit of eliminating or modifying an instrument that is not meeting its objectives. Communicating clearly and up-front the reasons for possible future changes to policy instruments can contribute to policy predictability.
- **Cost-benefit analyses** are necessary to establish the most efficient policy mix and should incorporate environmental, social and economic benefits. The side effects of policies in support of green vehicles should also be carefully assessed. Policies to foster the diffusion of green cars may inadvertently encourage environmentally harmful activities, for example if an improvement in fuel efficiency increases the use of vehicles on the roads and kilometres

travelled. Although improved fuel efficiency is expected to reduce negative environmental impacts and thus bring benefits to the economy and society, measures to that effect may also lead to some costs, which should be acknowledged and taken into account when evaluating policy outcomes.

MARKET DEVELOPMENT FOR GREEN CARS

1. CHALLENGES IN THE TRANSPORT SECTOR AND POTENTIAL SUSTAINABLE PATHS

This section reviews the main environmental and security challenges posed by the continuous upward trend in global road passenger and freight transport. It also describes different options for sustainable mobility that have been considered by governments, including alternative fuel vehicle (AFV) technologies.

1.1 The need to put transport on a more sustainable path

There are at least three reasons why transport needs to be put on a more sustainable path: *i)* to reduce the large – and in some areas, growing – environmental impact of the sector; *ii)* to increase energy security and independence from foreign suppliers; and *iii)* to search for new sources of economic growth and competitiveness.

OECD and non-OECD countries are increasingly facing serious environmental challenges. Among these, governments are confronted with the need to reduce greenhouse gas (GHG) emissions – caused mainly by carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) – as well as threats to air quality and human health posed by local pollutants, such as particulate matter (PM), carbon monoxide (CO), nitrogen oxides (NO_X), hydrocarbon (HC) compounds and volatile organic compounds (VOCs). In addition to these environmental issues, significant concerns in many OECD countries over energy security and dependence on foreign oil supplies have prompted governments to search for alternative sources of energy. Finally, "green growth" is increasingly seen by governments as a promising avenue in their exploration of new sources of growth, including in the transport sector.

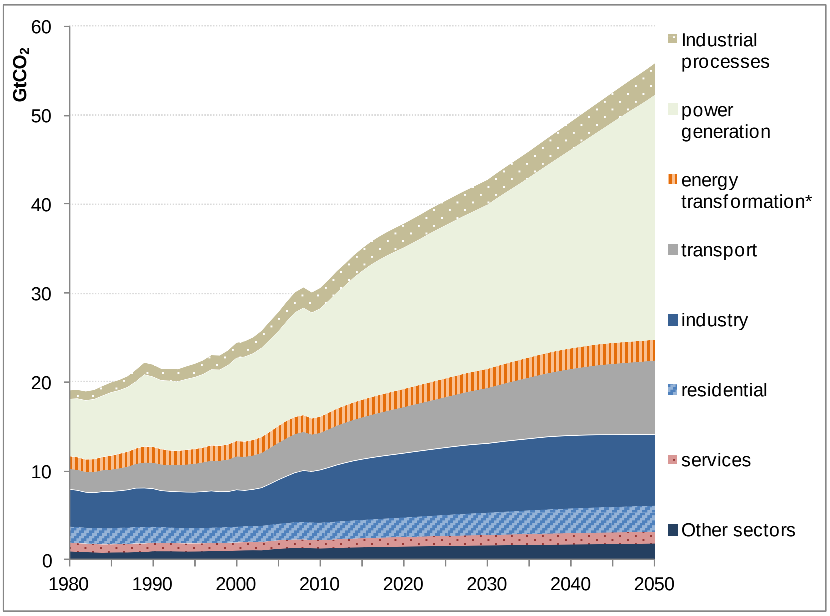
Reduction of climate change and other environmental impacts

Globally, the transport sector is a significant contributor to GHG emissions and local air pollution, as well as noise, especially in the most congested urban areas. In 2009, CO_2 emissions from the transport sector represented 23% of total world CO_2 emissions. They are projected to double between 2010 and 2050, due in part to a strong increase in demand for cars in emerging and developing countries and also to a strong increase in aviation (Figure 1). Within the transport sector, road transport (including both light-duty vehicles and heavy-duty trucks) consumes the most energy (approximately three quarters) and has experienced the most rapid growth in absolute terms (close to a 20% increase from 2000 to 2009) (International Energy Agency, 2012). Road transport accounted for 17% of total world CO_2 emissions in 2009. Ownership of light-duty vehicles (LDVs)[1] is expected to soar globally, mainly as a consequence of increasing income levels in emerging economies. Estimates

[1] LDVs include cars, sport utility vehicles (SUVs) and passenger light-trucks.

of the International Energy Agency (2009) for the number of LDVs range between 2 billion and 3 billion cars by 2050, up from 700 million in 2005.

Figure 1. Global CO2 emissions by source: Baseline, 1980-2050



Note: The category "energy transformation" includes emissions from oil refineries, coal and gas liquefaction.

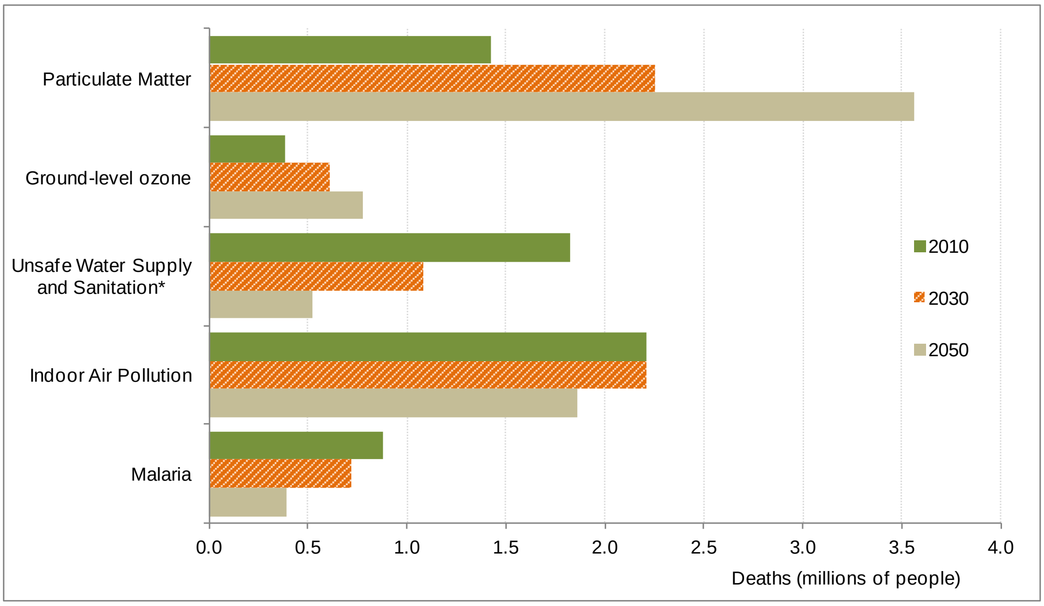
Source: OECD Environmental Outlook baseline; output from IMAGE.

Transport is the main cause of emissions of air pollution at the local, regional and global levels, and in urban areas as well. The main pollutants caused by transport activities are carbon monoxide (CO), nitrogen oxides (NO_X), particulate matter (PM), lead (Pb) and volatile organic compounds (VOCs). Box 1 summarises the main environmental impacts of emissions of these pollutants.

In OECD countries, car emissions account for 55% of CO and 36% of the ozone-causing NO_X emissions. Among other automobile pollutants, hydrocarbons (HC) and PM contribute 21% and 12% respectively to air emissions in OECD countries (Hascic *et al.*, 2009). In the United States alone, from 2004 to 2008, more than 50% of CO was generated by motor vehicles on highways, and more than 30% and 20%, respectively, of NO_X and VOC were generated by on-road motor vehicles (BTS, 2010). In 2009, the global cost of air pollution controls was around USD 280 billion; this cost is expected to increase to more than USD 550 billion by 2035, due to higher activity levels and the greater stringency of the controls (International Energy Agency, 2011a).

The OECD (2012a) projects that urban air quality will continue to deteriorate globally. By 2050, outdoor air pollution is projected to become the top cause of environmentally related deaths worldwide (Figure 2). Under the Baseline of the *OECD Environmental Outlook*, the number of premature deaths from exposure to PM worldwide is likely to more than double to 3.6 million in 2050, mostly in China and India. Substantial increases in sulphur dioxide (SO_2) and NO_X emissions are likely to occur in key emerging economies in the coming decades. Compared to the year 2000, emission levels of SO_2 are projected to be 90% higher and NO_X 50% higher in 2050 (Figure 3).

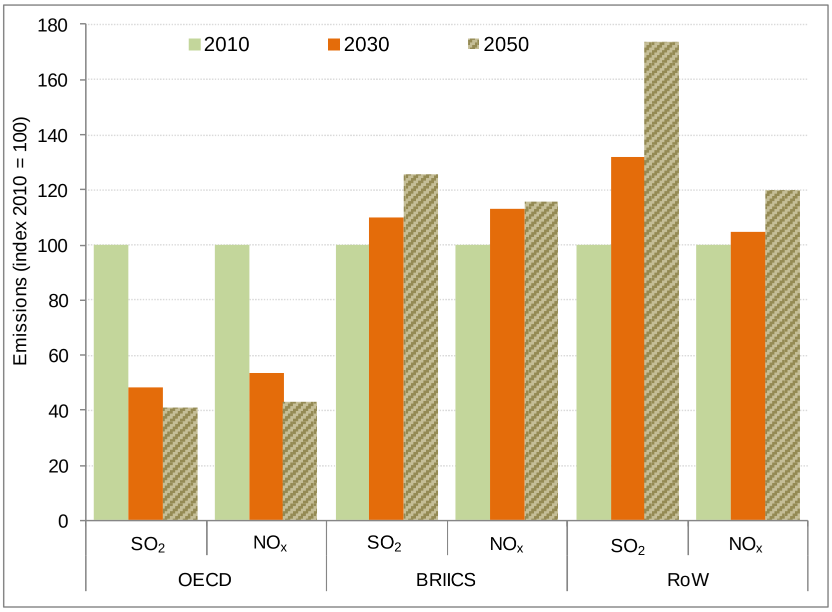
Figure 2. Global premature deaths from selected environmental risks: Baseline, 2010 to 2050



Note: Unsafe water supply and sanitation is for child mortality only.

Source: *OECD Environmental Outlook Baseline*; output from IMAGE.

Figure 3. SO2 and NOX emissions by region: Baseline, 2010-50



Source: *OECD Environmental Outlook Baseline*; output from IMAGE.

Box 1. Main emissions of road transport with effects at local level and their impacts

- *Nitrogen oxides (NO_x).* NO_X emissions are formed in the combustion of fossil fuels. They include nitrogen dioxide (NO_2) and nitric oxide (NO). They can negatively impact the human respiratory system and reduce lung function. They also contribute to the formation of ozone, which is a harmful secondary pollutant in the lower atmosphere. While it was assumed that NO_X emitted by vehicles typically consisted of 95% nitrogen oxide (NO) and 5% NO_2, increasing ratios of NO_2 to NO_X have been observed in recent years. It can be assumed that this trend is due to oxidation catalytic converters in vehicles, which facilitate the formation of NO_2 in the exhaust line. This matters because an increasing ratio of NO_2 to NO_X in the atmosphere causes higher ambient ozone concentrations. In addition, air quality has not improved as much as predicted with the tightening of emission standards, especially in respect to NO_X. One reason for this is the gap between the performance of emission control measures during type approval tests and their effectiveness under real operating conditions.
- *Hydrocarbons (HC).* HC are the result of incomplete combustion of fossil fuels. They cause eye and throat irritation, as well as coughing. They can also cause damage to crops and trees.
- *Carbon monoxide (CO).* CO is also the result of incomplete combustion of fossil fuels and interferes with the absorption of oxygen. Once it enters in the human bloodstream, it can inhibit the delivery of oxygen throughout the body and thus cause dizziness, headaches and fatigue, as well as negative impacts on fertility and general levels of health. It can also interfere with respiratory bio-chemistry and affect the central nervous and cardiovascular systems.
- *Sulphur dioxide (SO_2).* SO_2 affects the lining of the nose, throat and airways of the lungs; it can also cause respiratory illnesses, in particular bronchitis. It also contributes to acid rains.
- *Particulate matter (PM).* PM is a generic term used to describe a group of air pollutants that vary in size and composition. They have been linked to numerous adverse health effects, including increased hospital admissions and emergency room visits, respiratory symptoms, exacerbation of chronic respiratory and cardiovascular diseases, decreased lung function, and premature mortality.

Source: Santos *et al.* (2010); ECMT (2006); Alvarez, Weilenmann and Favez (2008).

Noise is another major negative environmental impact of road transport. For example, it was estimated that each year at least one million healthy life-years are lost in western European countries due to disabilities or disease caused by traffic noise, and this is considered to be a conservative estimate. Sleep disturbance and annoyance related to road traffic noise constitute most of the burden of environmental noise in Western Europe (World Health Organisation, 2011). This represents a significant cost to the economy and society, in addition to the high costs required to ensure protection against noise pollution, such as double-glazing in household windows and noise barriers installed along motorways (Santos *et al*., 2010).

Energy security and independence

Energy requirements in OECD countries with high levels of car ownership put significant pressures on the ability of governments to secure reliable oil supplies, and, in turn, make them highly dependent on foreign sources of energy. As transport is a large component of total demand for oil, switching to alternative fuels and technologies could go a long way towards reducing the energy dependency of OECD countries.

At the world level, the transport sector depends almost entirely on oil products, with 93% of all the fuel used in the sector being oil-based in 2010. Passenger light-duty vehicles remain the single largest component of transport oil consumption, though it is estimated that their share will shrink from about 45% today to 39% by 2035 (International Energy Agency, 2011a).

On a regional level, transport energy use is rising faster in non-OECD regions than in the OECD regions, yet North America and Europe still use the most energy compared with all other regions in the world. On a per-capita basis, North America and Australia have the highest transport oil use per capita, around 1 200 to 1 500 tonnes of oil equivalent (toe) per 1 000 capita. India and China, however, are in the range of 50 toe to 150 toe per 1 000 capita (International Energy Agency, 2012).

Energy dependency can be defined as the fraction of total primary energy supply (TPES)[2] not supplied by OECD production. Efforts have been made to reduce the use of oil in sectors where it can be substituted for by other fuels, but growing demand in captive sectors[3] such as transport explains why the share of oil in TPES remains the highest among all energy sources (International Energy Agency, 2011b).

Energy dependency is strongly influenced by the evolution of OECD oil production and imports. In 2010, the OECD produced 3 889 Mtoe of primary energy, while its total primary energy supply was 5 413 Mtoe. As a consequence, 28.2% of the energy consumed by OECD countries in 2010 (the energy dependency) was imported from non-OECD countries (International Energy Agency, 2011b).

Since the first oil shock in 1973, several efforts have been made to reduce the dependency of OECD countries on imported oil. These efforts have included the development of alternative sources of energy and exploitation of own oil reserves in some countries (*i.e.* the United Kingdom, Norway, Mexico, Canada).[4] However, OECD net energy imports have remained at relatively high levels, and this is mainly because of oil. The share of oil in total energy imports stood at 74.6% in 2010, which is lower than the 1971 figure (98.3%), but still high (International Energy Agency, 2011b).

Oil consumption was heavily affected by the high oil prices in the mid-1970s and early 1980s and declined in all non-captive sectors. But despite all the efforts made to reduce the oil dependency of OECD countries, transport has always been a captive sector for oil, which accounted for 94.4% of transport consumption in 2009, compared to 95.5% in 1971. In addition, the weight of transport in total final consumption (TFC) increased between 1971 and 2009 due to the rising number of vehicles, the tendency to use larger engines, the high use of road transport in trading goods and the relative decrease of the use of oil in all other sectors. In 2009, transport represented about one third of the TFC, while it only accounted for a quarter in 1971 (International Energy Agency, 2011b).

Sustainable transport as a new source of economic growth and industrial competitiveness

Advocates of government intervention to improve the energy efficiency of the transport sector also point to the advantages that these policies could bring in fostering new sources of economic growth and industrial competitiveness. However, a word of caution is in order regarding the overall

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2 Total primary energy domestic supply (sometimes referred to as energy use) is calculated by the International Energy Agency as production of fuels + inputs from other sources + imports – exports – international marine bunkers + stock changes. It includes coal, crude oil, natural gas liquids, refinery feedstocks, additives, petroleum products, gases, combustible renewables and waste, electricity and heat. Domestic supply differs from final consumption in that it does not take account of distribution losses. *Source:* OECD Glossary of Statistical Terms.

3 In this context, a sector is "captive" when it is constrained to consume a particular fuel (in this case oil). There can be various explanations for this phenomenon, *e.g.* alternatives to oil may be lacking; even when they do exist, alternatives may be too costly; oil may possess some unique features that cannot be replicated by alternative fuels.

4 Of course oil exploitation has been driven not only by efforts to reduce dependency on imported oil, but also by the high profitability of this activity.

net impacts of these interventions on the economy. Even a fully fledged sector-specific evaluation of these interventions would fail to grasp the totality of the resulting costs and benefits. A quantification of the general equilibrium effects would be more appropriate to assess the cost-effectiveness of these policies.

Among various arguments that are often given to support this view, the following tend to stand out in policy debates:

- *Public support to the automotive industry acted as a Keynesian stimulus during the economic crisis and contributed to shoring up aggregate demand, output and employment.*

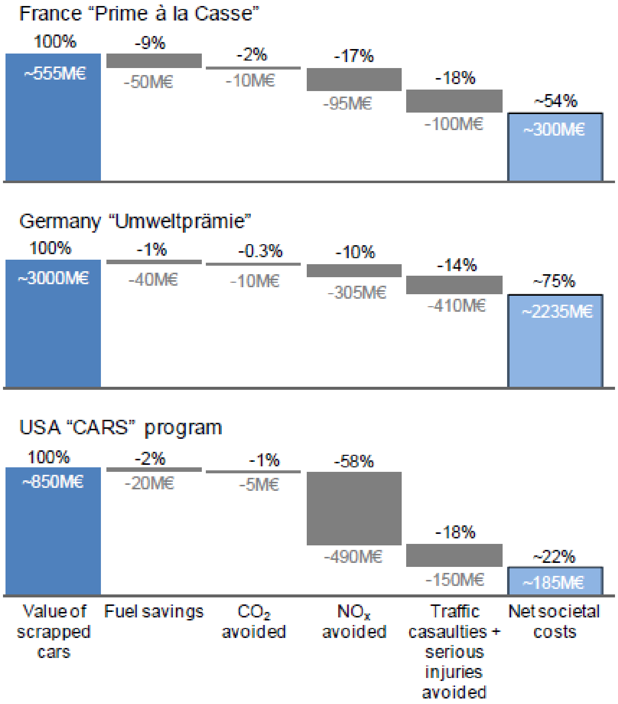
  It can be argued that an increase in public expenditure is likely to generate demand and output in any sector, at least in the short term and depending on the trends in other key variables (*e.g.* financial markets, exchange rates, and expectations, among others). However, a range of factors can be propounded to justify public support to the automotive industry. The car industry has an impact on broader economic performance, because of its interconnectedness with other industries. Its share in employment is often large and geographically concentrated, and thus politically sensitive. Bailing out carmakers is seen as a way to solve credit problems when these carmakers have financing companies. And finally, stimulating vehicle demand is seen as an effective way to strengthen aggregate demand by moving forward purchases, and may have environmental side benefits (Haugh, Mourougane and Chatal, 2010).

  For instance, many OECD countries introduced car scrapping schemes (also referred to as "cash for clunkers") subsidising the purchase of new vehicles to replace old energy-inefficient ones. The schemes contributed to a boost in new car sales around mid-2009 in both the United States and Europe. And these incentives appear to have contributed to the economy-wide recovery observed in many countries in the second half of 2009, by cushioning the impact of the downturn on output and employment (Haugh, Mourougane and Chatal, 2010). For example in the United States, motor vehicle output added 1.7 percentage points to the third quarter change in real GDP. The cash-for-clunkers initiative is estimated to have raised GDP by 0.1-0.4 percentage points at an annual rate in the third quarter of 2009, and to have saved between 22 000 and 59 000 jobs in 2009.

  Yet, the overall economic efficiency of these programmes is questionable. Firstly, the impact on economic activity is likely to have been lowered by the crowding-out effect on the demand for other household consumption products. Secondly, the expected impact on GDP depends on the "payback effect", *i.e.* the reduction in sales when the scheme is terminated, as these programmes simply bring forward future consumption (Haugh, Mourougane and Chatal, 2010). Thirdly, the expected net reductions in GHG emissions and other pollutants induced by car scrapping schemes are estimated to be too small for the environmental benefits to offset the cost (OECD, 2010a; Schweinfurth, 2009). Estimates of the implied cost of CO_2 reductions of the US cash for clunkers programme suggest that the programme is an expensive way to reduce GHG emissions, even accounting for reductions in air pollutants (Knittel, 2009).[5] OECD/ITF (2011) assessed the cost-effectiveness of fleet renewal schemes in France, Germany and the United States from the perspective of CO_2, NO_2 and safety, and found in all cases net societal costs as a result of the policy intervention (although with different magnitudes; see Figure 4).

5 Conservative estimates of the implied CO_2 cost exceed USD 365 per tonne; best case scenario parameter values suggest a cost of CO_2 of USD 237 per tonne.

Figure 4. Cost-effectiveness of the French, German and US fleet renewal schemes



Source: OECD/ITF (2011).

- *Reduced demand for oil can have a positive effect on the domestic economy and international competitiveness.*

  At the individual country level, a decrease in demand for oil can reduce the exposure to price shocks and negative terms of trade effects for oil importing nations. Oil shocks can also have negative effects on domestic prices and inflation, income, output and employment (OECD, 2004). In addition, decreasing demand for fossil fuels imports reduces the world market price of fossil fuels, causing the terms of trade of energy importers and thus trade competitiveness to improve, other things being equal (Zachmann *et al.*, 2012).

  Reducing dependency on foreign oil can also have positive effects on foreign policy and national security (and lead to reduced military expenditure), but these are very difficult to quantify (Leiby, 2007).

- *More stringent emission reduction and environmental regulation can induce innovation.*

  Since its original formulation by Porter (1991) and Porter and van der Linde (1995), the notion that more stringent but well-designed environmental regulation can spur innovation and improve competitiveness (the so-called "Porter Hypothesis") has received some theoretical and empirical support.[6]

6 While empirical evidence that stricter regulation leads to more innovation is fairly well established, evidence on the notion that stricter regulation enhances business performance is mixed, with some recent studies providing more supportive results (Ambec *et al.*, 2011).

In addition to the empirical literature, anecdotal evidence seems to suggest that the Porter hypothesis has contributed to the good innovation performance and trade competitiveness of the automotive industry in some countries, notably Japan. Following the introduction in Japan of an ambient standard for NO_X more stringent than anywhere in the world in 1973, Japanese firms invested heavily in R&D to invent new NO_X abatement technology. As a result, not only did they attain the pollutant reduction target, they also achieved a reduction in the cost of the abatement technology itself. But an empirical analysis of the impact on the firm level R&D expenditure and productivity in the Japanese automotive industry indicates that the Porter Hypothesis is not supported, as the regulation did not directly raise industry-level productivity. At the same time, it also found that more stringent regulation is likely to increase productivity indirectly, *i.e*. through the increase in R&D activity (Hibiki, Arimura and Managi, 2010).

Some also argue that the cleaner and more fuel efficient cars developed by Japanese firms as a result of more stringent government regulation contributed to their success in the United States market in the 1970s and 1980s (Osang and Nandy, 2003). However, it is also argued that this case does not fully support the claim that environmental regulations create technological innovation and rising productivity. For example, Tanikawa (2003) argues that advances made by Japanese automobiles in the United States market resulted mainly from the ability of Japanese carmakers to respond to challenges in structural demand, as consumers shifted to smaller models following the first oil shock. In addition, advances in hybrid vehicle technologies may have been driven by carmakers' efforts to attain competitive positions as a result of a long-term general trend towards strengthening regulation, rather than as a consequence of individual regulations. In any case, it is not clear whether the policy used by Japan was necessarily the most efficient way of reaching the stated policy goal.

- *Public support to clean vehicles could contribute to a better competitive position in the global race for green products and technologies.*

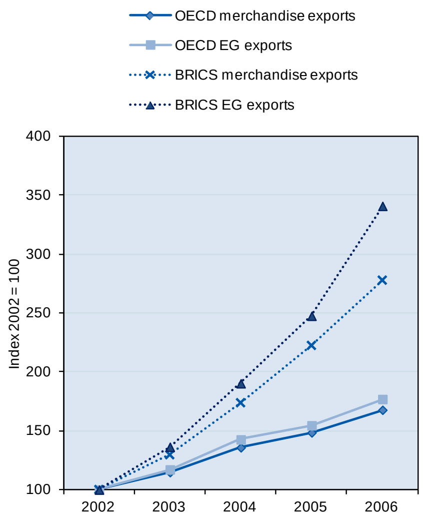
Global markets for environmental goods and technologies have been growing in recent years. In the period 2002-2006, trade in environmental goods grew dynamically, increasing faster than total merchandise trade, particularly in the BRICS, where exports grew at an annual average rate of 35% (Figure 5). Several governments in both OECD and non-OECD countries are providing some form of (direct or indirect) public industrial support to green industries in the hope of getting a head start on competitors and gaining a better position in what is sometimes regarded as a global race for green technologies. This argument assumes that it will not be easy for follower firms and countries to imitate or replicate the technological advances made by lead countries. Imitation typically depends on learning by doing and the ability to protect intellectual property through a variety of means.

Support to AFV technologies can play an important role in this respect. For example, several OECD countries are investing a significant share of their budgets for research, development and demonstration (RD&D) for energy efficient technologies in improving the energy efficiency of transport (Figure 6).[7]

[7] Including technologies for on-road vehicles (vehicle batteries/storage technologies; advanced power electronics, motors, EV/HEV/FCEV systems; advanced combustion engines; electric vehicle infrastructure; fuel for on-road vehicles excluding hydrogen; materials for on-road vehicles) but also other on-road transport, off-road transport and transport systems and other transport.

Figure 5. Trends in export market shares of environmental goods

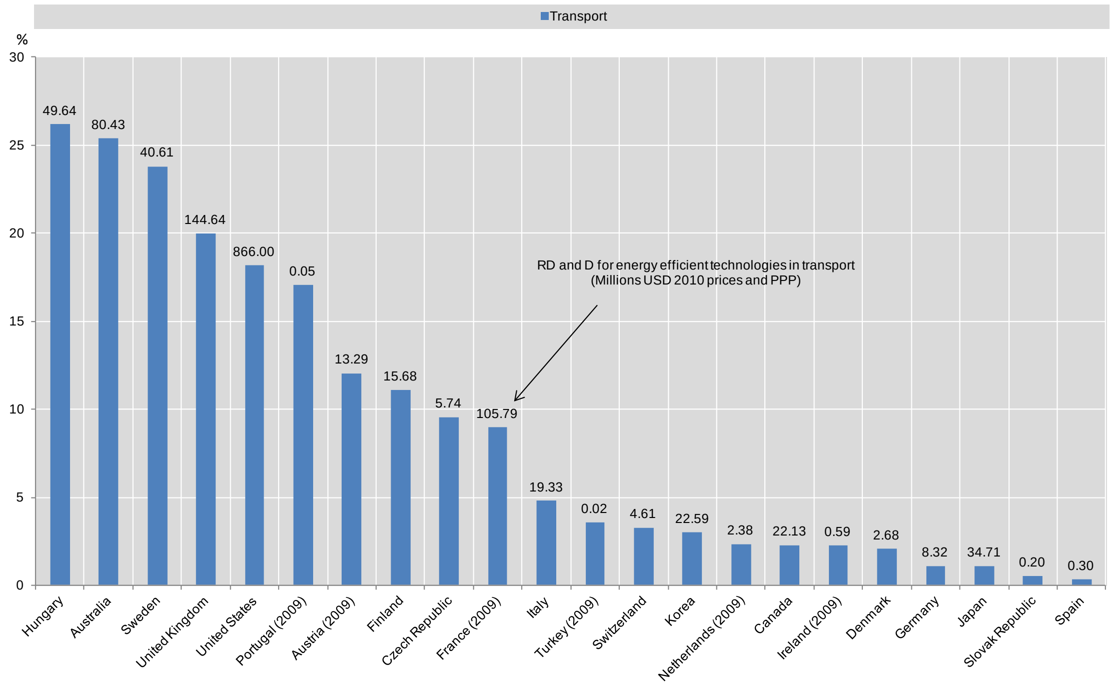
Index 2002 = 100



Source: OECD (2010b).

Figure 6. RD&D budgets for energy efficient technologies in transport, 2010

As a percentage of the total RD&D budgets for energy technologies



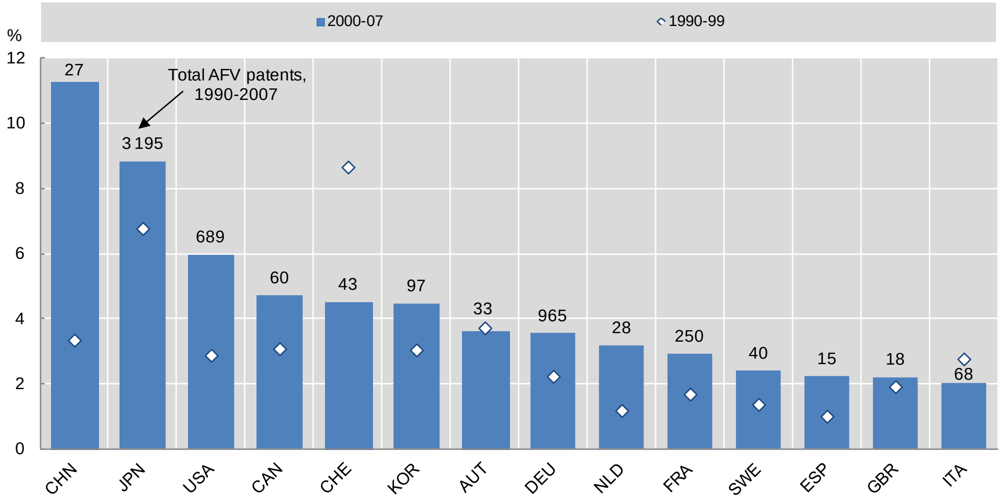
Note: There was a large increase in RD&D spending observed in 2009 due to the increased expenditures associated with the American Recovery and Reinvestment Act of 2009 (stimulus) spending. This is a one-year appropriation (although actual expenditures may go into future years) and so 2010 saw a significant decrease.

Source: Calculations based on IEA (2010b).

Patent counts can provide a measure of innovation in AFV technologies.[8] Innovation in AFV technologies has accelerated and is now the fastest-growing type of technological innovation in the motor vehicles sector. However, the rate of innovation in AFV remains low in absolute terms, and important differences exist among countries (Figure 7).

Figure 7. Transition to alternative fuel vehicle (AFV) technologies, 1990-99 and 2000-07

Share of AFV patent applications (claimed priorities) in motor vehicles patents



Note: Only countries with a minimum of ten patents (claimed priorities) deposited during the two decades are included.

Source: OECD, calculations based on the Worldwide Patent Statistical Database, EPO, April 2011.

1.2 Governments can explore several options to put transport on a more sustainable path

It is clear that a "business as usual" approach will be unsustainable: at current trends, the contribution of the transport sector to environmental degradation is bound to increase. The International Energy Agency (2011a) projects that the total number of passenger LDVs per 1000 people will increase from 10 in 2009 to over 100 in 2035 worldwide, driving a fourfold increase in demand for oil in the transport sector. Ng, Schipper and Chen (2010) estimate that if China follows the trend of motorisation growth that has been observed in countries like the United States and Japan, car ownership could exceed 100 million in the next 10 to 15 years. And the International Energy Agency (2011a) projects that the bulk of the net growth in global oil demand will come from the transport sector in non-OECD countries, particularly India, China and the Middle East.

Policy makers in both OECD and non-OECD countries can consider different options to put transport, both of passengers and freight, on a more sustainable path, which should also help to achieve a better management of congestion and better use of resources invested in transport

8 However, the use of patent counts as indicators of inventive activity also has some limitations, for example: not all innovations are patented; not all patented innovations have the same economic value; and the propensity to patent varies across countries and technological fields. For example, OECD research on patents for AFVs indicates that there are more patents of fuel cells, although hybrid vehicles dominate the market segment. Therefore, the number of patents is not necessarily an indicator of policy relevance, nor of market success or environmental benefit (OECD, 2011b).

infrastructure. This could enable a cut in transport-related GHG emissions, an improvement in air quality, reduction of transport-related noise as well as some mitigation of congestion. Shifts in passenger travel and freight transport to more efficient modes can play an important role in greening transport and should be an important policy focus. From the point of view of cities, developing in a manner that minimises reliance on private motorised travel should be a high priority given the strong co-benefits in terms of reduced traffic congestion, lower pollutant emissions and general liveability (OECD, 2012b).

Traditionally, policy interventions for GHG mitigation in transport have been included in one of the following categories: *i)* "avoid" the need to travel; *ii)* "shift" towards or maintain the share of sustainable modes; and *iii)* "improve" efficiency of all modes (Sakamoto, 2012). Hurford (2009) categorises and estimates sources of emissions reductions into three main groups: *i)* alternatives to the car, contributing to 20% of emission reductions); *ii)* better use of the car, contributing to 20% of emission reductions; and *iii)* lower emissions from cars (through improvements in ICEs and AFVs), contributing to 45% of emission reductions.[9]

Alternative fuel vehicles (AFVs) are the main focus of this paper, however they are not a silver bullet and other complementary options should be introduced along with (but not necessarily as an alternative to) green cars. At the same time, the side effects of policies in support of green vehicles should also be carefully assessed. Policies to foster the diffusion of AFVs may inadvertently encourage environmentally harmful activities, for example if an increase in fuel efficiency increases the use of vehicles and kilometres travelled. Although improved fuel efficiency is expected to reduce negative environmental impacts and thus bring benefits to the economy and society, measures to that effect may also lead to some costs, which should be acknowledged and taken into account when evaluating policy outcomes.

Vehicle kilometres travelled (VKT) be can be reduced by supporting alternatives to the car

Within the OECD, average car travel represents 60% to 80% of motorised passenger travel (based on passenger kilometres per year), except in Korea, where other modes have larger shares. North America has a large share of light trucks, which includes sport utility vehicles, whereas Europe has few light trucks and a larger number of small passenger vehicles. Road mass transportation represents a highly significant travel mode in India, Latin America and Africa, but is less popular in OECD countries, and the Middle East, where car ownership is high (International Energy Agency, 2012).

Data from the International Transport Forum suggest that some levelling off of car travel has taken place in some of the developed economies. Within the European Union, the decline was on average 0.7% in the 18 countries where data is available for 2008. In the United States, passenger travel by car fell 3.4% in 2008, the largest drop since the economic crisis of the 1990s. Data on passenger kilometres by private car in selected countries suggest a return to growth in 2009; total passenger kilometres by car grew 2.3% in Spain, 0.5% in France, 0.3% in the United Kingdom and 1.0% in Sweden (OECD, 2011c). Limits on vehicle travel per person may be about to be reached. These limits are quite different in different countries; for example, average vehicle travel per person and per vehicle in Japan (about 9 000 km per vehicle per year) is far lower than in Europe (about 14 000), which in turn is well below levels in the United States (19 000 per year) (International Energy Agency, 2012).

9 This is dependent on the effectiveness of combined measures, based on UK data.

As AFVs are more efficient, they also make driving less expensive. Because of the resulting rebound effects,[10] the volume of driving can actually increase and thus minimise any benefits deriving from improved energy efficiency in vehicles. Therefore, some argue that reducing vehicle kilometres travelled (VKT) is an essential component of reducing the environmental impact of transport (Hook, 2008). The following measures can be implemented in this context:

- *Put a higher price on driving.*

  This can achieved through fiscal disincentives, such as higher fuel prices or road user charges. Besides reducing VKT, these instruments can also promote eco-driving. For an extended analysis of price-based measures, see section 5.4 of the report.

- *Limit urban sprawl through effective land-use policies.*

  One of the main causes of increase in GHG emissions has been the soaring number of journeys by road, the most inefficient of which are city commutes. Hurford (2009) notes that there is a remarkable degree of similarity in the time people spend on travel per day.

  Limiting urban sprawl (the horizontal spread of cities to suburban areas) can give an important contribution to improving the energy efficiency of transport. Urban land area in the OECD has doubled and outside the OECD has grown by a factor of five since 1950s. The United Nations estimates that more than half of the world now lives in cities, and projects that approximately 75% of the world's population will live in urban areas by 2050 (International Energy Agency, 2012). This results in growing per capita burning of fossil fuels, as inhabitants of suburban areas have to make longer journeys when they commute to city centres (particularly when an extended network of public transport is lacking). Indeed, CO_2 emissions per capita drop significantly as urban areas densify (OECD, 2010c).

  Better urban design can contribute to cutting the need for motorised travel. Improving mass transit systems can make alternatives more attractive, and improving infrastructure can make it easier to walk and cycle for short trips. There may be limited scope for this type of policy to be effective within existing cities, but as cities grow and new cities are built, more emphasis should be put on land use for sustainable mobility (Santos, Beherendt and Teytelboym, 2010). If urban areas (where 70% of humans will live in 2050) can grow "smartly", the demand for travel could be 10% to 20% lower than if the urban areas grow in a haphazard manner (*e.g.* due to shorter trips) (International Energy Agency, 2012).

  "Smarter" city planning may also include granting permissions for new buildings only in already existing neighbourhoods or near public transport lines. Development controls, urban planning and zoning can contain urban sprawl, although these instruments often encounter political and economic obstacles (Amin, 2009).

  While land use planning tools can help, urban sprawl is not necessarily a problem in itself, provided that people moving from and to suburban areas opt for travel modes that have a softer impact on the environment.

[10] A "rebound effect" occurs when users adopt a more energy-efficient product or technology, but offset the environmental gains by increasing the use of such a product or technology.

- *Strengthen public transport.*

  Public transport generally causes lower CO_2 emissions per passenger kilometre than private cars and can reduce total road transport externalities. Therefore, public transport fares are subsidised in most places (Santos, Beherendt and Teytelboym, 2010).

  But in order for commuters to be willing to switch to more sustainable transport patterns, they need to be given options that are on balance as efficient and effective as using a private car. This includes strengthening public transport in high-density urban areas (thus facilitating the shift of passenger travel to more efficient modes, such as urban rail and advanced bus systems) as well as extending the public transport network to less populated areas outside urban cores, such as rural areas (thus contributing to limiting the negative environmental impact of urban sprawl described above).

  For example, bus rapid transit (BRT) systems involve operating high-capacity buses in corridors that use private lanes isolated from the rest of the traffic. They have been built around the world in recent years and have proven cost-effective and highly effective at moving people, with boarding rates far above conventional bus systems, and approaching those of underground metro systems. If implemented widely enough, BRT can contribute to potential cumulative CO_2 savings of up to 0.5 gigatonnes (Gt) in the 2010 to 2050 time frame (International Energy Agency, 2012).

  Other mobility options for public transport include light rail, more bike lanes, increased pedestrian access and improved mini-buses.

  In addition to public transport targeted at urban and suburban areas, the railway network for long haul can be extended, improved and made more efficient, and therefore turned into a credible alternative to cars and trucks. This modal shift is also important as road transport is much more polluting than rail per tonne-km of goods transported (Santos, Beherendt and Teytelboym, 2010).

- *Introduce innovative car-sharing and carpooling schemes.*

  Car-sharing is a special type of car rental whereby users (who often are engaged in a dedicated arrangement by paying an enrolment and/or a membership fee) are provided with a vehicle for a short period of time (even by the hour). In addition to the short-term nature of the rental agreement, car sharing is characterised by a more or less extended network of vehicle distribution and a peculiar charging system, which can be based on duration of use or distance travelled. Carpooling (or ridesharing) consists in an arrangement whereby two or more individuals go to the same destination riding in one single car (which normally belongs to the driver or one of the passengers) instead of going to that destination with separate vehicles.

  Although car-sharing is normally the result of a business venture and carpooling is mainly driven by users themselves, governments can play a role in creating the conditions that facilitate such innovative schemes to flourish. For example, governments can give preference to shared cars through dedicated high occupancy vehicle (HOV) lanes.

  These schemes can be effective in reducing VKT, both by slowing the growth of car travel and by reducing the vehicle stock. However, the aggregate reduction in congestion and CO_2 emissions due to such schemes has not been measured with precision in the literature (Santos, Beherendt and Teytelboym, 2010).

Climate change and other environmental impacts of road transport can be reduced through a better use of vehicles

Cost-efficient solutions to reduce the negative environmental impacts of road transport can be achieved through initiatives aimed at re-educating drivers about the use of their vehicles, as well as by increasing the efficiency of transport through the use of information technology in transport systems:

- *Promote eco-driving.*

  Eco-driving can be achieved by influencing consumer and fleet owner behaviour in order to make the use of vehicles more efficient. It involves the following practices aimed at reducing fuel consumption: keeping the engine of a moving vehicle turning at between 2 000 and 2 500 revolutions per minute; decelerating and accelerating gently and avoiding prolonged idling; ensuring that tyres are correctly inflated and limiting the use of on-board electrical accessories, especially air conditioning (Kauppila, 2008). It does not necessarily require a new technology (although dashboard-mounted vehicles computers and other on-board devices can be useful) and demands negligible public funding.

  Countries that have introduced eco-driving initiatives as part of their national CO_2 reduction policy include Austria, Canada, Germany, Finland, the Netherlands and Sweden. Real world tests in half a dozen countries leading national eco-driving campaigns found an immediate mean reduction of 10% of CO_2 among the vehicles of volunteer participants, and the European Commission's European Climate Change Programme estimated in 2001 that adoption of eco-driving across the then 15 EU countries had the potential to remove 50 million tonnes of CO_2 per year from their combined road traffic emissions (Kauppila, 2008).

- *Apply information technology in road transport systems.*

  Applying information and communication technologies (ICTs) to transportation can spur innovations leading to significant environmental benefits, such as limiting congestion and reducing emissions. "Intelligent transportation systems" (ITS) can be defined as "the application of advanced and emerging technologies (computers, sensors, control, communications, and electronic devices) in transportation to save lives, money, energy and the environment" (ITS Canada, n.d.). They include a wide range of technologies and applications, which can also optimise driving behaviour by teaching motorists how to drive more efficiently (eco-driving, see above) (Ezell, 2010).

  Studies on the impacts of ITS on the environment show mixed results, mainly due to rebound effects (OECD, 2009a). However, ITS can give a significant positive contribution to improving the efficiency of public transport (as opposed to private passenger cars), thus making it more attractive for potential users and promoting a modal shift.

Make road transport sustainable in the long term by improving energy efficiency of vehicles

Notwithstanding the key role of the measures presented above, especially in a short- to medium-term horizon, improving the efficiency of vehicles remains an important priority in order to put transport on a sustainable path. And although there is potential for further carbon reduction of incumbent technologies, new low-carbon technologies will have to be developed and enter the mass market. Innovation will play an important role in this respect. It will lead to new ideas and technologies, but also to new entrepreneurs and business models, thus contributing to the establishment of new markets.

2. THE GLOBAL AUTOMOTIVE INDUSTRY: STRUCTURAL CHARACTERISTICS AND MARKET DYNAMICS

This section reviews the main structural characteristics and recent market dynamics of the global automotive industry, especially in light of the impact of the financial and economic crisis. Even before the crisis, the automotive industry was mature and had been characterised by slow growth in OECD countries. It was one of the most heavily hit sectors in the global recession, as demand for cars plummeted. Many OECD and non-OECD governments put in place measures both to support the industry directly and to encourage car sales. In a number of cases, governments made their support conditional on the production of more energy-efficient cars, or provided direct incentives to consumers to purchase green cars, through car scrapping and replacement schemes.

2.1 The automotive industry value chain

The global automotive industry is characterised by the presence of a limited number of large international vehicle manufacturers and integrators of systems and modules, as well as several suppliers of components and raw materials. The industry value chain is characterised by a structure in "tiers". Original equipment manufacturers (OEMs), which are responsible for the assembly of the final product, sell the vehicles under their brand names. Along the value chain, suppliers are ranked in terms of the complexity of the components they manufacture. First-tier suppliers typically supply OEMs directly, not only individual parts but also entire modules and sub-systems of vehicles.

Marketing and advertising is an integral and important step in the value chain. As the car is increasingly becoming more of a service than a product, carmakers increasingly focus their attention on brand management and customer relationships.

Once the assembly process is terminated, vehicles are distributed to dealers. Car dealership has become a thriving business on its own, where players fiercely compete to attract the attention of the customers by investing in advertising and offering special incentives. Dealers can therefore play an important role in influencing the choices made by purchasers in terms of vehicle model and technology. In this respect, the provision of objective and reliable information from dealers can be decisive in directing a potential buyer towards a specific technology over another. In this particular sector, independent reviewers also play an important role in shaping consumer preferences, for example through specialised magazines and Internet websites.[11]

2.2 Industry-specific characteristics and recent trends

The automotive industry is capital intensive, with a relatively high capital-to-labour ratio. The investment intensity (calculated as the ratio of gross fixed capital formation to value-added in the industry) is high across OECD countries: it is above 20% in 12 of the 24 OECD countries for which

[11] For example, Edmunds.com is the most popular site for independent car-buying advice in the United States (*The Economist*, 2012a).

data are available[12] (OECD, 2011d). However, segments of the value chain differ considerably in terms of factor intensities: for example, vehicle assembly and production of components with low technological content are relatively more labour intensive (Humphrey and Memedovic, 2003).

The industry has a significant weight in manufacturing value-added in several OECD countries,[13] but it is almost non-existent in other countries. The share of employment of the industry in total employment is relatively small, being above 2% only in the Czech Republic and Germany[14] (OECD, 2011d). These numbers understate the size of automotive-related employment, as they do not capture employment in the upstream and downstream parts of the value chain (Haugh, Mourougane and Chatal, 2010).

The automotive industry is highly globalised and export-oriented. In 2009 (or latest available year), exports of the automotive industry represented more than 15% of manufacturing exports in 11 OECD countries, and more than 20% in the Slovak Republic and Spain[15] (OECD, 2011d). However, the dominant pattern of trade of finished vehicles and parts is intra-regional. This is generally the case for heavier or bulkier products, products with a relatively lower labour content, and products that require a faster turnaround (Jen and Bindelli, 2008).

Rising material costs, falling car prices and ever stricter environmental regulations have increased pressure on carmakers to reduce costs in order to remain competitive. Focusing on cost reduction has led to important changes in the industry, in particular increasing competition but also consolidation between major car brands.

Stagnant sales in OECD countries, consolidation and product proliferation have contributed to excess capacity throughout the industry. In addition, increased competition has forced carmakers partly to shift their focus from vehicle manufacturing to design, brand management and customer relationships. Carmakers are also shortening product life cycles to compete for customer loyalty.

These shifts in market dynamics have had two major implications in recent years: modularisation, and outsourcing of an increasing amount of the value of the vehicle to suppliers. OEMs design vehicles so that they can share individual components, modules and systems. Therefore, several models are normally built around the same "platform". As they move towards modularisation and shift the core of their activities from manufacturing to other activities along the value chain, OEMs outsource more and more of the value of a vehicle to suppliers. The latter have to take on significant responsibility in designing and developing all the characteristics of the components whose production has been outsourced to them.

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12. Portugal (51.4% in 2006); Slovak Republic (45.8% in 2009); Poland (38.4% in 2006); Sweden (37% in 2008); Italy (34.9% in 2007); Hungary (32.4% in 2009); Slovenia (29.1% in 2008); Czech Republic (29.0% in 2009); France (28.4% in 2009); Spain (28.1% in 2007); Korea (24.3% in 2006), Germany (22.4% in 2008).

13. It accounted for more than 10% manufacturing value-added in Germany (13.09% in 2008), Czech Republic (12.8% in 2009), Japan (12.4% in 2008), Hungary (12.0% in 2009), Slovak Republic (10.7% in 2009), Mexico (10.6% in 2009) and Korea (10.0% in 2009).

14. 2009, or latest available year.

15. Slovak Republic (23.4% in 2008), Spain (21.8% in 2008), Japan (19.7% in 2009), Czech Republic (19.5% in 2009), Mexico (18.9% in 2009), Poland (17.9% in 2008), Canada (17.9% in 2008), Germany (17.1% in 2009), Hungary (16.4% in 2009), Slovenia (16.2% in 2009) and Turkey (15.6% in 2008).

These dynamics have led to a complex economic geography, whereby centrally designed vehicles are manufactured in multiple regions, and relationships between buyers and suppliers typically span multiple production regions (Sturgeon and Van Biesenbroeck, 2008). This has also contributed to accelerating the shift of production to emerging economies, especially in Asia (OECD, 2009b).

2.3 Market dynamics and impact of the crisis

Empirical studies suggest that the automotive industry closely follows the economic cycle for the economy as a whole. Motor vehicles are the largest component of durable consumer goods in terms of total household expenditure (apart from housing). This means that demand for them is highly correlated with the general business cycle, but the amplitude of the cycle is actually higher in the automotive industry (Haugh, Mourougane and Chatal, 2010). Even before the 2008 recession, the automotive industry was mature and had been characterised by slow growth in OECD countries. However, the situation of the automobile industry in the OECD context contrasts sharply with market dynamics in emerging economies, notably Brazil, China and India.

The industry has been one of the most heavily hit sectors in the global recession, as demand for cars plummeted. The correlation between the business cycle and the industry was exacerbated by tighter credit conditions following the subprime crisis in the United States housing market in 2008 and the sovereign debt crisis that started in Europe in 2010. Sales in North America, Europe and Japan were badly affected (OECD, 2009b).

OECD countries accounted for 90% of global car production in 1999, while Brazil, China, India, Indonesia and Russia only had a 9% share of world production. However, the situation had changed dramatically as of 2011: car production in the OECD area represented 56% of global production, while the same percentage for the above-mentioned emerging markets was 38%. Car production in OECD countries had already been stagnating for several years before the crisis, but dropped by 5% in 2008 and 22% in 2009, before picking up again in 2010 and stabilising in 2011 (with a 16% and 1% increase, respectively). Production in emerging countries grew briskly in 1999-2007, and proved highly resilient during the crisis (with growth rates of 8% in 2008, 22% in 2009 and 31% in 2010, with a slowdown to 6% in 2011).[16]

Medium-term perspectives for car sales are also likely to differ across countries, both within and outside the OECD. In the mature markets of Europe, North America and Japan, sales will probably remain stagnant. However, rapid increases are forecast for China and India. In China, trend sales increased from around 4 million yearly in 2005 to around 9 million in 2009. Actual sales are also rising rapidly in line with the trend, increasing from approximately 4 million in 2005 to around 7 million in 2008. Starting from a lower level than in China, trend sales are also increasing at a fast rate in India (Haugh, Mourougane and Chatal, 2010). Although trend market sales are forecast to increase worldwide, they will be mostly driven by emerging economies (Table 1).

16. OECD calculations based on OICA.

Table 1. Sales in the automotive industry

Thousands

	Trend market sales[1]	
	2009	**2015**
Korea[2]	1 147	1 333
Japan	4 770	4 616
Germany	3 436	3 533
Mexico	855	1 111
Spain	1 501	1 543
Canada	956	1 102
France	2 190	2 354
Belgium	500	518
Turkey	702	1 446
Sweden	339	398
Austria	424	449
Australia	923	974
United Kingdom	2 519	2 675
Italy	2 223	2 277
China	9 329	24 673
India	2 207	4 116
United States[3]	17 875	18 697
W Europe Big [4]	11 868	12 382
NAFTA [5]	19 686	20 910
Total of above countries	**51 895**	**71 816**

Note: Data refers to sales of cars unless otherwise noted.

1. All sales in that country's market including those produced domestically (by nationally and foreign-owned firms) and imports.
2. Excludes sales of imports.
3. Light vehicles as it includes vehicles such as SUVs (4x4s) defined as cars elsewhere.
4. Germany, France, Italy, Spain and United Kingdom.
5. Canada, Mexico and the United States.

Source: Haugh, Mourougane and Chatal (2010).

Many OECD and non-OECD countries have put in place measures both to support the industry directly and to encourage car sales. In a number of cases, governments have made their support conditional on the production of more energy-efficient cars, or have provided direct incentives to consumers to purchase green cars, through car scrapping and replacement schemes.

2.4 On the demand side: major shifts in consumer requirements

Although the main objective of public support during the crisis was arguably to provide a stimulus to the car industry and to the broader economy, these schemes may also have contributed indirectly to improving the energy efficiency of vehicles and have underscored market trends that had already emerged, such as:

- *Increasing environmental awareness of car buyers*. Although the perception of environmental impact of car usage is likely to vary from one country to another, public opinion in most countries acknowledges the importance of climate change and the need to introduce stricter regulations limiting carbon emissions.

- *Importance assigned by consumers to vehicle total cost of ownership (TCO) relative to upfront purchase prices.* BCG (2010) estimate that by 2020 mass-market car buyers will consider the TCO of electric vehicles (EVs) – and, it can be implied, of other types of green cars – against internal combustion engine (ICE) vehicles when making their purchase decisions. Hence, consumers will weigh the potential savings generated by AFVs over their lifetime against higher upfront purchase prices.[17] However, Van Dender and Crist (2011) note that, although the evidence is mixed, households typically wish to recover the investments made in better fuel economy within 2-3 years, which is a far shorter period than the expected lifetime of a vehicle (*i.e*. typically 15 years). Whether such consumer expectations regarding shorter payback periods are due to "hidden amenities" (*i.e*. features of the decision process that are hidden to analysts but matter to households) or to market failures (leading to consumer myopia) remains to be settled.

[17] According to recent research (BCG, 2011), some consumers may even be willing to pay a premium for an environmentally friendly car even if its total cost of ownership is not more favourable than that of an ICE car.

3. GREEN CARS: TECHNOLOGICAL CHARACTERISTICS, MARKET OUTLOOK AND BUSINESS MODELS

Identifying a market for green cars and analysing its development present daunting challenges for policy makers. First, the very concept of a market for green cars is difficult to pin down: the existence of separate and competing technology trajectories indicates that there are only limited spillover effects and cumulative benefits between R&D efforts in different market segments, and these segments are not fully substitutable. Second, the economic and environmental benefits of green vehicles are still very uncertain, and this leads to difficulties in appraising the potential market outlook. Several factors are slowing down the development of the market, and the deployment of green vehicle currently seems to be following the more conservative sales estimates.

3.1 Several technological options can improve the energy efficiency and reduce the environmental impact of cars

Although they started to garner significant attention starting from the oil-shocks of the 1970s, the history of green cars is as old as that of petrol-powered engines (see Box 2). Broadly, eco-innovations to improve the energy efficiency of vehicles and reduce their environmental impact have taken two main approaches. After the first failed experimentations with electric cars at the turn of the 20th century, early efforts were concentrated on improving the design of the conventional internal combustion engine, and subsequently on improving the design of vehicle characteristics that improve fuel consumption, other than the engine. More recently, eco-innovations of a more radical nature have enabled the emergence of entirely new types of propulsion and fuels that in some cases allow the combination of conventional and alternative technologies (Hasčič and Johnstone, 2011). Figure 8 summarises the different approaches.

These approaches aim mainly at improving fuel efficiency and reducing CO_2 emissions, but some can also have other positive environmental effects. At the same time, other measures can be taken to specifically tackle local air pollution caused by emissions from road transportation. These include post-combustion (after-treatment) devices, engine design measures, and changes in fuel characteristics. As noted by Hasčič and Johnstone (2011), there can be a trade-off between efforts to improve engine fuel efficiency and efforts to reduce emissions of local air pollutants.[18] However, this is less the case for AFVs which are the main focus of this report.

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[18] For example, the installation of catalytic converters in gasoline cars may reduce emissions of local air pollutants but increase fuel consumption. Likewise, the introduction of direct injection in diesel engines improves fuel economy but can have negative impacts on emissions of NO_X and PM.

Box 2. A brief history of green cars

Although the idea of "green vehicles" is relatively new, some of the technologies underpinning the concept are anything but. For example, the history of electric vehicles began in the 19th century, as carriages pulled by horses were gradually phased out as the main means of transportation. In fact, in the second half of 19th century different motoring technologies co-existed: steam machines (which were believed by some to be the future of cars, as it had been for locomotives), petrol combustion engines, and electric motors. At the beginning of the 20th century, 40% of American cars were steam-powered, 38% were electric and 22% were internal combustion. In 1904, one-third of all the cars on the streets of Boston, New York City and Chicago were powered by batteries. One of their advantages compared to vehicles with a combustion motor at that time was that no manual starting was necessary, making them particularly popular among female drivers. In 1900, there were 2 000 such vehicles on United States' roads.

The invention of the electrical start motor for combustion engines took away that advantage, contributing to a rapidly declining market share of electrical vehicles. When Henry Ford began producing petrol-powered internal combustion engine cars (the Model T in 1907), the trend in favour of electric car started to change, and was completely overhauled by 1920 as consumers favoured internal combustion engine vehicles, which could go further and faster, and could be fuelled with cheap and abundant petrol.

Interest in alternatives to conventional fuel-powered engines was revived after the oil shocks of the 1970s. After some first attempts to develop and commercialise hybrid and electric vehicles in the 1980s and 1990s, in the 2000s virtually all carmakers engaged in bringing alternative propulsion technologies to the market, including hybrid, but also battery electric and fuel cell vehicles.

Source: *Encyclopaedia Britannica* (n.d.); A.T. Kearney (2009); Presentation by Janet Milne of Vermont Law School at the Global Conference on Environmental Taxation in Madrid in October 2011.

Table 2 summarises the currently available AFVs solutions. The report focuses on vehicles that use alternative fuels (other than petrol or diesel) and/or alternative types of propulsion (other than the conventional internal combustion engine). Alternative fuels include biofuels, natural gas, hydrogen and electricity from the grid. Alternative propulsion systems include hybrid and electric engines. Vehicles using these technologies and fuels are referred to as "green cars".

However, it would be misleading to include only hybrid and electric vehicles in the "green car" category. Petrol- and diesel-engine vehicles are becoming much more efficient, to the point that the gap between CO_2-emissions from internal combustion engine (ICE) vehicles and those from hybrid and plug-in hybrid vehicles is forecast to be closing quite quickly (*The Economist*, 2011a). This makes it more complicated to predict future technology trajectories, and has important implications for carmakers' strategies and government policies. Therefore, the role played by energy efficiency and environmental improvements in ICE vehicles will be considered and reflected upon throughout the report.

Figure 8. Main approaches to reducing emissions and improving environmental performance of vehicles

Improved petrol- or diesel-fuelled ICEs vehicles

- **Improved engine efficiency (*e.g.* through engine design)**
  - Improvements in thermal efficiency (*e.g.* direct injection)
  - Electronically-controlled fuel injection and computerised engine management systems
  - Better control ignition timing
  - Reduction of friction loss
  - Downsizing
  - Expansion of lockup area
  - Expanded number of transmission gears
  - Continuously variable transmission
  - Air-to-fuel ratio sensors
  - Performance during vehicle idling, accelerating, cruising, decelerating (start-stop and cold start)
  - Improved combustion air and fuel conditioning
- **Improved vehicle design (by reducing aerodynamic drag and vehicle weight)**
  - Improved body configuration
  - Reduced vehicle size
  - Expanded use of lightweight materials
  - Improved body structure
  - Low rolling resistance tires
  - Electronic power steering

Alternative propulsion technologies and fuels

- **Alternative drivetrains**
  - Hybrid
  - Hydrogen (combustion, fuel cells)
  - Electric motors with battery
- **Alternative fuels**
  - Biofuels
  - Synthetic fuels
  - Liquified petroleum gas (LPG)
  - Liquified natural gas (LNG)
  - Compressed natural gas (CNG)
  - Hydrogen
  - Electricity (from external grid)

Source: OECD based on Hasčič and Johnstone (2011) and Abe (2011).

Table 2. Alternative systems of vehicle propulsion and fuel supply

			Type of propulsion		
			Internal combustion engine	***Hybrid system***	***Electric engine***
Type of fuel	***Liquid***	***Hydrocarbons***	Conventional gasoline/ diesel vehicle	Hybrid electric vehicle Hybrid hydraulic vehicle	Fuel-cell electric vehicle[1]
	Gaseous	***Hydrocarbons***	LNG/LPG vehicle		
		Hydrogen	Hydrogen vehicle		
	Grid electricity (external supply)		-	Plug-in hybrid vehicle	Battery electric vehicle

Note:

1. Fuel cell vehicles using hydrocarbons as primary fuel would require reformers. However, the technological characteristics currently foreseen for reformers make them unlikely to be suitable (and affordable) for cars.

Source: OECD based on Hasčič and Johnstone, 2011.

3.2 Alternative fuels include biofuels, gaseous hydrocarbon fuels, hydrogen and electric energy

Biofuels

Biofuels refer to liquid and gaseous fuels produced from biomass, *i.e.* organic matter derived from plants and animals (International Energy Agency, 2011c). Biofuels are mostly in liquid form and can be used to power combustion engines in road transport. Today two main types can be distinguished: bioethanol and biodiesel. With today’s first generation technologies, bioethanol is mostly produced from sugar cane, cereals and sugar beet. Biodiesel is derived from any source of fatty acids, such as soybean, rapeseed, palm oil and other vegetable oils but also from sources such as animal fats or used frying oils. They can also be blended with conventional fuels. Technologies are being developed that can make it possible to use cellulosic material, such as wood and plant stems and leaves, to produce so-called “second generation” bioethanol and to enable the use of any type of biomass to produce synthetic fuels. These technologies are currently still very expensive for transport use, but there is considerable potential for their commercial application over the medium term (OECD/IEA, 2007).

Although biofuels are commonly divided into first-, second- and third-generation, a categorisation of biofuels can be based on different criteria, such as technology maturity, GHG emission balance or the feedstock used. The International Energy Agency (2011c) uses a definition based on the maturity of the technology, and accordingly classifies biofuels as “conventional” or “advanced”. Conventional biofuels (which correspond to those that are commonly referred to as “first-generation”) are already being produced on a commercial scale through well-established processes. Feedstocks used for their production include sugarcane and sugar beet, starch-beating grains like corn and wheat, oil crops like rape (canola), soya bean and oil palm, and in some cases animal fats and used cooking oils.

Advanced biofuel technologies (commonly referred to as second- or third-generation) are still in the R&D, pilot or demonstration phase. They are produced from non-food feedstocks such as cellulose, hemicellulose or lignin. Advanced biofuels face significantly higher capital and production costs; in order for them to be commercially deployed, substantial further investments in RD&D and specific support for commercial-scale advanced biofuel plants will be required (International Energy Agency, 2011c).

The use of these alternative fuels requires only minor technical modifications to the conventional ICE vehicle, in particular the development of dual-fuel or flexible-fuel (flex-fuel) vehicles capable of running on conventional petrol or diesel, an alternative fuel or a combination thereof.

The production and use of biofuels for road transport has had a mixed reception. The extent to which biofuels are really carbon neutral is subject to considerable ongoing debate. Concerns have been raised about their neutrality over the entire life cycle of the product, the need to take into account land-use change resulting from conversion of land to biofuel production and whether or not "neutrality" requires additionality of carbon sequestration over and above that which would have taken place in any case. Another concern is the flow-on effect of increased biofuel crop cultivation on food prices (OECD, 2012c).

Gaseous hydrocarbon fuels: natural gas (CNG and LNG) and LPG

Gaseous hydrocarbons can also be used as alternative fuels, under two main forms:

- *Natural gas.* Its high calorific value and low CO_2 content make natural gas attractive as a fuel for the transport sector, but its low energy density requires compression or liquefaction (International Energy Agency, 2012). Compressed natural gas (CNG) and liquefied natural gas (LNG) are predominantly made up of methane, but CNG is stored as a gas at high pressure, while LNG is stored in an uncompressed liquid form. CNG is more commonly used for light-duty vehicles, while heavy-duty vehicles require more energy to run and tend to use LNG to maintain an acceptable range (Nijboer, 2010).

- *Liquefied petroleum gas (LPG)* is a mixture of several gases commonly called “propane” after the main ingredient. It changes to liquid state at moderately high pressures.

Gaseous hydrocarbon fuels require the development of onboard pressurised storage systems. Vehicles fuelled by gaseous hydrocarbons can be manufactured by carmakers directly, or result from retrofitting of conventional ICE vehicles.

Natural gas vehicles (NGVs) and fuel technology are almost cost competitive with conventional powertrains, and present distinct advantages over electric powertrains. NGVs have lower GHG emissions than today's gasoline-powered ICEs. The comparison with diesel vehicles, however, depends on the type of vehicle (*e.g.* passenger car or heavy-duty vehicle). Local emissions from NGVs, namely unburnt hydrocarbons, NO_X and particulate matter, are generally lower than from either diesel or gasoline engines (International Energy Agency, 2012).

Hydrogen

While hydrogen had been used as energy vector in the past and the vision of a hydrogen-based economy saw the light after the oil shocks of the 1970s, interest in hydrogen in road transport has been revived since the late 1990s thanks to advances in fuel cell technology. The chemical energy of hydrogen can be transformed into mechanical energy either through thermal expansion in an ICE, or into electric energy without combustion through a fuel cell. Unlike the ICE, fuel cells convert chemical energy into electric energy directly (Ball and Wietschel, 2009).[19]

As a fuel for road transport, hydrogen requires an on-board storage system or a system for the production of hydrogen from hydrocarbon fuels (*e.g.* steam reforming, shift reaction) (Hasčič and Johnstone, 2011).

Hydrogen is not an energy source in itself, but a secondary energy carrier. Therefore, the advantages of using hydrogen as a fuel in terms of environmental impact, emission reduction and energy security depend crucially on how it is generated. Because hydrogen creates neither carbon emissions nor air pollutants at the point of final use, it has a great potential for reducing the impact of road transport on climate change and environmental degradation, if produced exclusively from renewable energy sources.

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[19] In fuel cells, electricity and water are usually produced from hydrogen and oxygen in an electrochemical reaction which also releases heat. Different fuel cell types exist which do not require hydrogen as a fuel. However, the high electricity to heat ratio and the high overall conversion efficiency of fuel cells powered by hydrogen makes it almost inevitable that hydrogen and fuel cells will enter the road transport sector together in the long run (Ball and Wietschel, 2009).

Electric energy

Electricity supplied from outside the vehicle (*i.e*. from the grid) can be used as a fuel for propulsion systems other than the ICE. This requires on-board storage systems in the form of a rechargeable battery, originally lead acid batteries (which are currently the standard vehicle battery) and, since the 1980s, nickel-cadmium batteries, later replaced by nickel-metal hybrid batteries. None of these battery technologies provide enough energy density to drive in pure electric mode for long distances. Lithium-ion batteries are considered to be most promising storage systems and are likely to remain so for the coming decade. Other non-chemical energy storage devices are super-capacitors and flywheels (Valentine-Urbschat and Bernhart, 2009).[20]

Like hydrogen, electricity is a secondary energy carrier, and any benefit in terms of GHG emissions, air pollution or security of supply will depend on a full calculation of the entire production and consumption life cycle of the fuel.

3.3 Alternative propulsion systems include hybrid systems and electric engines[21]

Hybrid powertrains

Hybrid powertrains combine two or more energy storage systems, both of which must provide propulsion power, either together or independently. The ICE is typically the primary system, coupled with another propulsion system. The latter may include, for example, hydraulic motors and pumps and rely on a hydraulic energy storage system (rather than a battery). However, currently the main propulsion system coupled with ICE in a hybrid powertrain is an electric engine (International Energy Agency, 2009).

Hybrid-electric vehicles (HEV)

In hybrid-electric powertrains, the ICE is typically the primary system, with the electric motor used to power the vehicle for short distances or to support the main engine (for example at a stop light) (Hensley, Knupfer and Pinner, 2009). The energy storage system is recharged automatically by the engines (where the load is low) and from regenerative braking. Through regenerative breaking, energy that would normally be dissipated as frictional heat is captured and stored in batteries as electric power.

HEVs can be classified according to different criteria. Broadly, HEVs can be either mild or full hybrids, and full hybrids can be further categorised on the basis of the type of powertrain as series, parallel and combined.

A mild hybrid (also called micro hybrid) is the least electrified type of HEVs. An electric motor assists the ICE, but the vehicle cannot be powered by electricity alone. In addition, the motor/generator (powered by the electric battery) can be used to enable idle stop, so that the engine shuts off at stop lights and stop-and-go traffic. Mild HEVs can also make use of regenerative breaking.

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20 Although these devices cannot compete on range with plug-in hybrids, which can travel long distances on electric power alone, flywheel hybrids could provide a cost-effective technology to make cars more fuel-efficient until the technology of electric vehicles matures (*The Economist*, 2011b).

21 Internal combustion engines alone can also be "cleaner" if used with fuels that have lower carbon content than gasoline or diesel. As seen in the previous sub-section, these include biofuels, natural gas and hydrogen.

At low loads, the motor/generator increases load on the engine and recharges the electric battery (Hybrid Center, n.d.; MIT Electric Vehicle Team, 2008).

As for full HEVs, in all cases the electric motor is powered from a battery pack that is recharged by the ICE. In a series configuration, the ICE charges a battery that delivers power to the wheels. The ICE is used exclusively to generate electricity, not to power the wheels directly via the transmission. In a parallel powertrain, both the electric motor and the combustion engine can provide power to the wheels. Finally, in a combined series-parallel hybrid system, the engine can both drive the wheels directly (as in parallel drivetrain) and be effectively disconnected from the wheels, so that only the electric motor powers the wheels (as in the series drivetrain). A power-splitting device enables the use of both an ICE and one or more electrical motors depending on the driving conditions and the state of charge of the battery (EVAAP, n.d.; Hybrid Center, n.d.; International Energy Agency, 2009).

When hybrids use the battery as the main energy source for daily trips but use an ICE (or any other propulsion system) to sustain the battery and extend the range, they are sometimes called range-extended electric vehicles (REEVs). The range extender is an autonomous auxiliary power unit added to pure electric drive vehicles to extend the operational range beyond that obtained in pure electric mode.

Plug-in hybrid-electric vehicles (PHEV)

The main difference between PHEVs and simple HEVs is the possibility to charge the battery of a PHEV through an external supply of electricity (*i.e*. the grid) into which the vehicle can be plugged. They require electrical motors with sufficient power to drive the vehicle on their own in different driving conditions. They also require more battery capacity to increase the vehicle range on battery power and provide more motive power (International Energy Agency, 2009). In fact, they have a larger battery pack than conventional HEVs, which makes it possible to drive for an extended range using just electricity. The size of the battery determines the vehicle's "all-electric range", *i.e*. the distance that can be travelled using just electricity (MIT Electric Vehicle Team, 2008).

PHEVs rely mainly on stored electricity in the so-called charge-depleting mode. This is especially appropriate for urban commuting: for example, a driver can commute to and from work on all-electric power, and charge the vehicle at night by plugging it to the external grid, so that it will be ready for the same journey the following day (the vehicle can also be charged while it is stationed at the workplace). But PHEV can also work in the same way as conventional HEVs (in the so-called charge-sustaining mode), so that when the battery is relatively low (for example on longer trips), the ICE can recharge the battery (International Energy Agency, 2009). They can also be charged through regenerative breaking, with the electric motor acting as a generator, using the energy to charge the battery.

Electric powertrains

Electric vehicles (EVs) are entirely powered by batteries, without any ICE. They can be powered by electricity from the grid in the case of pure battery electric vehicles (BEVs) or by the conversion of chemical energy contained in hydrogen into electricity, in fuel cell electric vehicles (FCEVs).

Battery electric vehicles (BEV)

BEVs have only one storage system (a battery) and no primary on-board means of generating electricity. There are two options for power supply: either charging the battery by plugging the vehicle to an external electricity source, or exchanging the used battery for a new (charged) one (Hensley, Knupfer and Pinner, 2009). Of course, BEVs also possess the technologies that are typical of electric engines, including regeneration of deceleration energy (*e.g.* regenerative breaking), automatic engine shutdown (start-stop mode) and optimisation of engine drive conditions.

With a BEV, the use of electricity involves transport by the grid, storage in a battery and final transformation to mechanical energy by an electric motor. Starting with 100 kWh of electric power, it loses only 26 kWh, leaving 74 kWh available for propulsion. If renewable electricity is used, the BEV pathway is more than twice as efficient as the hydrogen FCEV pathway (International Energy Agency, 2012).

Fuel cell electric vehicle (FCEV)

Like BEVs, FCEVs use electricity to power motors that drive the wheels. However, FCEVs produce their electricity using a fuel cell, which is powered by filling the fuel tank with hydrogen (US Department of Energy, 2011a). For hydrogen used in FCEV, renewable electricity generates hydrogen via electrolysis. Then the hydrogen is compressed and loaded into the vehicle. On board the FCEV, hydrogen is re-electrified usign a fuel cell. Out of the original 100 kWh of electricity, only 31 kWh will be used for vehicle propulsion in the end (International Energy Agency, 2012).

A fuel cell is a device which transforms the chemical energy of hydrogen into electric energy without combustion. Several types of fuel cells exist or are being developed, all with different electrode materials, electrolytes and membranes (Hasčič and Johnstone, 2011). However, the dominant vehicle application is the proton exchange membrane or polymer electrolyte membrane (PEM) fuel cell, which uses hydrogen fuel and oxygen from the air to produce electricity (U.S. Department of Energy and U.S. Environmental Protection Energy, 2012a). They operate at relatively low temperatures (about 80 degrees), have a high power density (*i.e.* generate more power per volume) and can vary their output quickly in order to meet demand. They are available in a range of sizes suitable for both cars (60 kW to 80 kW) and large trucks (up to 250 kW), with efficiencies of around 50% (International Energy Agency, 2012).

Comparison of AFVs technologies based on the driving range, refuelling time, type of driving and infrastructure requirements

Because of their specific characteristics in terms of the driving range, refuelling time, type of driving and infrastructure requirements, different AFVs technologies can be more or less suited to different types of trips, especially with with regard to their length. Table 3 compares AFVs technologies on the basis of their driving range and the type of trips for which they can be used.

Table 3. Comparison of AFVs technologies based on driving range and type of trips

AFV Technology	Vehicle Range in 2015	Refuelling time in 2015	Type of driving	Infrastructure requirements
Battery Electric Vehicles	Minimum necessary range may vary by region – possibly significantly lower in Europe and Japan than in North America, given lower average daily driving levels. 100 km to 150 km may be a typical target range in the near term.	8.1 hour at 3kW / 30 minutes at 50 kW.	Urban driving, given the short distances and the high value of eliminating vehicle pollutant emissions in the urban context. Can be used for driving longer distances, conditional on the development of public-access charging infrastructure, and eventually either fast-charging facilities or battery swap centres.	Home-charging or public-access charging infrastructure. Network of battery-swapping stations.
Plug-in hybrid electric vehicles	PHEV optimal battery capacity (and range on grid-derived electricity) may vary by market and consumer group. Range is around 700 km.	2.6 hours at 3kw / 27 minutes at 50 kW. Gas: 3 minutes.	Can be used for long trips thanks to a combination of a primary system (typically the ICE) and an electric motor that can be used for short distances.	Existing refuelling infrastructure for ICE; home-charging or public-access charging infrastructure for battery (but less important than for BEVs).
Fuel cell electric vehicles	500 km.	5 minutes.	Could be used for longer trips thanks to hybridisation. Use of fuel cells alone for longer trips is conditional on the development of public-access hydrogen refuelling infrastructure.	Network of hydrogen refuelling stations (where hydrogen can be produced on-site using electrolysers).
Natural gas vehicles	Because most existing NGV models favour better loading space over cruising range, the latter is between 180 and 450 km.	Fast-fill stations: less than 5 minutes for 20 gallon equivalent tank. Time-fill stations: from several minutes to many hours (depending on number of vehicles, compressor size, and amount of buffer storage).	Can be used for long trips, although the range is shorter than ICEs.	Network of natural gas refuelling infrastructure.

Source: International Energy Agency (2012); International Energy Agency (2010); IEA (2009); Wang-Helmreich and Lochner (2012); U.S. Department of Energy (2012a); U.S. Department of Energy and U.S. Environmental Protection Agency (2012b).

3.4 The market outlook for green cars is still very uncertain

Green cars are generating increasing interest among policy makers, carmakers and users, but their market penetration is still relatively low. In addition, there are significant differences in the diffusion of alternative fuels and propulsion technologies across countries.

Although their diffusion is slowly increasing, green cars will likely command only a small share of the automotive market in the coming years, relative to total world vehicle sales. In addition, a high degree of uncertainty surrounds market developments for different products and technologies, particularly with respect to which product and technology will emerge as the most widespread.

Gasoline-fuelled ICE still dominate the light-duty vehicle (LDV) market, with diesel in OECD Europe and India, flex-fuel in Brazil, and LPGVs in Korea being notable exceptions. The share of gasoline-powered vehicles in the worldwide stock of LDVs decreased from 90% in 2000 to 80% in 2010. In some regions (*e.g.* Europe), diesel engines have gained significant market shares, thanks to higher efficiency and advantageous fiscal and exhaust emissions policies. Among non-OECD countries and regions, India has the highest passenger LDV diesel market share. Globally, diesel sales have risen from 5% in 1990 and 8% in 2000, standing at 13% in 2010 (International Energy Agency, 2012).

It is almost universally believed that ICE vehicles will continue to dominate the market (and that they will become increasingly more energy efficient and hopefully less pollutant) in the next 10 to 15 years. Some forecasts for hybrid vehicles are quite optimistic, although they are considered to be a "bridge technology" to full EVs or PHEVs for long-distance trips (IEA IA-HEV, 2011). In fact, there is a growing belief that, eventually, also PHEV could act as a bridging technology between conventional powertrains and full BEVs (AEA, 2009).

The experience of the deployment of HEVs can give some useful lessons for the market development and consumer uptake of other AFV technologies, in particular PHEVs and BEVs (see Box 3). HEVs became available in global markets in 1997, and it took until 2010 to reach 1% of the world's sales share. However, judging by government policies in some countries and by the strategies of some carmakers, there are hopes that BEVs can become widespread in the market in a shorter period than the experience of HEVs would suggest.

Box 3. Lessons from the market deployment of HEVs

Deployment of BEVs in the market could occur faster than that of HEVs for the following reasons:

- HEVs created an impetus for manufacturers to expand their production lines beyond traditional engines and fuel options, with expanded consumer choices.
- The ability to produce hybrid vehicles was not widespread in 1998, and it took many years for a significant number of models to become availbale. That number is still fairly low and has already been surpassed by the number of BEV models available.
- Recently enacted sustainability goals and fuel economy standards will put additional pressure on manufacturers and consumers to lower CO_2 emissions per km.
- Rising oil prices may encourage consumers to shift away from fossil-fuel based vehicles toward other energy sources with potentially more stable fuel prices and better efficiency.
- Governments have put in place ambitious programmes involving significant funding to manufacture vehicles, deploy infrastructure and reduce costs to consumers.

Source : International Energy Agency (2012)

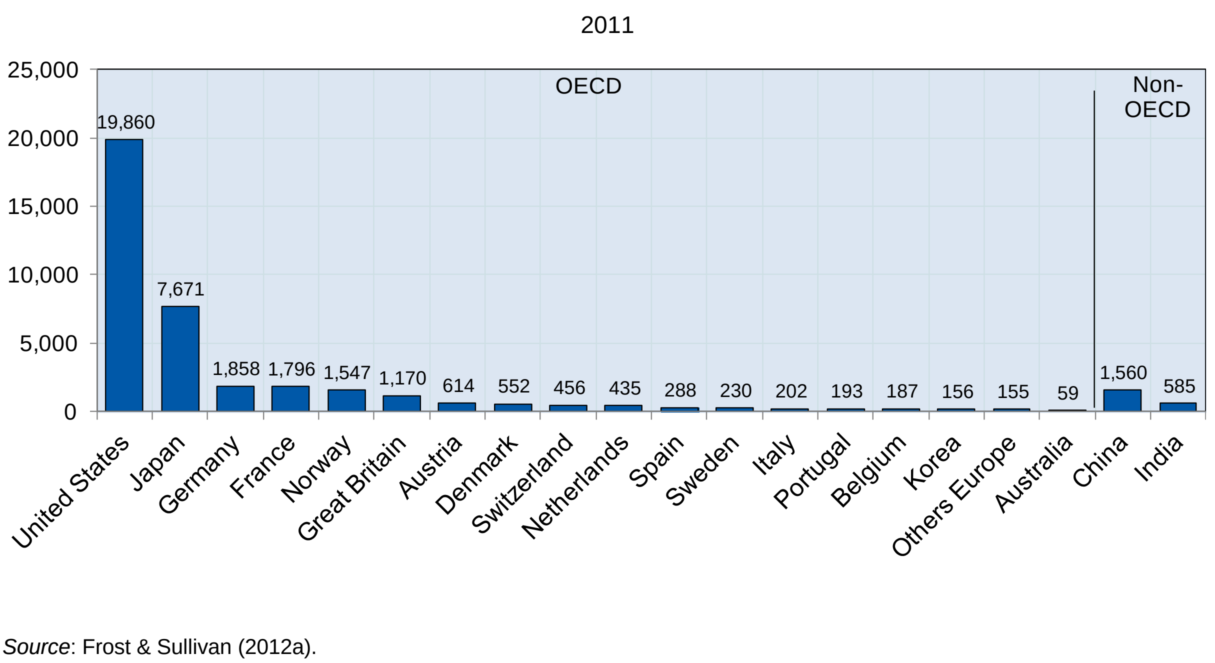
Hybrid and electric powertrains have attracted the most attention, therefore data on sales concentrate mostly on these technologies. Frost & Sullivan (2012a) estimates that global EV sales in 2011 amounted to around 43 000 vehicles. This figure was lower than expected, due to delays in planned new model launches by carmakers and the March 2011 earthquake in Japan. But despite low sales, 14 EV models were launched globally in 2011. It is perhaps encouraging that the number of EVs sold in 2011 matches the number of HEVs sold in six years (from 1997 to 2003) (IEA, 2012).

A breakdown of 2011 sales for a selection of OECD and non-OECD countries shows that the United States is by far the biggest market for EVs, followed by Japan and some European countries (Figures 9 and 10). Relative to the size of the population, market penetration of EVs appears to be particularly strong in a number of European countries, especially Norway, Denmark and, to a lesser extent, Austria. On the other hand, sales were very low in Asia and the Pacific, except for Japan.

As regards the growth of the market, although ICE vehicles still dominate and will continue to do so in the next decade, sales of green cars are forecast to grow. Automakers launched 25 green car models between 1997 and 2007, and major automakers and new EV developers are scheduled to introduce over 50 EV models by 2015 (Cleantech, 2011a; Conley and Hickman, 2008). Several forecasts of future sales have been made, coming from different sources. Frost & Sullivan (2012b) surveyed a number of these forecasts and compared them to their own projections. Forecasts of sales of EVs as a percentage of total car sales in 2020 range between 10%–12% in the more optimistic scenarios and 2%–4% in the more conservative scenarios (Figure 11).

The consensus on the limited size of the estimated market in the coming decade has important consequences for the potential for economies of scale, a crucial factor for the widespread adoption of EVs. These volumes are perhaps too small to trigger effectively economies of scale and to recoup development and manufacturing investment (OECD, 2011e).

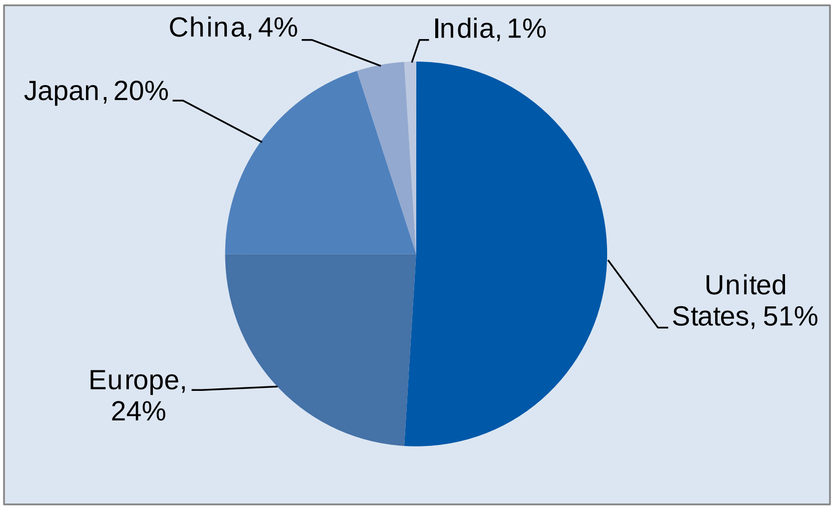
Figure 9. Electric Vehicle Market: Electric Vehicle Sales (World)



Source: Frost & Sullivan (2012a).

Figure 10. Electric Vehicle Market: Breakdown by Region

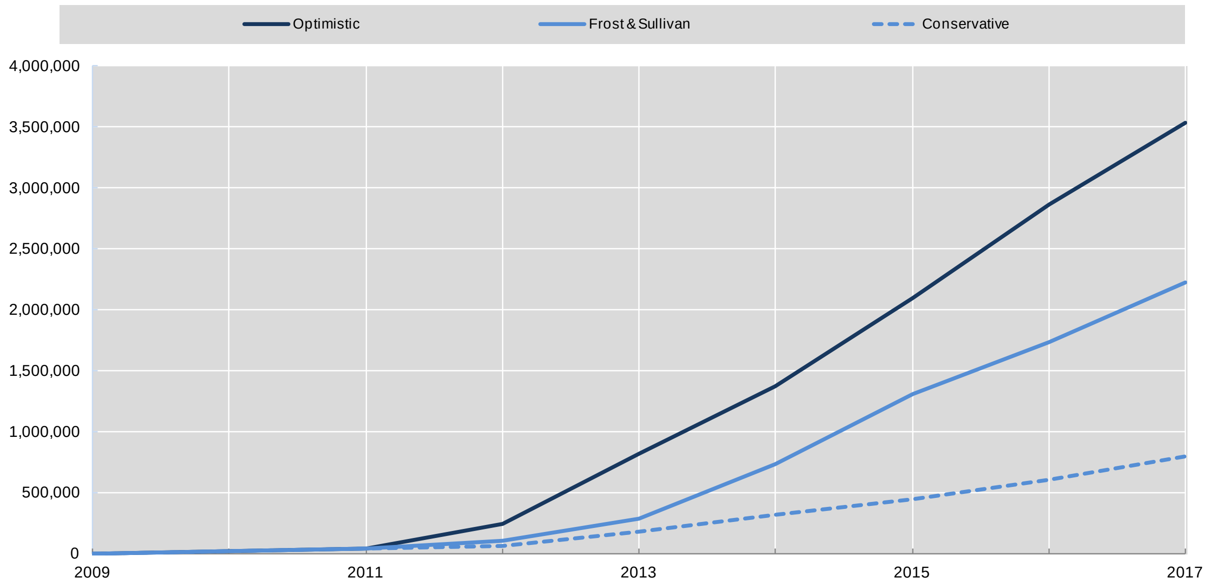
2011



Source: Frost & Sullivan (2012a).

Figure 11. Electric Vehicle Market: Sales Forecasts Scenario Analysis (World)

2009-17



Scenarios	2009	2010	2011	2012	2013	2014	2015	2016	2017	2020 (% of total car sales)
Optimistic	5,060	16,100	43,200	248,400	816,200	1,373,200	2,094,800	2,865,200	3,531,500	10-12%
Frost & Sullivan	5,060	16,100	43,200	110,100	286,500	735,800	1,314,300	1,741,000	2,228,400	5-7%
Conservative	5,060	16,100	43,200	66,500	178,600	318,300	451,000	602,400	796,800	2-4%

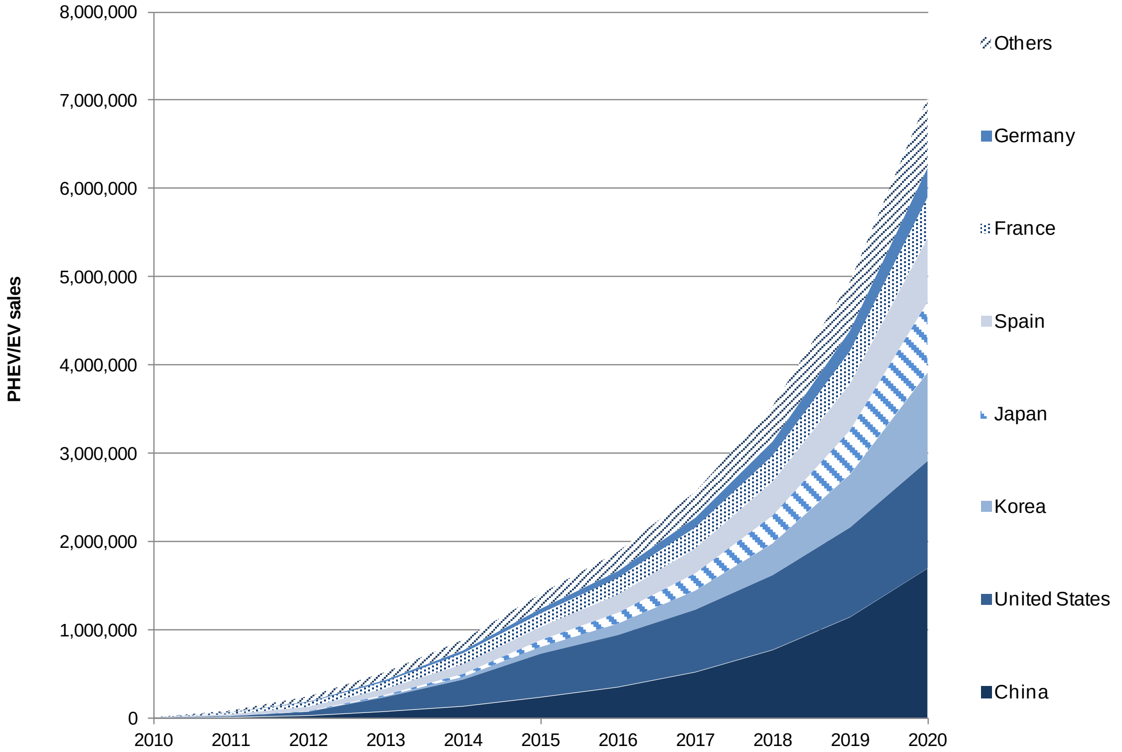
Note: All figures are rounded; the base year is 2010.

Source: Frost & Sullivan (2012a).

As regards the diffusion of EVs and PHEVs in individual countries, projections by the Electric Vehicle Initiative (EVI) based on announced goals of its member countries show that the United States should maintain the lead in the number of vehicles on the road, but China could also become an important market in terms of sales (Figures 12 and 13). Governments in OECD and non-OECD countries have adopted ambitious targets for sales of EVs. However there seem to be a strong divergence between government targets and expected production and sales as announced or reported by car manufactures, with the former largely surpassing the latter (Figure 14). Even if the cumulative target of 20 million EVs is reached by 2020, this will only represent 2% of vehicles worldwide, and will therefore constitute the "take-off" point. Intermediate and long-term targets will not be met without adequate preparation and ramp-up time.

Figure 12. Projected EV and PHEV sales, based on national targets

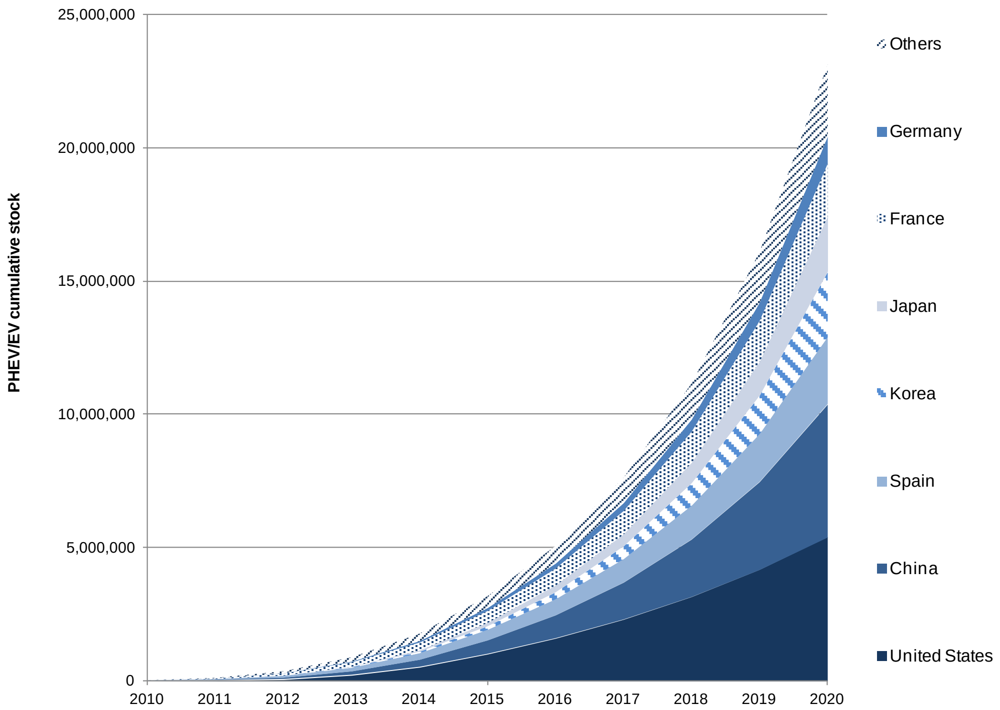
2010-20



Source: Electric Vehicles Initiative (EVI), http://www.iea.org/evi/index.asp.

Figure 13. Projected EV and PHEV stock (cumulative sales), based on national targets

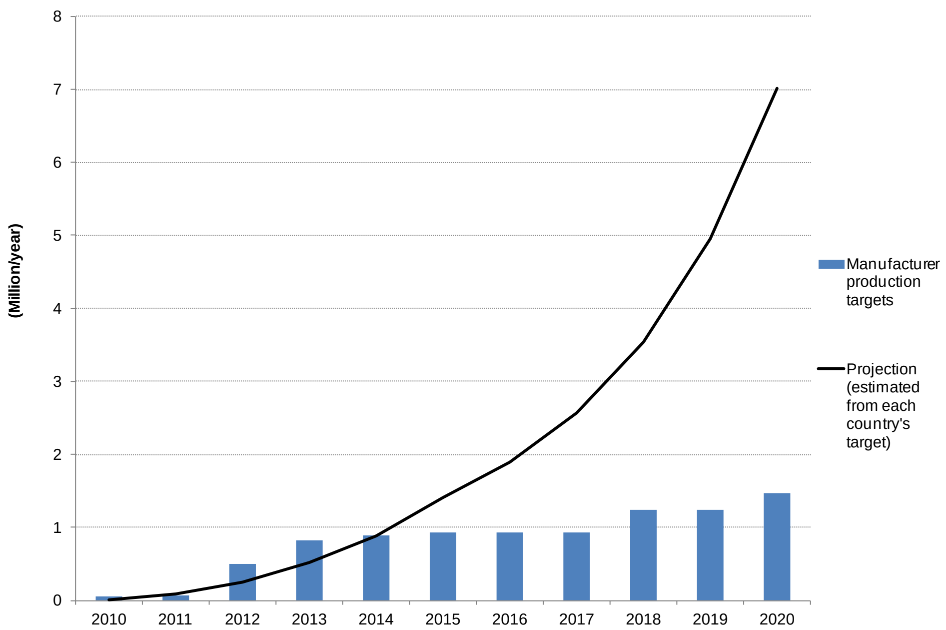
2010-20



Source: Electric Vehicles Initiative (EVI), http://www.iea.org/evi/index.asp.

Figure 14. Government targets and EV/PHEV production/sales as reported by OEMs

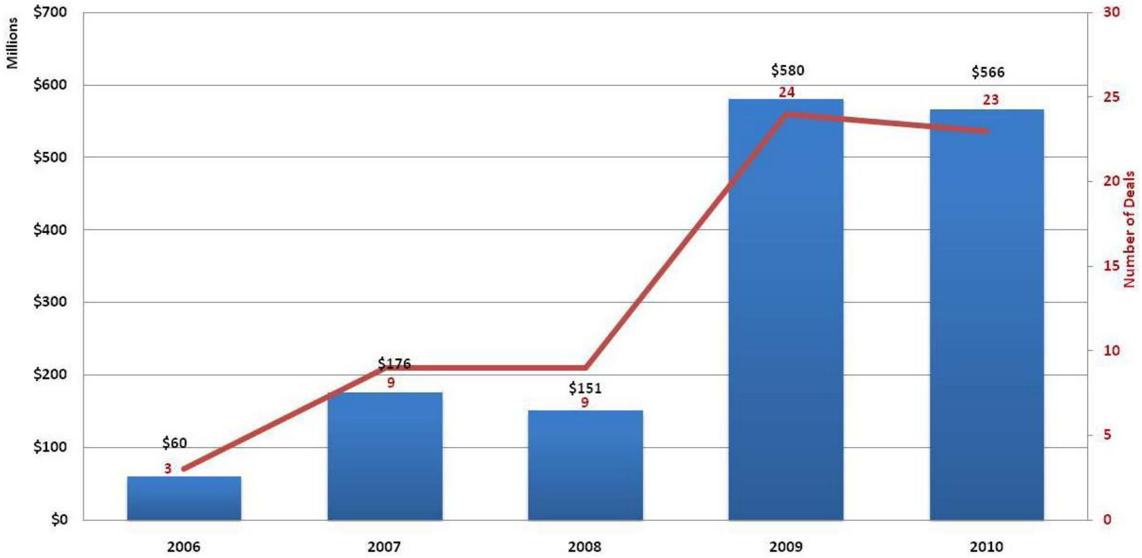
2010-20



Source: Electric Vehicles Initiative (EVI), http://www.iea.org/evi/index.asp.

Figure 15. Cleantech VC investment in EVs

2006-10



Source: Cleantech Group Market Insight Database.

The momentum behind HEVs and EVs is also witnessed by an increasing interest from investors. Venture capitalists invested USD 1.5 billion in electric and hybrid vehicle start-ups between 2006 and 2010, the majority of which was in 2009-2010 (Figure 15) (Cleantech, 2011a).

Although much of the public's attention and carmakers efforts have been devoted to electrification (and hybridisation), the use of other alternative fuels for ICEs has also been growing steadily, especially in certain regions.

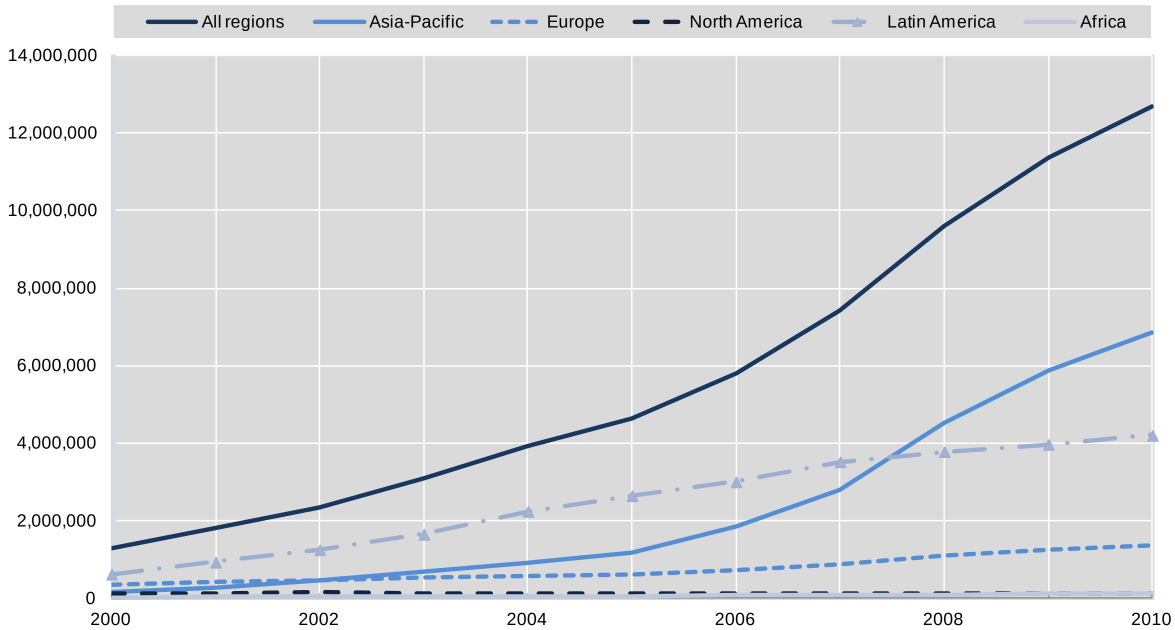
For example, figures from the International Association for Natural Gas Vehicles show that the global number of vehicles propelled by natural gas grew on average by 24.2% in the decade 2000-10. This growth was driven mainly by the Asia-Pacific region (42.1% average growth) and Latin America (18.2%), followed by Africa (15.3%) and Europe (14.1%). In North America, the number of natural gas vehicles (NGVs) actually decreased slightly (Figure 16). In 2011, there were 15.2 million NGVs on the roads, representing 1.2% of total vehicle stock. In some countries, natural gas plays an important role, with the market share of NGVs exceeding 10%: Armenia, 77%; Pakistan, 64%; Bolivia, 23%; Iran, 18%; Bangladesh, 18%; Argentina, 15% (IANGV, 2012).

At the same time, the transport sector is a minor consumer of natural gas, relative to other sectors: in 2009 it represented 1% of world total primary natural gas demand, with peaks in Brazil (10%) and India (4%). Primary natural gas demand for transport was 1% of the total in OECD Asia Oceania, and 0% in all other OECD regions (International Energy Agency, 2012).

Data for the United States show that in 1995-2009, CNG grew to be the most widespread alternative fuel used in green cars, having surpassed LPG and well ahead of biofuels, electricity and hydrogen (Figure 17).

Figure 16. Natural gas vehicle fleet, global and by region

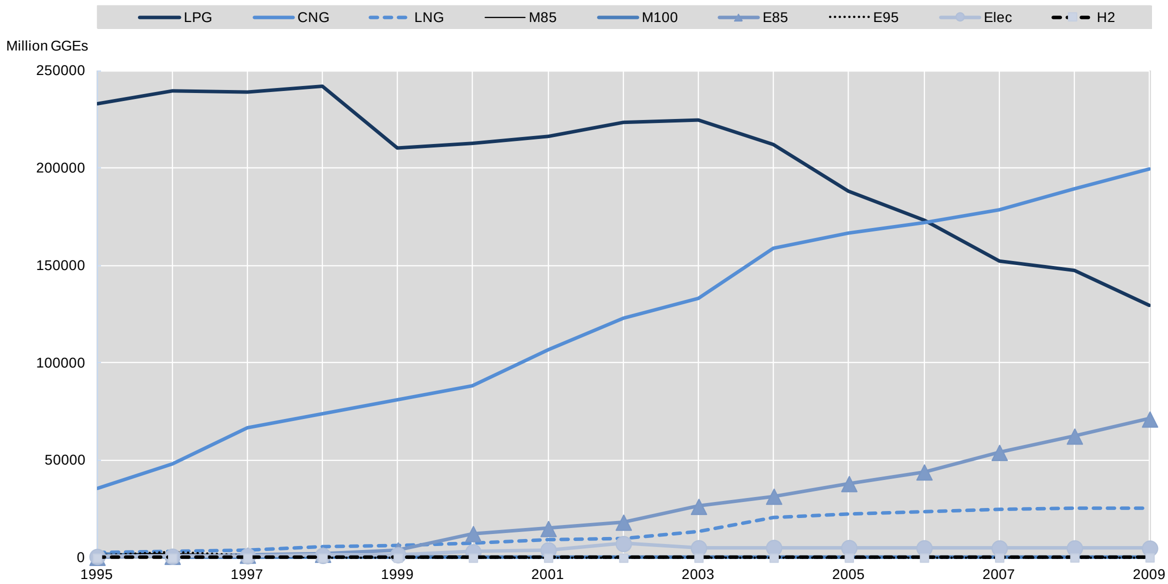
2000 - 2010



Source: IANGV (2012).

Figure 17. Estimated Consumption of Alternative Fuel by AFVs in the U.S.

1995 - 2009



Notes:

1. For Ethanol 85% and Ethanol 95%, the remaining portion is motor gasoline. Consumption data include the motor gasoline portion of the fuel.
2. "Electricity" excludes electricity generated and used by hybrid electric vehicles.
3. 2009 numbers are preliminary.

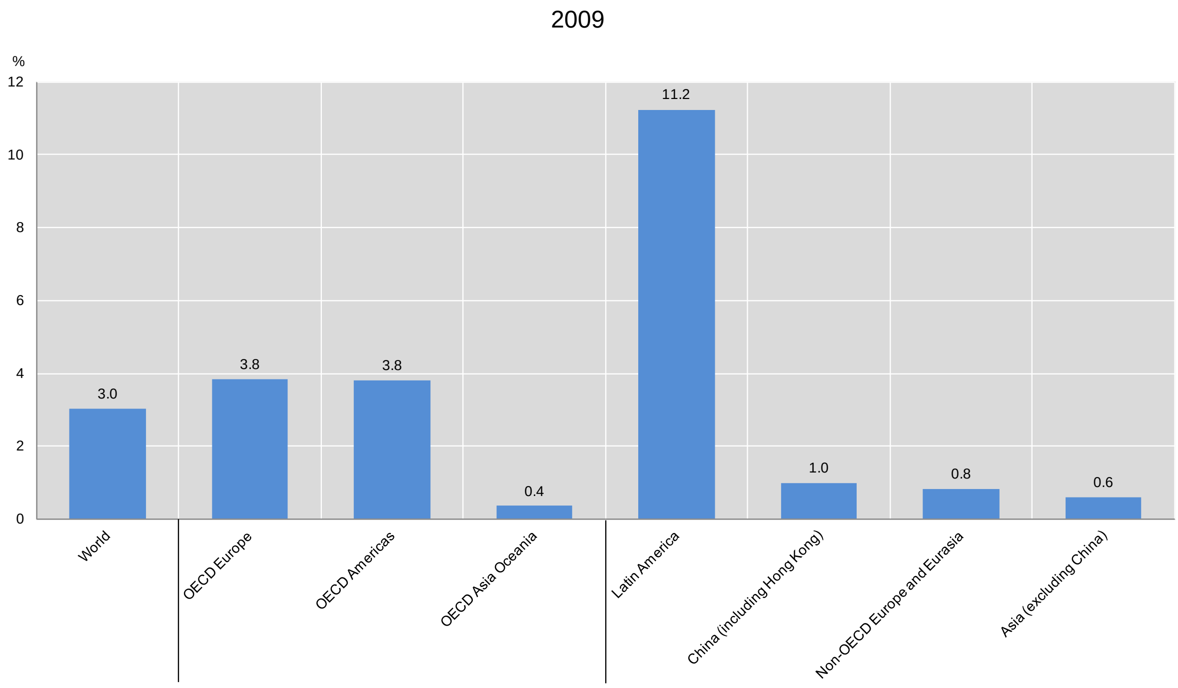
Source: U.S. Department of Energy (2012b).

As regards biofuels, in 2009 their share in total road transport fuel was particularly high in Latin America, at 11.2% (Figure 18). Biofuels have a significant share in Brazil (3%) and an increasing share in the United States (4%) and the European Union (3%) (International Energy Agency, 2012). In the OECD context, use of biofuels for road transport was relatively high in North America and Europe, compared to Asia.

Installed advanced biofuel capacity (lignocellulosic ethanol, biomass-to-liquid and other types) today is less than 200 million liters per gasoline equivalent (Lge), with most plants operating well below capacity. Another 1.9 billion Lge/year production capacity is currently under construction and projects for an additional 6 billion Lge annual capacity have been announced[22] (International Energy Agency, 2012).

Blending mandates for transport fuels and financial incentives have driven the rapid growth in the biofuels sector over the last ten years, but high feedstock prices, overcapacity, changing government policies and public discussion on the sustainability of biofuels have recently slowed this growth. For example, in Brazil bioethanol production dropped by 15% in 2011, due to poor sugar cane harvest and resulting high sugar prices. In the European Union, overall biofuel production continues to grow, but the biodiesel sector is struggling with plant utilisation rates of around 50% of production potential (International Energy Agency, 2012).

Figure 18. Share of biofuels in total road transport fuels, selected regions and countries



Source: IEA (2011a).

As regards hydrogen-fuelled vehicles, FCEVs are currently in the demonstration phase, but some car manufacturers claim they will start commercialisation in 2015. Today about 650 FCEVs are on the

22 . Given the industry's volatile nature and limited operational history, many of these facilities may experience delays and cancellations, or begin with lower production rates.

road worldwide, of which around 200 are buses (Table 4). Initial demand for end-use hydrogen in the transport sector is likely to come from fleet vehicles, such as city buses, commercial fleets or taxis, because they can be centrally fuelled and hence generate sufficient demand to justify investing in a supply system (International Energy Agency, 2012).

Table 4. Hydrogen vehicles in today's leading countries

	United States	Japan	Germany	Korea	World
FCEV stock (number of vehicles)	~300	~50	~65	~130	~650
Of which: buses	~60	~15	~8	~4	~200

Source: International Energy Agency (2012).

Overall, it appears that the current outlook for the development of green vehicle markets follows a conservative scenario, rather than a more optimistic one. This is especially the case for BEVs. The following factors may explain the slow development:

- High price of AFVs (especially BEVs, due to the cost of the battery) relative to conventional ICE vehicles.
- Lack of refuelling/charging infrastructure, which will take many years to be built fully.
- Restricted driving range compared to conventional ICE vehicles, and the perceived distance needs of consumers, which often do not correspond to their regular driving habits. But, even if BEVs have enough range for daily commutes, consumers may be reluctant to pay for a vehicle that is not suitable for a trip longer than 150 km before charging.
- Refuelling times that are longer than what consumers are accustomed to.

These factors affecting the market development of green cars will be described and analysed more in detail in section 4 on market failures and systemic barriers.

3.5 Emerging countries are increasingly important markets, potentially also for green cars

An important trend for the coming decades is the increasing importance of emerging countries as automotive markets. However, it is still unclear if this trend will also translate into a more widespread diffusion of green vehicles in those markets.

For example, while the United States and Europe are mature markets, car ownership in China is still relatively low. Only 2% of China's population own cars and 80% of sales in 2009 were to first-time buyers (Cleantech, 2011b). Accenture estimates that China will have 200 million cars on the road by 2020. It is expected that car purchases by the growing Chinese middle class will soar in the next decade, just at the time when EVs will become more mainstream. HSBC forecasts that China's share of the global EV market will grow from 2.7% in 2010 to 35% by 2020. Frost & Sullivan (2012b) believes that China is not a "hot" market for EVs currently, but will be a market leader in the long term.

As emerging economies are driving the growth in car sales (especially in Asia), demographic profiles and urban environments are likely to shape market developments significantly. Two-wheelers are the most popular mode of transportation in Asia, with an emergence of electric scooters and e-bikes; the total stock of electric two-wheelers has reached more than 120 million in China alone (including pure electric mopeds and power-assisted bicycles). China's government drove the rapid penetration of electric two-wheelers, by restricting sales and use of ICE two-wheelers in many urban areas. In addition, the ownership cost of e-bikes is competitive with traditional motorised two-wheelers (International Energy Agency, 2012). Inexpensive two-wheelers are also popular in India.

However, according to OECD (2010d), the potential for electric cars in large economies such as China and India still seems quite limited, at least as a means to cutting transport emissions. This is because in India constraints on electricity production prevent widespread use of EVs, and in China, power production will rely on coal for the next 20 years at least.

3.6 The emergence of green cars disrupts automotive value chains and fosters the emergence of innovative business models

Green cars, especially EVs, are likely to disrupt the automotive value chain both on the demand and on the supply side. On the demand side, consumers will need to cope with three traditional value chains: automotive (the vehicle); battery (the vehicle battery pack); and energy (the electricity supply). On the supply side, activities will expand beyond the traditional automotive value chain, *e.g.* in managing and delivering the electricity supply; operating and maintaining the associated infrastructure; providing the necessary support services. It is expected that these changes will lead to significant innovations (Accenture, 2011a).

Recent OECD work shows that business models can contribute to systemic innovation if they are widely diffused and scaled up.[23] However, their diffusion and impact is influenced by the framework conditions which determine the economic viability of any value proposition. At the same time, eco-innovation business models themselves may be one of the factors changing economy and society, *e.g.* in triggering the emergence of new production and consumption patterns.

As new business models can be important drivers of eco-innovation, public policy should consider the potential role they can play in government strategy. This reflection should take into account the possible wider impacts of business model changes on shifts in value creation, value chains and value systems. Four types of policy measures can have a direct or indirect influence on eco-innovation business models, even if in most cases they do not target business models explicitly: *i)* regulatory and market based instruments (eco-tax, carbon tax, cap and trade schemes, removal of harmful subsidies); *ii)* supply-side measures (support for R&D, business development, testing and demonstration, provision of training, information and advisory services); *iii)* demand-side measures (provision of infrastructure, performance standards, labelling, certification, public procurement, consumer subsidies and pricing, support for technology transfer and standardisation of technical elements); and *iv*) cross-cutting measures (support for networks, foresight, road-mapping and scenario development).

[23] According to Osterwalder and Pigneur (2009), "a business model describes the rationale of how an organisation creates, delivers and captures economic, social and other forms of values". For additional information on the role of business models in fostering radical eco-innovations, see OECD (2012), *Business Models for Systemic Eco-innovation*, forthcoming.

The analysis of business models also has important links to entrepreneurship policies. OECD analysis shows that a large share of radical innovations emerge from new firms (OECD, 2011f). New and young firms are prone to exploiting technological or commercial opportunities which have been neglected by more established companies, often because radical innovations challenge the business models of existing firms. Policy needs to create the room for such new firms by enabling their entry, exit and growth, ensuring fair competition and improving access to finance (a major constraint for the entry and growth of young firms).

The role of entrepreneurship policies in support of newcomers can be particularly crucial in the development of AFVs. Important players in this segment may originate outside the car industry and eventually affect the whole value chain, for example battery suppliers. Newcomers will have an important role in shaping technological model innovation through their impact on industry structures.

The potentially disruptive effect of innovation will depend on the market segments. For instance, hybrid vehicles are developed and manufactured by traditional manufacturers, whereas full electric cars may originate outside the car industry (as battery technology may be a more critical element for the development of the product than traditional car assembly or component manufacturing activities).

Innovative business models may play a fundamental role in determining the success of green vehicles, by bringing them to the market and promoting their dissemination. For example, the increasing importance of HEVs and BEVs is prompting automakers to expand their supply chains and develop strategic relationships with battery manufacturers. New business models are emerging, and this entails new roles and responsibilities for different players, as can be seen in Table 5 (Accenture, 2011a).

New business models also foster the emergence of collaborative partnerships among entrepreneurs, who work together to develop business opportunities, for example in the area of e-mobility. Such innovative forms of collaboration are normally driven by private sector efforts, but governments can play a role in facilitating them. For example in the Netherlands, the government co-ordinates interactions among business players, both to provide the long-term vision for e-mobility, and to solve specific technical issues that hamper the deployment of EVs.

In terms of the sales business models of carmakers, two main approaches are emerging as the preferred options: *outright (direct) sale* to consumers and *leasing of the vehicle*. The former approach does not entail a radical change in the traditional business models of automotive manufacturers, who rely on dealers to sell the vehicles to consumers. The second approach allows customers to avoid the high upfront cost of purchasing a HEV, PHEV or BEV, and spread it over the duration of the lease. This second approach has been adopted by several automobile manufacturers for different models: PSA C-Zero, the Vauxhall Ampera, the Mitsubishi iMiev (although outright purchase is also possible). Renault-Nissan is likely to be the first OEM to sell a complete range of EVs (including light commercial vehicles) under both sales models. Especially in the case of direct sale, warranty conditions are very important; these will need to go beyond basic warranty to include also the battery/electric propulsion and EV components (Accenture, 2011a; Frost & Sullivan, 2012b).

Table 5. Roles and responsibilities of market players in the electrification of transport

Role	Responsibility	Examples of market players
Electricity retailer	• Provide electricity to charging stations • Identify licensees	• Utility companies • New market entrants, *e.g.* Google
Charge point owner	• Pay upfront investment cost of charging • Enable access to charging point operators	• Municipalities • Utility companies • Automotive companies
Charge point operator	• Operate and maintain charging point • Align billing system	• Municipalities • Utility companies • Automotive companies • New market entrants; *e.g.* end-to-end solution providers, charge point developers
Charging services provider	• Provide charging services (charging and billing)	• Utility companies • New market entrants
IT service provider	• Provide customer services • Provide billing services	• IT companies • New market entrants; *e.g.* end-to-end solution providers, charge point developers, automotive companies, telecom operators.

Source: Accenture (2011a).

New business models are also emerging around the battery itself, as the battery represents a high share of the final vehicle price. For example, *battery leasing* makes the vehicle more affordable to consumers and removes a significant element of financial risk. The manufacturer retains liability for the battery, and this makes the issue of the warranty for the battery negligible. It also solves the issue of who is responsible for the residual life of the battery. The monthly fee for leasing the batteries can simply switch from one consumer to another. In addition, the consumers benefit from any technological improvement that might have occurred when the battery is replaced (AEA, 2009; Accenture, 2011a). A variation of this business model adds the feature of *battery swapping* to battery leasing, and can be seen as a "mobile-phone-style transportation contract" (AEA, 2009). The provider offers a subscription package that includes access to a network of charging points and battery swap stations. At the same time, the provider retains ownership of the batteries and leases them to customers. This is in a nutshell the Better Place business model (see Box 4).

Box 4. The Better Place business model

The aim of Better Place is to facilitate mass consumer adoption of BEVs by making it more affordable and convenient to own and operate an electric car. Consumers can sign up for a subscription plan under which they have to use a certain number of miles per month for a certain number of years, and receive an electric car on lease.

The innovative value proposition of Better Place consists in giving consumers the choice of either charging the batteries (at night-time through a private charge spot or through a network of charging stations) or simply swapping the drained batteries at a designated battery swapping facility. Better Place considers battery switching stations to be a viable solution both for range extension and for energy storage. By separating electric car ownership from the battery, the total cost of ownership for consumers is greatly reduced.

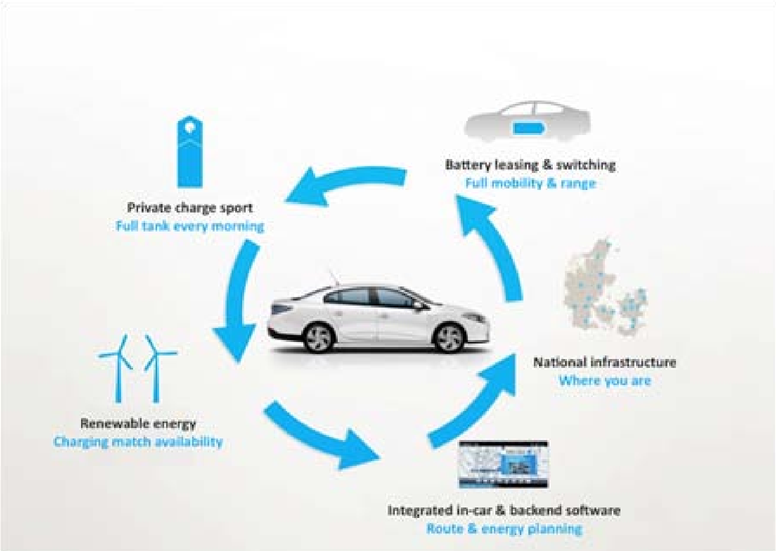
Each car is to be equipped with a global positioning system device for determining the geographical location and with software (developed by Better Place and called Oscar) that can alert the driver as to the level of battery charge, the estimated distance that the car can travel with the available charge, and the location of nearby charging stations and battery swapping facilities.

By using renewable energy sources whenever possible, and therefore making use of cleaner electricity, the aim of Better Place is to reduce well-to-wheel GHG emission from road transport to a minimum.

The company has entered into partnerships with automobile manufacturers, battery manufacturers, renewable energy producers, as well as governments, parking lot operators, and companies that install charging stations.

Better Place is scaling up its global presence, and currently is preparing to deploy its operations in the following locations: Israel, Denmark, Ontario, California, Hawaii, Australia, and Japan (through the Tokyo Taxi Project).

2012 is the launch year for the company when thousands of charging spots are installed in Israel and Denmark. Several battery swapping facilities are already installed in these two countries.



Source: Patir (2012); Hansen (2012); Meenakshisundaram and Shankar (2011).

Charging infrastructure is another area where innovative business models are being developed and tested. Charging an EV can take place at different locations. The *public infrastructure model* aims at providing charging facilities in public areas, and is mainly targeted at customers who are not able to charge their vehicles at home or in the workplace; it also serves the needs of drivers who need to drive longer distances than a normal daily commute. The *private infrastructure model* entails installing charging stations in peoples' homes or in other private sites (for example, parking lots in the workplace or in commercial centres, and street parking). This model benefits from the fact that many households already have parking locations with access to electricity plugs; although for many others such access will require new investments and modifications of electrical systems. Many vehicles should be able to use standard outlets and home electrical systems, at least for slow charging (such as overnight charging) (IEA, 2009). Indeed, charging from private infrastructure (and especially overnight charging) is expected to be the prevailing business model for the near future (Frost & Sullivan, 2012b). Box 5 gives an overview of charging modes in Europe as defined by the International Electrotechnical Commission (IEC).

Box 5. Overview of EV charging infrastructure modes in Europe

IEC defines four modes of charging:

- Mode 1 ("Overnight charging" – slow charging): An on-board charger converts alternate current (AC) power to direct current (DC) high voltage to charge the EV battery. It cannot be integrated into a smart grid. This mode can be used for home charging and for fleets. A city EV with a 16 kW battery would take approximately 4.5 hours to charge at 3.7 kW.
- Mode 2 ("Overnight charging" – semi-fast charging): An on-board charger converts alternate current (AC) power to direct current (DC) high voltage to charge the EV battery. It cannot be integrated into a smart grid. This mode can be used for home charging, and it is safer than Mode 1. A city EV with a 16 kW battery would take approximately 2.2 hours to charge at 7.4 kW.
- Mode 3 (Dedicated EV charging – fast charging): An on-board charger converts alternate current (AC) power to direct current (DC) high voltage to charge the EV battery. It can be integrated into a smart grid. It can be used for home charging and for public charging. A city EV with a 16 kW battery would take approximately 1.1 hours to charge at 14.5 kW.
- Mode 4 (Dedicated EV charging – fast charging): An off-board charger delivers high-voltage, high-current to the vehicle. It can be integrated into a smart grid. It can be used for emergency public charging. A city EV with a 16kW battery would take approximately 20 minutes to charge at 50 kW.

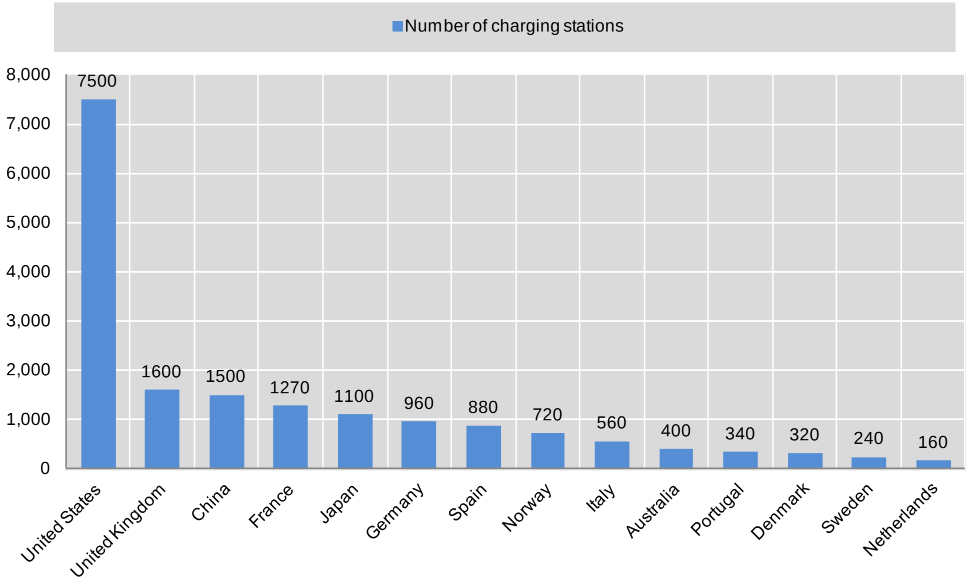
A final mode consists in slow inductive charging, *i.e*. wireless charging using an alternating electromagnetic field. It can be integrated into a smart grid and be used for public charging. A city EV with a 16 kW battery would take approximately 4.8 hours to charge at 3.7 kW.

Source: Frost & Sullivan (2012b).

Several players can provide these different charging solutions, and the landscape for infrastructure is still very much evolving. Governments can support investment in public infrastructure, which may be important especially in the early stages of EVs deployment. Utilities may also play an important role: as suppliers of electricity, they can use their distribution capabilities to install charging stations and partner with other industries to develop an extensive charging infrastructure. OEMs may also have an interest in partnering with governments and utilities to invest in charging infrastructure, as this is likely to foster further diffusion of green vehicles and consumer adoption. Utilities and OEMs can either develop their own charging stations, or source them from third-party manufacturers. Finally, OEMs, utilities or other third parties can take ownership of charging stations' hardware, charge payment, maintenance and after-sale services (Frost & Sullivan, 2011). Figure 19 presents a worldwide overview of the deployment status of public charging infrastructure in 2011.

Figure 19. EV Public Charging Infrastructure, worldwide

2011



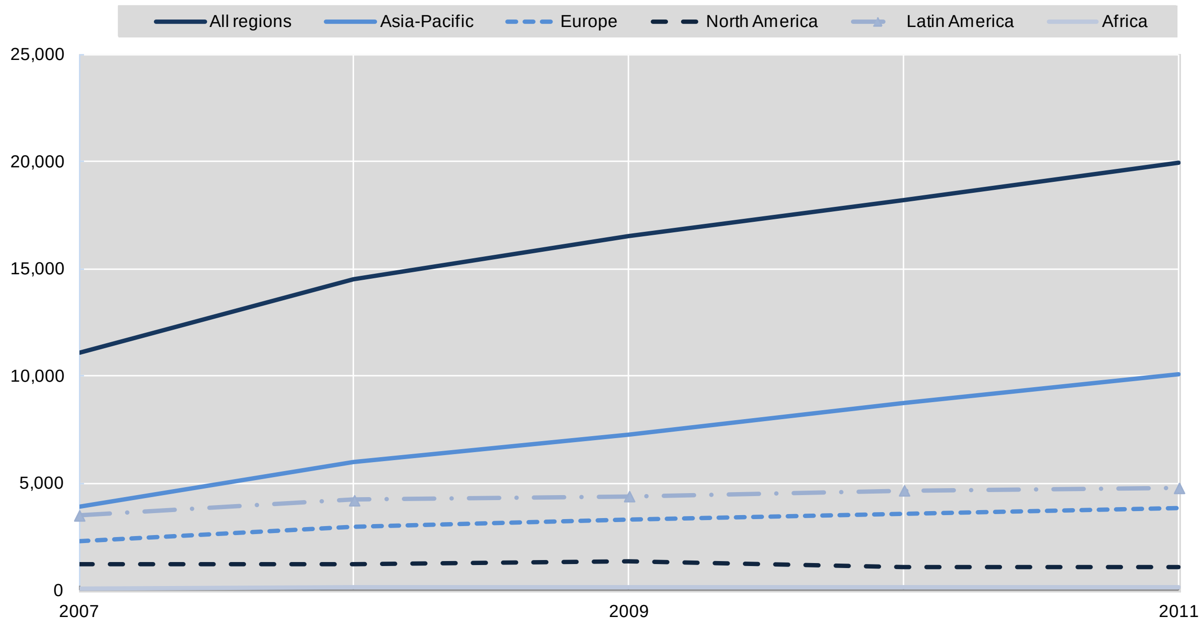
Source: OECD, based on Frost & Sullivan (2011).

The issue of refuelling infrastructure also applies to other alternative fuels, for example in the case of natural gas stations, which are not compatible with conventional gasoline stations. The changes to be made in gasoline stations are not radical: since NGV engines are only slightly different from gasoline engines, natural gas stations do not differ fundamentally from conventional ones (Wang-Helmreich and Lochner, 2012).

Figure 20 shows the current status of NGV fuelling infrastructure. The number of natural gas stations grew on average by 8.2% in 2007-11, and reached 19 941 in 2011. This growth was driven mainly by Asia (5.9% average growth in 2007-11), followed by Europe (2.9% average growth), Africa (2.4% average growth) and Latin America (1.4% average growth). In North America, the number of NGVs fuelling stations actually decreased by 1.2% in 2007-11. At the level of individual countries, those with the highest number of natural gas stations in 2011 were: Pakistan (3 300); China (2 120); Argentina (1 902); Iran (1 820); and Brazil (1 719). Among OECD members, there were: 1 000 stations in the United States; 903 in Germany; 858 in Italy; 333 in Japan; 223 in Austria; and 184 in Korea (IANGV, 2012).

Figure 20. Number of NGVs fuelling stations worldwide

2007-11



Source: IANGV (2012)

Therefore, natural gas stations are still relatively rare. But in order to facilitate consumer adoption, it is estimated that natural gas stations should be between 10% and 20% of existing conventional gasoline stations. Above this threshold, diffusion of NGVs would occur, as the number of refuelling stations would be sufficient for most drivers. Only a small number of users would require an infrastructure for refuelling NGVs equivalent to the existing infrastructure for conventional fuels (Wang-Helmreich and Lochner, 2012).

As regards refuelling infrastructure for FCEVs, about 200 hydrogen stations currently exist worldwide, of which 80 in the United States, 16 in Japan, 13 in Korea and 8 in Germany. These are mostly non-public. Different refilling technology layouts are being tested through pilot and demonstration projects. Around ten stations per city[24] may be sufficient if stations are clustered. In a second step, corridors connecting urban centres could be equipped with hydrogen refuelling stations, before building denser area coverage (International Energy Agency, 2012).

Car-sharing is also increasingly seen as a business model that can facilitate the diffusion and adoption of green vehicles, especially PHEVs and BEVs, as it may facilitate the shift in consumers' minds from thinking of the car as a product to thinking of it as a service. Although the concept of car-sharing has been around since the early 1970s, it became popular worldwide in the early 1990s

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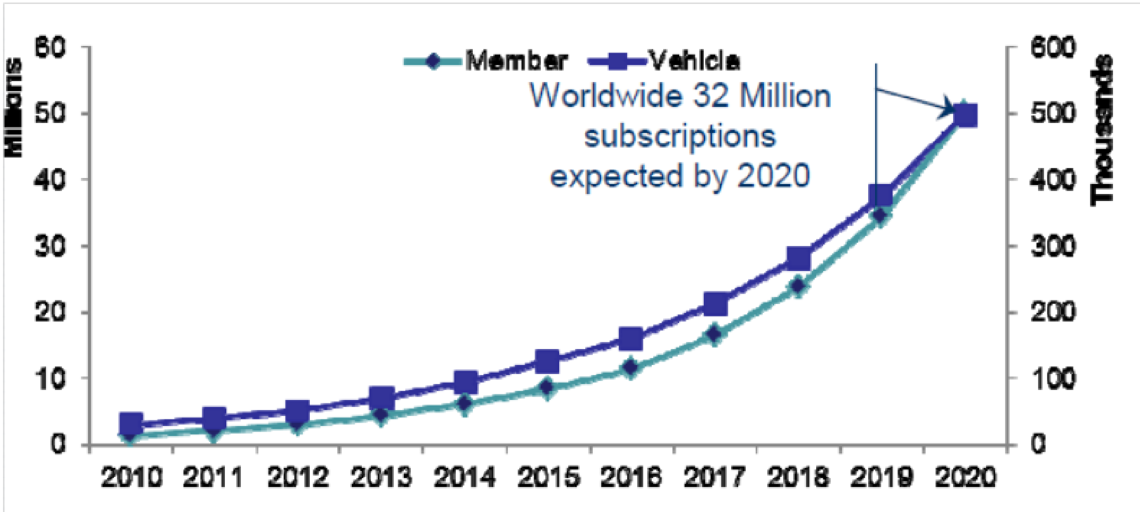
24 Assuming 500 000 inhabitants and a density of around 2 800 inhabitants per km^2, if the time per trip to the station was not to exceed 10 minutes at an average speed of 20 km per hour and a tortuosity factor (deviation from straight line) of 0.7, ten stations per city would be the lower limit.

(Shaheen and Cohen, 2007).[25] As of 2007, car-sharing schemes were in place in approximately 600 cities around the world, in 18 countries and on 4 continents; an estimated 348 000 car-sharing members worldwide shared nearly 11 700 vehicles (Shaheen and Cohen, 2007). Frost & Sullivan (2012b) estimates that the number of worldwide subscriptions will be 32 million by 2020 (Figure 21).

Figure 21. Car-sharing vehicles and members, world

2010-20



Source: Frost and Sullivan (2012b).

In the last decade, car-sharing companies have started to integrate green vehicles in their fleets. This has been the case of Zipcar, which is considered to be the inventor of today's car-sharing business model and has 540 000 subscribers and 8 000 vehicles in the United States, Canada and the United Kingdom (Cleantech, 2011c). Zipcar was the first car-sharing company in the United States to introduce EVs into its fleet in 2002. Currently, the company offers converted PHVs in San Francisco and pure EV models in London. 1 000 HEVs are offered internationally, representing between 15% and 20% of the company’s entire fleet. In 2012, Zipcar announced the introduction of eight Toyota Prius PHEVs into its network (Zipcar, 2011).

Other car-sharing companies are following this trend. For example, Daimler's car2go car-sharing fleet is 100% electric in three out of the eight cities where the scheme is present (Frost and Sullivan, 2012b). eHi, China's pioneering car-sharing company, will introduce HEVs and PHEVs in its fleet (Cleantech, 2011d). A 100% electric vehicle car-sharing scheme, the Autolib', is currently being implemented in the city of Paris (Box 6).

25 In fact, one of the earliest European car-sharing schemes was set up by a co-operative known as Sefage (Selbstfahrergemeinschaft) in Zurich in 1948, and operated until 1998.

Box 6. A 100% electric car-sharing scheme: Autolib' in Paris

The Autolib' car-sharing scheme is a co-operative initiative of a *syndicat mixte* embracing the City of Paris and neighbouring municipalities in the Ile-de-France region. The total investment in the project is estimated at EUR 250 million, of which approximately EUR 35 million by the syndicat. The city of Paris will cover most of the cost of the stations, through a grant of about EUR 50 000 for each station. But the bulk of the investment is borne by the concessionaire, Vincent Bolloré, who will pay an estimated EUR 105 million to supply his design of 100% electric "Bluecar" vehicles and their batteries, in addition to operating costs amounting to EUR 80 million a year. The Bluecar is manufactured by Italian designer Pininfarina, and has a range of up to 250 km before requiring recharge, which will take about four hours.

As of early 2012 there were 66 cars running, with 6 000 subscribers. The scheme aims to put 3 000 electric cars into service, while taking 22 500 conventional gasoline-powered vehicles off the road by 2014. It is expected that the pilot test should familiarise consumers with the technology.

Source: International Energy Agency (2012), Frost & Sullivan (2012b); BBC (2011); *The Economist* (2011c).

3.7 Automobile manufacturers have different strategies vis-à-vis green cars

The perception of automakers with regard to sustainability and energy efficiency is changing. Some evidence suggests that sustainability is no longer seen exclusively as a burden imposed by governments leading to additional costs, but also as an opportunity for cost reduction, revenue growth, risk management, innovation, brand management and other intangibles. A UN Global Compact–Accenture CEO Study shows that automotive executives identify climate change as one of the two most important development issues for their business (UN Global Compact and Accenture, 2011).

Following this trend, most automotive manufacturers have announced that they will introduce some type of green vehicles in their fleets between 2011 and 2012. However, OEMs' corporate strategies in respect to green cars differ significantly in terms of technological choices (Accenture, 2011a; see also Table 6). At the same time, most carmakers have taken the approach of not putting all their bets on one technology, but rather diversify their vehicle offerings to customers.

Table 6. Priorities in cleaner automobile strategies of some carmakers

Priority to less polluting fuels: gas, biofuels	Equip the entire range with hybrid engine and test plug-in hybridisation	Priority to hybrid but also all other types of engine, according to the country and use	Priority to plug-in hybrid and electric vehicles	Priority to pure electric vehicles
• Fiat • Chrysler? • Volvo • Russian carmakers	• Toyota • Honda • Mazda • Porsche	• Ford • PSA • Volkswagen • BMW • Daimler • Hyundai	• GM • Mitsubishi • BYD	• Renault-Nissan • Many Chinese and Indian carmakers • Nearly all start-ups and newcomers

Source: OECD based on Freyssenet (2011).

When considering whether, when and how to introduce new green vehicle models, OEMs often take a global perspective of the automotive market. However, different world regions present distinct features, depending on the maturity of the market, consumer preferences and other characteristics.

This also helps to explain why carmakers aim at offering a wide range of AFV solutions. However, this variety makes it difficult for OEMs to utilise economies of scale fully, which is one of the reasons why green cars are still expensive and thus less acceptable for consumers.

In addition, interoperability of recharging infrastructure can reduce the level of uncertainty on the development of the market, thus enhancing incentives for OEMs to introduce green vehicles early. Reducing market uncertainty and utilising economies of scale as early as possible will help reduce the price of green cars, especially BEVs, thus accelerating market development.

3.8 Governments need to consider the full product life cycle and well-to-wheel emissions of green vehicles

The energy efficiency of green vehicles should be assessed taking into account the full product life cycle and performing a "well-to-wheel" (WTW) calculation of how they perform in comparison with traditional ICE vehicles.[26] This is important to ensure that low- or zero-emission vehicles are not in fact "displaced-emission" vehicles (*e.g.* emissions from carbon-intensive electricity generation), since in most instances electricity generation entails both GHG and pollutant emissions (Crist, 2012).

A Life Cycle Analysis (LCA) assesses how the vehicle itself is produced and treated as waste: for example, the environmental impact of manufacturing and end-of-life treatment of vehicles in China is likely to be different from that in Europe or other OECD regions. In addition, the weight of the batteries may result in EVs requiring lighter frames, which in turn depend on lightweight aluminium components whose production can generate significant CO_2 and other pollutants.[27]

Among other aspects, a well-to-wheel analysis considers the generation of the electricity used as a fuel (for example, if the electricity has high carbon content or if it comes from renewable sources). Countries have very different energy mixes, and the incentives to produce and buy EVs vary significantly depending on whether electricity comes from fossil fuels, or from renewable sources such as wind or solar, or from nuclear power. In fact, low-carbon electricity generation is already competitive in many markets and will take an increasing share of generation in coming years. Integrating a much higher share of variable generation, such as wind power and solar photovoltaic, is possible (International Energy Agency, 2012).

In particular, it is crucial to consider the carbon intensity of marginal electricity generation, not necessarily the average or the base load generation profile. It may be the case that base load generation capacity is insufficient to meet additional electricity demand related to EVs, and that marginal capacity is brought in to handle such excess demand. This can have a significant impact on overall CO_2 emissions, as the carbon intensity of marginal generation (*e.g.* from gas or coal rather than from nuclear or renewable) can be much higher than base load generation. This will depend on the number of EVs in the fleet, the time of the day, season of the year and the geographic location (Crist, 2012).

26 A well-to-wheel (WTW) analysis can be sub-divided into: well-to-tank (WTT), accounting for the energy expended and associated GHG emitted in the steps required to deliver the finished fuel into the on-board tank of a vehicle, as well as the potential availability of the fuels through their individual pathways and associated production costs; and tank-to-wheel (TTW), accounting for the energy and the associated GHG emitted by the vehicle/fuel combinations, and including also an assessment of the expected relative retail prices of the various vehicle configurations. A WTW analysis is, however, not a Life Cycle Analysis, as it does not consider the energy or the emissions involved in building the facilities and the vehicles, or the end-of-life aspects (EUCAR, CONCAWE and JRC/IES, 2007).

27 At the same time, also ICE vehicles increasingly require lighter, and more energy-intensive, materials to meet mandated fuel economy requirements (*The Economist*, 2012a).

Increasing the overall share of power generated from "cleaner" sources is also crucial in integrated electricity markets in order to avoid that the uptake of EVs only results in displaced emissions rather than reduced emissions. For instance in the United States, capacity is traded as local need for electricity rises and falls and the cheapest power available is transmitted across the grid where there is demand for it. Therefore, even in places where local power-generation capacity is low in carbon content (*e.g.* because it relies heavily on hydro and renewable), the electricity used to charge an EV could come from a coal-fired power plant in another state (*The Economist*, 2012a). The same reasoning could be applied to an integrated European electricity market, where electricity is continuously transmitted across countries: it would be very difficult to determine with certainty the original source of the marginal electricity generation.

In assessing the impact of replacing conventional ICE-powered vehicles with green vehicles, it should also be considered if the CO_2 emissions are "capped" by other instruments, for example a "cap-and-trade" system such the EU Emission Trading Scheme (ETS). It has been argued that once a cap-and-trade system has been put in place, further emission reductions are unlikely to be obtained by applying additional policy instruments to the same emissions from the same sources, as long as the cap is unchanged. However, instruments that effectively bring new emissions under the cap can contribute to net "global" emission reductions. Because transport emissions are not presently covered by the EU ETS, measures to encourage their reduction could contribute to a reduction of EU-wide CO_2 emissions. In this context, the need to take into account the CO_2 emissions caused by the generation of the electricity used by EVs loses its significance, as long as the total cap of the EU ETS is not increased. Promoting the replacement of ICE vehicles with EVs would cause emission reductions equal to the emissions that ICE vehicles would have caused – without any "correction" related to CO_2 emissions stemming from the necessary electricity generation (OECD, 2011g).

Also in relation to emission trading schemes, policy makers should consider the indirect impact that policies addressing non-capped sectors (such as road transport) could have on the setting of a future cap. Measures aimed at deploying EVs vehicles could result in lower overall CO_2 emissions, but at the same time lead to an increase of allowance prices in the electricity sector. This in turn could contribute to reinforcing political pressure for setting a less strict cap in the future. However, this is an unlikely scenario in the medium term: the switch to EVs should be very significant (and greater than what is currently observed) to have an impact on future caps. In addition, carbon emission permits are currently oversupplied in Europe, mostly as an effect of the economic crisis.

WTW calculations should also be applied to the assessment of the climate change mitigation impact of FCEVs. Currently hydrogen is produced from fossil resources (such as natural gas) without carbon capture and storage, but the use of hydrogen and FCEVs would still reduce emissions as the WTW efficiency is higher than using natural gas directly with an ICE (International Energy Agency, 2012).

There are also some important environmental issues with regard to the batteries used in EVs. For example, when nickel-cadmium and lead-acid rechargeable batteries no longer hold sufficient charge, they cannot simply be disposed of in a landfill, as they contain dangerous heavy metals. Nickel-metal hydride battery technologies that are currently used in many hybrid vehicles are free of cadmium and lead, and yet contain nickel, which is a dangerous environmental toxin. Because valuable metals are only present in small quantities in the batteries, recycling may not be economically viable (Better Place Australia, 2011).

The latest generation of lithium-ion batteries contain materials (lithium, iron, phosphate and graphite) that are not dangerous to the environment and can all be recovered in the recycling process (Better Place Australia, 2011). Yet, dumping lithium-ion batteries in landfill would be wasteful and could potentially pollute area groundwater (Taylor, 2009). Notter *et al.* (2012) found that the impact of a lithium-ion battery used in BEVs for transport service is relatively small. Another study assessing the life-cycle environmental impact of the production and use of three types of batteries for EVs found that lithium-ion technologies outperform nickel-metal hydride batteries (Majeau-Bettez, Hawkins and Stromman, 2011). The nickel-metal hydride had the highest environmental impact, except for ozone depletion potential. The difference is explained by the greater performance of lithium-ion batteries in the use phase and the fact that each kilogramme of lithium-ion battery stores two to three times more energy than a nickel-metal hydride in the course of its lifetime. In addition, lithium-ion batteries contain at least one order of magnitude less nickel and virtually no rare earth metals.

Batteries can also be given a "second life", once their storage capacity falls below a certain level and can no longer provide the range that drivers require.[28] For example, batteries could be repurposed to manage power flow in smart grids, especially during peak times or outages (Witkin, 2011). They can be situated in "battery farms" next to intermittent renewable generators such as wind or solar to help these plants better manage the timing and rate at which they supply electricity to the grid (Better Place Australia, 2011). Once the battery reaches the end of its second life, it can be recycled to recover the materials that can be used to produce other products.

3.9 Potential trade-offs between policies to foster green cars

One word of caution concerns the inevitable trade-offs that emerge from a government decision to pursue the greening of the transport sector as part of a strategy towards sustainable economic growth (Van Dender and Crist, 2011). Although improved fuel efficiency is expected to reduce environmental impacts and thus bring benefits to the economy and society, measures to that effect may also lead to some costs, which should be acknowledged and taken into account when evaluating policy outcomes. This issue has been discussed at length with regard to taxes, but also applies to other demand-side instruments, such as regulations and standards.

An example of such trade-offs can be observed in the case of environmental taxes and subsidies. Environmental taxes may very well internalise negative externalities such as pollution, but may not necessarily overcome the lock-in of existing technologies. On the other hand, while government support to a specific technology may contribute to breaking the lock-in, it can also reduce the utility that users get from the established technology, or disrupt existing networks of services (Dietrich and Sieg, 2011).

Policy makers should also consider that the impact of the wider deployment of green cars on climate change and the environment depends not only on the absolute number of vehicles purchased and driven, but also on what transport mode people were using before buying a green car. For example, it may be the case that a majority of the people who purchase a green vehicle were using public transport before, rather than switching from an ICE-powered vehicle. In this case, policies to promote the diffusion of green cars could in fact lead to an increase in GHG emissions and local air pollution.

Crist (2012) finds that the societal cost of BEVs (compared to the ICE equivalent) ranges from EUR 7 000 to EUR 12 000. This calculation ignores taxes on fuel (as from society's point of view these are a transfer rather than a cost), includes subsidies and accounts for air pollution impacts, and excludes energy security benefits. Therefore, the costs of reducing CO_2 emissions by promoting electric cars, even with low carbon electricity, remain high.

[28] Based on different estimates, this level is between 80% and 60% of the original battery capacity (Better Place Australia, 201; Witkin, 2011).

3.10 Industrial and competition issues related to green vehicles: different technological trajectories and the role of government

The concept of technological trajectory refers to a single branch in the evolution of a technological design of a product or service. Development of a product or technology can either continue along a unique and well-defined trajectory, or be split into separate trajectories, which will eventually fragment markets into segments which are characterised by limited demand substitution between one another. In addition, when different technological trajectories are characterised by limited R&D economies of scope, a superior R&D effort by firms in one trajectory may have little impact on the other trajectories. Therefore, a superior innovation performance will not necessarily enable a firm operating in one trajectory to win market shares in another trajectory (OECD, 2011b).

The green car industry is characterised by a proliferation of technological trajectories: ICEs running on alternative fuels, hybrid-electric vehicles, plug-in hybrid-electric vehicles, battery electric vehicles, hydrogen-fuelled vehicles, etc. These different technologies lead to market segments that are not fully substitutable.[29] In addition, they depend on different critical elements (batteries, fuel cells, combustion engines) with little or no R&D scope economies, and little or no spillovers between one to another (OECD, 2011e). The infrastructure needed for the deployment of the vehicles (*e.g.* refuelling and charging stations) is also not the same for the different technologies.

At the same time, there are also some complementarities between the different trajectories. For example, FCEVs, BEVs and PHEVs are likely to benefit from each other's mass deployment. Roughly one-third of total production costs for FCEVs, BEVs and PHEVs are dedicated to the electric powertrain. The vehicles also have similar parts. In addition, these technologies might occupy different market niches. Because BEVs are limited in range and have a long recharging time, they are most suitable for small- to medium-sized vehicles for urban use. FCEVs have a considerably higher driving range than BEVs, and their refuelling time is comparable to conventional ICE vehicles. It is more likely that FCEVs and PHEVs target the same niche, medium- to large-size cars with a driving range of 500 km of more. PHEVs could also provide a pathway to FCEVs, since eventually the ICE could be replaced by a fuel cell, a final step to reach non-petroleum, very low CO_2-emission driving (International Energy Agency, 2012).

An analysis of trajectories for green vehicles has important public policy implications. If a government were to favour one trajectory over another (for example, by providing R&D subsidies to a specific propulsion technology or fostering consumer adoption of vehicles relying on a specific fuel and propulsion system), it could run the risk of giving a competitive advantage and economic rents to some industrial players over the other. In addition, there is a risk that such a technological trajectory becomes locked in, potentially preventing the emergence and diffusion of alternative, and potentially better solutions.

Although policy makers should generally favour technological neutrality, governments at the same time have a role in overcoming some of the failures and barriers that prevent the adoption and diffusion of green vehicles. The next section explores these failures in more detail and outlines how governments can design and implement policies to overcome the barriers, while still maintaining competition between alternative technologies.

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29 However, when the gap in price and performance becomes very large, substitution may occur.

4. THE RATIONALE FOR PUBLIC POLICY: FAILURES AND BARRIERS TO THE DEVELOPMENT AND DIFFUSION OF GREEN CARS

Decarbonising the transport sector requires a fundamental transition towards a new paradigm. However, this is bound to be a very complex process, as the current energy and transport systems have developed over centuries. On the one hand, very significant changes are required, and the power of incumbent technologies and actors is very strong. On the other hand, the case for new technologies in the transport sector is not always an easy one to make, as they are often more expensive than the incumbent technologies they are meant to replace, and great uncertainty still surrounds them in terms of the benefits they bring to individual users and to society at large. Such uncertainty concerns not only economic benefits, but also the net environmental impacts.

More specifically, the transition to a more sustainable transport system is hampered by the existence of market and systemic failures which prevent the development and diffusion of green cars. These barriers can be identified on the basis of the "green growth diagnostic framework" (Figure 22) developed in the context of the OECD Green Growth Strategy (OECD, 2011g). As for many other eco-innovations, the development and diffusion of green cars is constrained by low returns to "green" activities, innovation and investment. These constraints can be divided into two categories: *i)* low overall economic returns stemming from inertia (*i.e.* fundamental barriers to change and innovation) or "low social returns"; and *ii)* low appropriability of returns, which can arise when government and market failures prevent firms or consumers from capturing the full value of improved environmental outcomes and efficiency of resource use generated by using green cars. In this diagnostic framework, the categories of constraints are not entirely separable. For example, there are some overlaps between market and government failures, and incomplete property rights are in many cases a market failure.

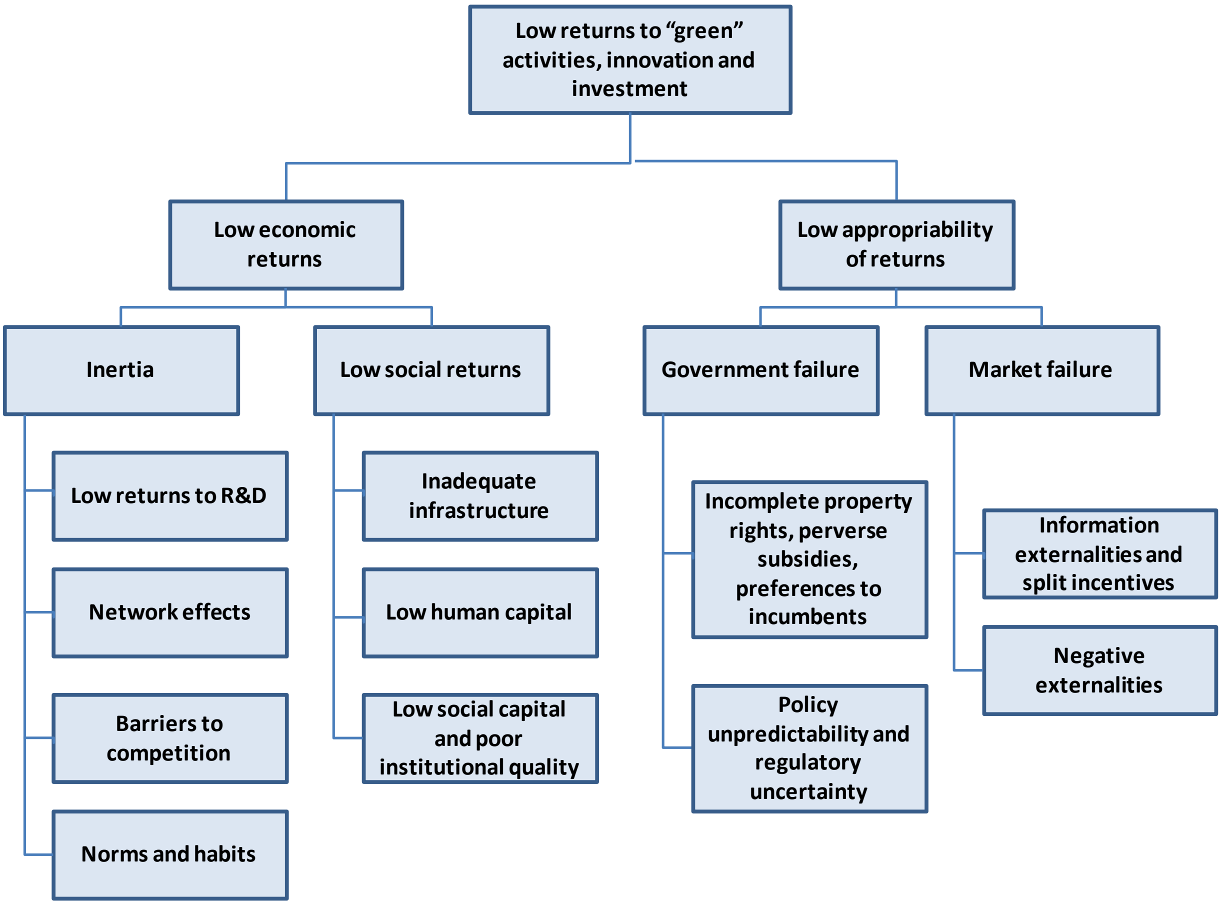
Because of the existence of these multifaceted and interacting failures and barriers, policies to foster innovation in AFV technologies will only be successful if they enhance the performance of the innovation system as a whole, targeting weak links between elements that can hurt performance. Shifting towards a more systemic or horizontal approach can also lead to greater coherence.

At the same time, not all potential failures make government intervention necessary or desirable. There is often no guarantee that government policy will be able to address a market or systemic failure in a way that effectively improves the initial situation. And even when governments may improve welfare in principle, they may lack the means or information to do so in practice. Awareness of the possibility of government failure and *ex ante* evaluation of policies (especially cost-benefit and cost-effectiveness analyses) can help to limit the risk of costly but ineffective intervention (OECD, 2011f).

In addition, governments are not the only player in addressing market and systemic failures preventing the development of the market for green cars. Especially in times of tight public budgets, limited resources may restrict government ability to deal with policy concerns on its own. For example, as shown in the previous section, different actors (including government, utilities, OEMs) can provide private or public charging infrastructure solutions. In this case, policy makers should consider carefully whether to address the market failure directly or to instead ensure the right framework conditions and a sound business environment enabling private operators to overcome the barriers.

The main barriers to the diffusion of green vehicles can be ascribed to inertia, inadequate infrastructure, government failures and market failures.

Figure 22. Green growth diagnostic framework



Source: OECD (2011h), concept based on Hausmann, Velasco and Rodrik (2008), "Growth Diagnostics", in J. Stiglitz and N. Serra (eds.), *The Washington Consensus Reconsidered: Towards a New Global Governance.*

4.1 Inertia causes a slow transition to low-carbon and energy efficient transport systems

Inertia can be defined as a resistance to change or a tendency of economic, human and physical systems to change very slowly. It can be a major obstacle to the development and diffusion of green cars. Elements of inertia include low returns to R&D, network effects, barriers to competition and slowly changing norms and habits.

Low returns to R&D

R&D targeted at eco-innovation in the automotive industry may have two main focus areas (UN Global Compact and Accenture, 2011):

- *R&D aiming at improving efficiency of the ICE*, which can be defined as "evolutionary". R&D in this area is more likely to lead to incremental innovation as it aims at modifying and improving existing technologies without fundamentally changing the underlying core technology.

- *R&D pursuing alternative powertrains*. R&D in this area could lead to innovations of the more disruptive sort, as they have the potential to change how specific technological functions are fulfilled, and may lead to significant changes in the full value chain.

All automobile manufacturers have been investing heavily in R&D targeted at reducing emissions from conventional gasoline- and diesel-fuelled powertrains. At the same time, several of them are also focusing their innovation efforts on AFV technologies, although the depth and breadth of their strategies differ.

However, as the market for the more disruptive AFV technologies is still relatively limited, the return on these investments may not be high enough to encourage sufficient private sector involvement. This adds to the riskiness of R&D investment in this area: the uncertainty surrounding the development of the market for green cars means that companies may gain a return only after a very long payback period, and it is unclear if they will be able to gain sufficiently large market shares to recover R&D costs.

Network effects

Network effects (or *positive network externalities*) stem from the interactions among technologies, infrastructures, innovators and users. They arise because the value of networks to users is positively correlated with the size of the network (*i.e*. the mass of users) and its interconnectedness (Katz and Shapiro, 1985). The most obvious source of network effects in green vehicle markets is the need for a refuelling/charging infrastructure (or battery swapping, in the case of BEVs) (Becker, 2009). The more green vehicles are taken up by consumers, the more infrastructure will be deployed, thus increasing the net value of a green vehicle through improvements in the availability, performance and affordability of such infrastructure (Transport Electrification Panel, 2011).

Network externalities can cause inertia in the development and diffusion of green cars. Barriers to entry can arise from increasing returns to scale in networks and contribute to creating a bias in the market towards existing technologies. Consumers may be reluctant to purchase an AFV if they are uncertain that a network of refuelling/charging infrastructure will be extended far enough to cover their needs. Instead, they will tend to favour the incumbent ICE technologies for which gasoline and diesel refuelling stations abound. Of course, cars with different engines and/or requiring different fuels may use the same network, *e.g*. a fuelling station equipped with pumps for natural gas and hydrogen posts along with gasoline and diesel posts (Conrad, 2004). However, such multi-functional stations are still quite rare.

Indirect positive network effects may also stem from a reduction in the unit price of green vehicles, resulting from increased production and sales. This positive externality arises under the condition that economies of scale exist in green vehicle supply chains, thus lowering unit production costs. Also in this case, the presence of network effects may create barriers to the development of AFVs, as firms may have an incentive to wait and free ride on the innovative activities of their competitors aimed at fostering diffusion in the market (Transport Electrification Panel, 2011). At the same time, firms can exclude competitors from benefitting from their innovations: for example, intellectual property rights (IPRs) provide an important incentive to invest in AFV technologies by enabling firms to recover their investment costs. In addition, learning from other innovators may not be easy or free.

Therefore, in the presence of network externalities, there may be a role for governments to support the development of green vehicle markets, when infrastructure is underdeveloped, production volumes are low and unit costs are high (Transport Electrification Panel, 2011). At the same time, an *ex ante* evaluation of public support to infrastructure deployment should consider that the additional investment required for different technologies to become competitive represents a cost to society, that should be assessed against the expected benefits.

Barriers to competition

The development of markets for green vehicles is hampered by high barriers that favour incumbent firms and technologies and impede entry by potential competitors. The main players in this field are likely to be existing firms that diversify and expand in new market niche as entry from outside is hard due to the very high sunk costs for new producers.[30] On the other hand, there may be some room for new business models and firms providing services that are closer to the customers (*e.g.* car-sharing or battery swapping).

Path dependence[31] may lead to lock-in failures and dominance of existing designs in systems and technologies. Broader aspects of the socio-economic system can be "locked in" to a particular technological paradigm. This may be a characteristic of the road transport sector: the dominant design creates entry barriers for new technologies, due to high fixed costs of developing new infrastructures (The UK Committee on Climate Change, 2010).

High entry costs may exist for new technologies, and therefore lead to high costs of switching to these new technologies for users. This is the case of AFVs, especially EVs: their high price (with the battery representing 50% of the cost of a BEV) is constantly reported to be one the main barriers to consumer adoption – the so-called "sticker shock" (*The Economist*, 2010). The price premia relative to ICE vehicles have been estimated as: 10% for HEVs, 30% for PHEVs and 100% for BEVs (Danish Technological Institute in co-operation with Ecorys Research and Consulting and Cambridge Econometrics, 2011).

Notwithstanding the importance of behavioural aspects, potential vehicle buyers are also economic actors who base their purchasing decisions on a cost-benefit analysis, but with a reasonable payback period. Hence, AFV technologies may fall into a vicious circle: they are not adopted because they are too expensive, but at the same time they are too expensive because they have not yet been adopted.

Many barriers to entry and competition are of a technical nature. For example, one factor that is holding back purchases of EVs in particular is the limited range, giving rise to the so-called "range anxiety", *i.e*. the fear that the vehicle will not have sufficient power to take the driver to his or her final destination. Although range anxiety is in a large part a psychological factor, it cannot be denied that it currently represents a technical limitation compared to conventional engines. It is clear that many people buy cars with a view to the full range of travel services, including longer trips.

The maximum range of current first generation BEV models is somewhere between 150 and 200 km. In the case of HEVs, the range powered by the battery is much shorter; however, a complementary source of power (ICE) or range extender enables the vehicle to drive for longer distances without running out of power. In any case, the range of BEVs is currently much shorter than

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30 Sunk costs are investments that are fully committed to the market once they are made. They cannot be recovered, and therefore may deter a newcomer from embarking on a risky venture.

31 Path dependence occurs when the timing of an innovation precipitates an advantage of one technology over another.

what can be achieved with an ICE-powered vehicle. FCEVs and perhaps especially PHEVs can provide very long service (International Energy Agency, 2012).

Another technical shortcoming linked to the limited range of electric EVs is the time required for charging. While this varies significantly according to the different modes of charging (see Box 5), even the fastest option dedicated to public emergency charging (and not to daily charging) would currently take about 20 minutes. Obviously, this cannot match the rapidity of refuelling a gasoline- or diesel-powered vehicle (and of other AFV technologies, such as NGVs and FCEVs). Business models based on battery-swapping have emerged as a promising alternative solution to this technical constraint.

Barriers related to vehicle characteristics also exist for NGVs. For example, CNG has a lower energy density than petroleum; therefore, to achieve a cruising range comparable to that of conventional cars, larger and heavier gas tanks need to be installed. Because most existing NGV models favour better loading space over cruising range, the latter is only between 180 and 450 km (Wang-Helmreich and Lochner, 2012).

In terms of mass and volume (and, consequently, vehicle on-board energy storage systems), hydrogen has a far lower weight than batteries, and comparable (at 350 bar) or less (at 700 bar) space requirements. However, at 700 bar, hydrogen is still well below the energy density that gasoline, diesel or other liquid hydrocarbon fuels (*e.g.* biofuels) provide. Therefore, hydrogen storage takes up considerable space on vehicles. Reaching a 500 km range is possible with 5 kg storage capacity. However, at 700 bar, the tank would be as large as 190 litres (International Energy Agency, 2012).

Significant technical entry barriers also exist on the supply side, in particular for battery manufacturers. They face high initial capital investment and R&D costs. Estimating battery costs is difficult and hard to separate from total vehicle prices. In addition to production costs, prices often reflect other overhead costs, such as marketing. Batteries had, roughly, a cost-based price at medium-high volume production of around 750/kWh in early 2011. At the beginning of 2012 they stood at around USD 500/kWh. If this improvement continues, batteries can reach USD/325 kWh or less by 2020, which is sufficient to bring EVs close to cost-competitiveness with ICE vehicles (and this is years ahead of past projections) (International Energy Agency, 2012).

In addition, access to inputs and raw materials may represent a significant hurdle for battery producers, especially as concerns rare earths which are a critical constituent of the battery.[32] 99.7% of world production of rare earths currently occurs in only three countries, of which 96.9% in China, 2.2% in India, and 0.5% in Brazil (Korinek and Kim, 2010). There have been efforts to find alternative supplies, but these are made complicated by the pollution generated by rare earth mining and processing. Efforts are underway to develop mines in Canada, South Africa, Vietnam, Kazakhstan and Mongolia (*The New York Times*, 2012). China has imposed increasingly stringent export taxes and quotas on its supply of rare earths, which has contributed to a steep increase in prices.[33] However, since the peak in the summer of 2011, prices have been decreasing (by three-fifths for some rare earth elements, as of March 2012) (*The New York Times*, 2012).[34] At the same time, a growing number of

32 Rare earth elements or rare earth metals are a collection of 17 chemical elements in the periodic table, namely scandium, yttrium and the 15 lanthanides (Korinek and Kim, 2010).

33 On 13 March 2012, the United States, Japan and the European Union requested consultations with China under the dispute settlement system concerning the latter's restrictions on export of various forms of rare earths, tungsten and molybdenum.

34 The near completion of the world's largest refinery in Kuantan, Malaysia, has contributed to the decrease in price.

carmakers and automobile component manufacturers (including Tesla, BMW and Toyota) are developing EVs that use no rare earths (*The Economist*, 2011d).

Cost represents a significant hurdle for manufacturers of FCEVs as well. Fuel cells for transportation use a polymer electrolyte membrane (PEM), a thin plastic sheet that allows hydrogen ions to pass through. It is coated on both sides with highly dispersed metal allow particles, most of which are platinum. Although the quantity of platinum required for PEM fuel cells is declining with R&D efforts, its cost is still high. As of 2010, costs per kW were somewhere around USD 1 000 for PME fuel cells in transport applications. Major carmakers claim to be able to introduce FCEVs on a commercial scale (perhaps 50 000–100 000 units per year), at around USD 50 000 by 2015. This suggests fuel cell system costs of about USD 25 000, or around USD 300/kW. This cost is expected to decline to under USD 100/kW in the future, but when is unclear (International Energy Agency, 2012).

Norms and habits

Slowly changing norms and habits of consumers have been identified as another potential barrier to the diffusion of green cars. They depend on psychological factors that include: attitudes, lifestyles, personality and self-image (for private individuals); and risk-perception, corporate culture and corporate image (for fleet purchasers) (Lane and Potter, 2007). If these factors are biased in favour of traditional ICE vehicles and against AFVs, they will act as strong disincentives for carmakers to propose green vehicle options to potential purchasers. When deciding which car to purchase, consumers focus on the overall vehicle price, fuel prices, fuel type, parking space availability, design and style, interior space and design, cargo volume, power and power-to-weight ratio, reliability, and brand image (International Energy Agency, 2012).

As mentioned above, one of the main psychological factors impinging on consumer adoption of hybrid and electric propulsion systems (especially the latter) is "range anxiety". This is because drivers are not accustomed to thinking precisely about how far they drive to get to their destination, but pure BEVs demand that they do so (*The Economist*, 2010). However, evidence shows that the current EV driving range is well above the average daily vehicle use in many countries (International Energy Agency, 2012).

A number of test trials and studies have suggested that consumer concerns about the range are in fact misplaced. For example, BMW conducted a test of electric motoring and range anxiety with the Mini E, a demonstration electric car developed as a conversion of the Mini Cooper. The test showed that driving patterns of electric Minis differed only slightly from those of the conventional engine-powered vehicles. In California, Mini E users drove 48 km a day, not far from the American driving average of 64 km a day. Most Mini E users charged their cars at night at home, and only two or three times a week. This suggests that public fast-charging infrastructure may not be so essential for drivers. Overall, the results of this test suggest that electric cars are in fact suitable for most drivers and range anxiety may be overdone (The Economist, 2010).

Similar conclusions can be reached based on a real-life trial by the University of Newcastle of 44 EVs in the Northeast of England, in relation to a national programme funded by the United Kingdom Office for Low Emission Vehicles (OLEV) for charging infrastructure ("Plugged in Places"). Results of the trial show that for over 90% of the driving time in the North East, the EV is within 5 km of a charging point, and within 15 km for 99% of the driving time. 95% of the journeys are well within the battery range (in line with the national average for the United Kingdom over 2002-2006, at 93%). In addition, the project finds that users on average overestimate their driving range (Neaimeh, 2012).

At the same time, psychological and behavioural factors may also play in favour of consumer uptake of green vehicles. EV drivers are likely to be young, early adopters with high disposable income, who prize the satisfaction of doing something positive for the environment and society and the "green" status they acquire by showing their vehicles.[35] This is why Carlos Ghosn, CEO of Renault-Nissan, sees EVs as a "complementary technology" (*The Economist*, 2010). Replacing a petrol- or diesel-driven car with an EV would reduce CO_2 emissions, especially in the EU and other countries that put a cap on emissions from electricity generation. Therefore, purchasing an EV could be a good option for individuals that are willing to contribute to fighting climate change and environmental degradation.[36]

A test trial with mainstream users sponsored by the UK Energy Technologies Institute shows a more nuanced picture, as it distinguishes between PHEV and pure BEVs. "Pioneers" (about 2% of the population) are the main target of carmakers in terms of EV adoption. The results of the test confirm the importance of attitudinal factors, as many drivers see the car as a status symbol. Pioneer consumers are willing to pay a price premium of up to GBP 10 000 to purchase a PHEV rather than an ICE vehicle. However, for pure BEVs the situation is different, and more challenging, as consumers want to be rewarded for adopting the vehicle. In the case of BEVs, pioneers are not willing to pay a price premium as readily as with PHEV; in fact, consumers tend to demand a discount of thousands of GBP relative to what they would pay for a conventional vehicle.[37]

4.2 Low social returns: inadequate infrastructure

A high level of uncertainty about the prospects of success of green vehicles and the long timescale for setting up the charging infrastructure may deter firms from investing in the necessary technologies. This barrier is made more acute by timing: the private sector may eventually invest in charging infrastructure, but it will probably not do so until sufficient demand generates a revenue stream capable of earning a reasonable return on investment (Lee and Lovellette, 2011). For utilities and other operators, investment in charging stations can be very hefty: the cost incurred in buying and installing different types of charging stations in North America range between USD 2 200 and 2 400 for a residential station and between USD 65 000 and 71 500 for a DC public charging station (Frost & Sullivan, 2012b).

4.3 Government failures

The role of the government may involve not only removing factors of inertia and failures in the market, but also tackling barriers to the development and diffusion of green vehicles created by its own institutional and regulatory systems. These barriers include subsidies and (implicit or explicit) preferences to incumbent technologies as well as policy unpredictability and uncertainty.

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35. For example, a 2009 survey of 1 564 customers in Europe shows that adopters of EVs are likely to live in France or the United Kingdom, in the age ranges 26-35 and 55+, male and with high disposable income (Frost & Sullivan, 2011).

36. An example can help quantify the magnitude of this contribution. Under a cap-and-trade scheme, if an ICE vehicle emits 180 g CO_2/km, and would be driven 200 000 km over its lifetime, replacing it with an EV would avoid 36 tonnes of CO_2. But if the price of an emission allowance in the EU ETS is EUR 15, a similar environmental impact could be obtained for EUR 540, by buying and cancelling 36 emission allowances.

37. *Source*: Telephone Interview with John Batterbee, Programme Manager for Transport, Energy Technologies Institute, 17 January 2012.

Perverse subsidies and preferences to incumbents

Among government failures, *perverse subsidies and preferences to incumbents* (*i.e*. conventional fuels and ICE) represent a disincentive for manufacturers to develop green vehicles and for consumers to adopt them.

The OECD and the IEA (as well as other organisations) have estimated the support given to production and consumption of fossil fuels, including in the road transport sector, in both OECD and non-OECD countries, using several data sources and methodologies (see, for example, OECD, 2012d; and International Energy Agency, 2010). For example, in 2010 fossil fuel subsidies were estimated at USD 409 billion (up more than 37% since 2009), against USD 66 billion for renewable energy (International Energy Agency, 2012). The IEA *World Energy Outlook 2010* estimated that the cost of consumption subsidies to fossil fuels in 2009 was USD 312 billion, the vast majority of them in non-OECD countries. The annual level fluctuates widely with changes in international energy prices, domestic pricing policy and demand: subsidies were USD 558 million in 2008. Only a small proportion of these subsidies goes to the poor. This figures is even more striking when compared with the cost of support given to renewable energy (USD 57 million) and the cost of ending global energy project by 2030 (USD 36 billion). It is clear that removing fossil-fuel consumption subsidies could make a big contribution to meeting energy security and environmental goals, including mitigating CO_2 and other emissions (International Energy Agency, 2010). In addition, subsidies provided to producers of fossil fuels may be in the order of USD 100 billion per year (IEA, OPEC, OECD and World Bank, 2010).

In addition, the OECD has compiled an inventory of over 250 measures that support fossil-fuel production or use in 24 industrialised countries, which together account for 95% of energy supply in OECD countries. Those measures had an overall value of about USD 45–75 billion a year between 2005 and 2010. In absolute terms, nearly half of this amount benefitted petroleum products (*i.e.* crude oil and its derivative products), with the rest equally split between coal and natural gas (OECD, 2012d).

Governments support consumption and production of fossil fuels in numerous ways: by intervening in markets in such a way as to affect costs or prices, by transferring funds to recipients directly, by assuming part of their risk, by selectively reducing taxes they would otherwise have to pay, and by undercharging for the use of government-supplied goods or assets. More than one transfer mechanism can be used. On the consumption side, a government may provide tax breaks to purchasers of motor vehicles and at the same time regulate the price of transport fuels below the international market price or even below the cost of producing the fuel (IEA, OPEC, OECD and World Bank, 2010).

Governments can also provide support to the manufacturing of motor vehicles. This issue became particularly topical as many OECD and non-OECD governments provided financial support to automobile manufactures during the financial and economic crisis, both directly and indirectly through vehicle purchase incentives as part of their stimulus packages. However, some of these schemes have been characterised by a reorientation of support towards AFVs.

Policy unpredictability and regulatory uncertainty

Policy unpredictability and regulatory uncertainty can have a significant impact on manufacturers' decisions as regards the production and commercialisation of green cars as well as on consumers' adoption. Manufacturers and investors need transparent information and a long-term predictable policy framework, especially for the market for green vehicles whose future prospects are still highly uncertain. In addition, investments in the development of AFV technologies can be irreversible (as in most innovative activities), and sunk costs cannot be recovered in the market. Therefore, governments that do not provide clear signals about their policy intentions over the duration of firms' planning horizons will tend to retard investment in innovation (Johnstone, Haščič and Kalamova, 2011).

Government policies should be consistent, foreseeable and credible vis-à-vis all the actors involved in green vehicle supply chains. For example, uncertainty over standards and interoperability between vehicles and charging infrastructure may hold back potential investors and buyers.

4.4 Market failures

A number of market failures potentially impinge on the diffusion of AFV technologies. If markets were perfect, there would be little need for government policies in support of market development for green cars. Market prices would fully reflect the externalities in road transport. Environmental costs would be fully reflected in the price of vehicles and the fuels used to power them, and thus be internalised by firms and households. Automobile manufacturers would invest optimally in new technologies. Information on the available alternative fuels and propulsion technologies would flow freely and transparently among producers and consumers.

But if failures in the market for road transport fuels and technologies do occur – as most would argue is the case – prices set in the market will not fully reflect the externalities caused by the use of fossil fuels and conventional engine vehicles, and will not therefore send the right signals to economic agents. There are two main types of such failures: information externalities and negative environmental externalities.

Information externalities

Information externalities occur when information is not transparent and the transformation of potential market needs into clear market signals may be lacking. For example, evidence from semi-structured interviews with 57 households in northern California suggests that consumers do not always act rationally in terms of incorporating fuel savings into their purchasing decisions. In particular, they do not have the basic building blocks of knowledge and information when they buy a vehicle. They also make large errors estimating gasoline costs and savings over time (Turrentine and Kurani, 2007). However, using panel data on new car registrations in Germany (681 models between 1995 and 2005, with each model observed an average of 7.35 years, giving a total of 5 007 observations), Vance and Mehlin (2009) find that consumers are not myopic in their car purchasing behaviour, but instead take into account the incremental costs that occur over ownership of the car.

Consumers also tend to have a high level of risk aversion, as purchasing a vehicle is the second highest spending item for a household after housing. This, coupled with the still scarce diffusion of green vehicles, implies that potential purchasers prefer to wait for others to try AFVs. In addition, consumers often have doubts over the reliability of green cars (*e.g.* on the battery in the case of EVs) and on general maintenance and operating costs (Natural Resources Canada, 2009).

Negative environmental externalities

Another market failure preventing widespread adoption of green cars can be ascribed to the existence of *negative environmental externalities*. For green vehicles, these refer mainly to unpriced environmental impacts related to GHG emissions and air pollution. If these costs are not internalised by households, there will be little demand for AFVs. Most of the benefits from green cars (beyond climate change mitigation and reduction of pollution, including also energy security) have the characteristics of public goods, meaning that firms and households cannot exclude others from benefitting from them. This particular market failure implies that policies will be needed in order to correct for the negative environmental externality. Of course, the most direct approach would be to put a price on the relevant externality, rather than promoting AFV technologies.

These market failures have been made particulary acute by the fact that gasoline and diesel prices have been volatile, and thus have not provided sufficient incentives for drivers to change their behaviour by reducing car usage (Gallagher *et al.*, 2007).

5. POLICIES TO FOSTER MARKET DEVELOPMENT FOR ALTERNATIVE FUEL VEHICLE TECHNOLOGIES

Several OECD and non-OECD governments have made a strategic decision to encourage the development and diffusion of green vehicles. For example, they have set very ambitious targets for the uptake of hybrid and electric vehicles.

This section reviews efforts by a number of OECD and non-OECD governments to encourage the development, market introduction and diffusion of green cars. It considers policies to foster technological innovation in the car industry aimed at this market segment, but focuses in particular on policies to facilitate market introduction, acceptance and diffusion, including those related to public procurement, regulation, standards, pricing and infrastructure. Where possible, the analysis points to the results of evaluations that could inform policy learning about good practices in OECD and non-OECD countries, which could be applied by other governments in their own national context. At the same time, the potential drawbacks and limits of targeted policy interventions are also highlighted.

In particular, governments should be careful to avoid locking in a sub-optimal AFV technology when designing measures in support of green cars. When determining the technologies that should be used to meet a given target, policy makers need to consider the dynamics of marginal abatement costs in relation to learning effects deriving from the deployment of AFVs technologies in the market (see Box 7).

Box 7. Marginal abatement costs, learning effects and technology targeting

Two main processes work in opposite directions on marginal abatement costs of CO_2 emission-reduction technologies, other things being equal: *i)* costs increase as emissions reductions get deeper; but *ii)* the cost of using each technology may also decline as a result of learning. Whether marginal costs will rise or fall over time depends on whether learning outpaces the move up along the cost curve, among other factors.

An analysis by the IEA of the changes in CO_2 emission reductions and abatement costs for road transport technologies shows that potential reductions rise over time because it takes time to roll out the improvements, and increase the use of specific technologies over the entire stock of vehicles. For example, reductions related to FCEVs only begin to show up by 2040 and become much more significant by 2050.

Time also has an effect on abatement cost reduction. For example, the IEA analysis shows a fairly strong cost reduction for batteries and fuel cells. In addition to changes in technologies, abatement cost reductions also result from rising fuel prices (because fuel savings become more valuable over time).

In 2020, marginal abatement costs quickly become very high while the amount of CO_2 reduction achieved is quite low. This is due to the high cost of BEVs and PHEVs, which needs to be reduced through policy support. Such intervention would not be justifiable from a societal perspective unless there are reasons to believe that the costs of AFVs technologies will come down over time, thanks to learning effects brought about by cumulative production.

As production rates of AFVs (together with fuel prices) increase over time (the IEA analysis extends to 2050) the cost of AFV technologies (such as BEVs, PHEVs and FCEVs) declines rapidly.

The implication of this analysis is that AFVs technologies should not be rejected simply because of a high cost per tonne in the early years, when very few vehicles are being produced. At the same time, policy makers should be cautious when predicting technology cost reductions, also because variations in technology costs are very sensitive to assumption on learning.

Source : International Energy Agency, 2012.

Governments should also be cognizant of the fact that policies may have different impacts according to the targeted alternative fuel or propulsion technology. For example, Hasčič and Johnstone (2011) assessed the relative importance of fleet-level fuel efficiency standards, after-tax fuel prices, and public support for R&D on innovation in electric and hybrid vehicles. They found that relatively minor changes in a performance standard or automotive fuel prices would yield effects that are equivalent to a much greater proportional increase in public R&D budgets. Their results suggest that depending on the type of technology there are significant differences between the effects of different policy measures. In the case of EVs the role of after-tax fuel prices is statistically insignificant in driving EV innovation, but fuel efficiency standards played an important role. The inverse is true for innovation in hybrid vehicles: after-tax fuel prices have a strong impact and are statistically significant, while standards have a minor impact and are not statistically significant. Therefore, ambitious performance standards and significant public support for research have a relatively more important role to play in fostering radical innovations than relative prices.

The timing strategy of policy intervention is critical. Achieving a low-carbon transportation system will require a combination of fuel economy improvements and adoption of alternative propulsion technologies. In both cases, it is important that policies foster a rapid market uptake of energy-efficient vehicles. Fuel economy is an area where the transformation has already begun, and should continue for the next 20 years to reach sustainability targets. As regards alternative fuels and propulsion systems, the transformation is incipient, but also needs to be successful (Fulton, 2012). Although AFVs technologies such as PHEVs and BEVs will have to be part of the solution in the long term, policy makers should not neglect the “low-hanging fruit” that fuel economy improvements represent in the short term. In addition, governments should recognise that ambitious intermediate and long-term targets for AFVs deployment will not be met without adequate preparation and ramp-up time.

Governments can implement the following types of policy instruments in order to promote the development, diffusion and adoption of green vehicles:

- R&D support
- Demonstration and verification (pre-commercialisation phase)
- Public procurement
- Performance-based regulations and standards
- Technology-based regulations and standards
- Price-based measures
- Support to commercialisation
- Information-based measures (Labelling and certification; consumer education and awareness-raising)
- Infrastructure provision
- Networks and partnerships.

The analysis in this report focuses specifically on policies that act on the demand (pull) side. Of course, supply-side (or technology-push) measures, such as direct public support to R&D, demonstration and verification also play an important role in fostering the development of alternative fuels and alternative propulsion technologies (Box 8).

Box 8. Supply-side policies to promote the development of green vehicles

Governments may provide support to R&D in order to overcome some of the market failures and systemic barriers that may result in a slow transition to low-carbon and energy-efficient transport systems. The main sources of market failures that have traditionally provided the rationale for public funding for R&D are indivisibilities, uncertainty and externalities (OECD, 2011f):

1. R&D activities often incur high fixed costs and economies of scale, while learning by doing gives rise to dynamic economies of scale. The government can contribute to fostering the still-limited market for R&D in AFV technologies, and thus increase the opportunities for innovators to gain returns on their R&D investment.
2. Investment in R&D is inherently risky and information asymmetries abound in markets for knowledge and technologies. This can be especially the case for innovations in AFV technologies, as they have yet to fully prove their commercial and technological viability and cannot yet show sufficiently clear economic and environmental benefits.
3. Knowledge has properties of a public good as performers of R&D can only imperfectly appropriate the results of their effort and the use of knowledge does not preclude its simultaneous use by others. Therefore, there are positive externalities whereby social returns exceed private returns, and under-investment in the production of new knowledge will occur. The non-appropriability of the results of R&D is common to innovation in general, including in AFV technologies.

Ensuring policy predictability is particularly important in the context of government support to R&D, due to the high fixed costs and economies of scale in R&D activities, as well as the riskiness of R&D investment and information asymmetries that exist in markets for technology. However, political priorities can shift. For example in the United States, government budgetary support was reoriented from hydrogen fuel cells to electric vehicles following the change in administration in 2008 (Voorhees, 2009).

Government support for R&D can be provided directly, through investment in public research, or indirectly, through support for research activities in other public and private institutions. It can take several forms, typically grants or tax credits, but also through other measures, such as technology inducement prizes. In many OECD countries, R&D programmes seem to be mainly sector- or technology-specific (OECD, 2009c). R&D subsidy schemes for the development of alternative vehicle technology have been implemented in many OECD countries (Haščič and Johnstone, 2011).

For example in **Canada**, the Automotive Innovation Fund is an R&D initiative aimed at developing fuel-efficient vehicles. In the **European Union**, part of the financial envelope under the European Green Car Initiative goes to research activities. In **Finland**, TransEco is a five year (2009-13) Research Programme on Energy Efficiency and Renewable Energy in Road Transport initiated by VTT (Technical Research Centre of Finland) on vehicle technology and biofuels.

In recent years, considerable funding was allocated to hydrogen RD&D in the United States, Germany, Japan and Korea among others, with a clear focus on transportation. For example, in **Germany** the National Innovation Programme Hydrogen has a budget of about EUR 1.4 billion for hydrogen RD&D between 2007 and 2016. In the **United States**, annual expenditure on hydrogen RD&D averaged around USD 160 million over the past five years. In **Japan**, funding for hydrogen-related RD&D via the Japanese New Energy and Industrial Technology Development Organisation was about USD 100 million in 2011. Hydrogen RD&D was funded with some USD 600 million over the past ten years in **Korea**. In the **European Union**, USD 600 million were allocated to research and demonstration projects for 2008 to 2013 (International Energy Agency, 2012).

A word of caution is in order when using public R&D expenditure as an indicator of support to innovation in an industry characterised by a proliferation of technology trajectories. In this context, an indicator of R&D expenditure may be too aggregate to be meaningful from a policy perspective: for instance, it may be misleading in the case of hybrid and electric vehicles, as expenditures in one technology area may not benefit others (OECD, 2011b).

Governments can also facilitate the development of green cars by supporting testing of first-time or early-stage technologies (demonstration) or testing of ready-to-make technologies and reporting on their performance to guarantee their quality to users (verification) (OECD, 2009c). For example, the Centre of Excellence for Low

Carbon and Fuel Cell Technologies in the **United Kingdom** focuses on catalysing innovation in these areas through knowledge transfers and technology demonstration. In the **United States**, the Department of Energy's Vehicle Technologies Program supports demonstration, testing and technology validation of advance vehicle technologies and renewable fuels.

The inventory of ongoing policy initiatives reviewed and analysed in this report shows that AFVs are being deployed with diverging sets of standards, incentives, business models and degrees of government involvement across countries. This reflects different approaches to how to promote green transportation as well as differences in countries' regulatory frameworks, experiences and policy goals. Governments can play different roles in fostering the development of green vehicle markets: either as facilitators (*e.g.* in the Netherlands and Korea) or as leaders with a more proactive, top-down approach (*e.g.* in Estonia).

In particular, the following elements may explain the sheer variety of initiatives and paths followed in different countries:

- *Industrial structure and presence of incumbent firms.* Established automobile manufacturers and newcomers are likely to have different strategies as regards the development of green car technologies. Traditional carmakers are divided between taking a leading exploratory role to leverage rapidly their market power in the sector, and taking an imitative approach to avoid costs of search-and-try errors and seeking to protect their historical brands. On the other hand, newcomers may explore more radical innovative alternatives. In countries lacking a strong historical automobile manufacturer, it is more likely that governments promote the introduction of disruptive technological solutions and business models (OECD, 2011e). In addition, government policies in countries where automotive manufacturers are well established are sometimes closely aligned with the business strategies of those incumbent firms. Among incumbents, utilities also play an important role: for example, the electric grid will be crucial because it determines to what extent EVs can be zero-emission vehicles rather than displaced-emission vehicles. In addition, utilities can contribute to the creation of a secondary market for used batteries, which could be used by households to generate electricity much as is the case with photovoltaic panels.

- *National policy priorities to improve environmental performance.* The environmental context and priorities have an important bearing on the choice of policies to foster clean vehicle markets. Jurisdictions that place a high value on climate change mitigation and environmental improvements (*e.g.* reduction of local air pollution) such as the European Union and California are more likely to adopt a broad array of instruments. These include more stringent, more flexible and more transparent environmental regulations and standards, but also R&D support and information services (OECD, 2011b).

- *Distance from the technological frontier and size of the market.* OECD analysis shows that the choice of instrument to support eco-innovation is related to a country's innovation potential and level of development. Countries with a higher potential for innovation tend to focus mostly on supply-side measures to support eco-innovation and favour R&D support. Less advanced countries tend to rely more on demand-side instruments, such as standards and regulations or technology transfer. This reflects their technological capability and their emphasis on diffusion and adaptation (OECD, 2011b). At the same time, as suggested by the OECD Innovation Strategy, countries with small domestic markets or less innovation/knowledge capacity could develop more targeted strategies and focus on specific areas of innovation. For example, while a number of OECD countries are introducing policies in support of a broad range of AFV technologies, others are targeting EVs more directly (*e.g.* Estonia, the Netherlands, Israel).

One overarching observation emerging from policy cases in OECD and also non-OECD countries is that many initiatives to promote the adoption of green vehicles are taking place at the level of cities, as part of strategies to improve air quality and reduce congestion and noise. According to the IEA, urban programmes are critical for reaching the target of 20 million electric vehicles (EVs) worldwide by 2020, a goal that is deemed important to increase energy security and reduce CO_2 emissions at the same time.

For example in **Canada**, provincial and municipal authorities have taken a leadership role in fostering development of demand and infrastructure for EVs. This is leading to experimentation and demonstration at a local level and regional scale that could later be applied more broadly (OECD, 2011b).

A comprehensive review of measures implemented at the sub-national level is beyond the scope of this report. However, some lessons can be drawn from an analysis of 16 cities in 9 countries on 3 continents (EVI, Rocky Mountain Institute, IEA HEV-IA, 2012). While demonstration and deployment approaches are tailored to each city's particular circumstances, some common practices emerge:

- Many cities offer a mix of financial and non-financial consumer incentives to boost demand for vehicles and public charging infrastructure.
- Financial incentives include rebates or tax credits on vehicles (often paired with incentives offered at the level of national governments), exemptions from vehicle registration taxes or licence fees, discounted tolls and parking fares, as well as discounts for recharging equipment and installation.
- Non-financial incentives include preferential parking spaces, access to restricted highway lanes, and expedited permitting and installation of EV supply equipment.
- Many cities are playing a central role in public procurement programmes, for example by purchasing EVs for the municipal fleet and by incorporating hybrid buses into public transportation.
- In many OECD and non-OECD countries, the deployment of charging infrastructure is mainly driven by municipalities. In particular, cities are placing charging stations in public buildings and offering discounted electricity rates for EV users from utilities owned by municipalities.
- Finally, many networks and partnerships to promote the development and diffusion of AFVs are implemented at the level of cities. They include city planners, automakers, utilities, infrastructure suppliers, academics and research institutions, and city and national officials.

5.1 Public procurement

Rationale for the instrument

Economic demand from public procurement can create or enlarge markets for greener products and services. Since the 1980s, "Green Public Procurement" (GPP) has been promoted and implemented in a number of OECD and non-OECD countries (and 2002 saw the adoption of the

OECD Council Recommendation on Environmental Performance in Public Procurement). In addition, public procurement has long been considered a tool to foster innovation.

Public procurement can play an important role in tackling many of the factors of inertia that impinge on the diffusion of green vehicles. For example, automobile manufacturers have an incentive to develop and produce AFVs because procurement can help them recuperate the sunk costs of large and risky investment over a pre-determined period of time. The concentration of public demand brought about by bundling together the demand emanating from various government agencies and bodies can create clear incentives for suppliers and reduces their commercial risk (Fraunhofer Institute for Systems and Innovation Research, 2005).

Public procurement programmes to purchase a fleet of green cars (or in public transport) can also promote adoption by private motorists, thanks to network effects. Public sector fleets can be sizeable: for example, the fiscal year 2010 census of the United States federal fleet reports a total of 249 359 passenger cars in all agencies, of which 152 775 in civilian agencies, 87 242 in military agencies and 9 342 in the US Postal Service. In addition, there were 403 129 trucks – of which 97 022 in civilian agencies, 103 583 in military agencies, and 202 524 in the U.S. Postal Service – and 9 666 other vehicles (Government Fleet, 2011a). State agencies have the largest median annual budget (less capital) at USD 8 million, followed by federal agencies (USD 6 million), counties (USD 3.4 million) and cities (USD 2.7 million). 83% of public fleets have a formal replacement programme, and the median rolling stock fleet size amounts to 376 units (Government Fleet, 2011b). In the United Kingdom, the Central Government fleet (excluding local authority and Transport for London) in 2008-2009 consisted of 108 139 vehicles, of which 74 256 passenger vehicles and 33 883 commercial vehicles (DEFRA, 2010).

By creating a signalling effect as lead users, governments can induce the diffusion of innovation and thus create and/or expand the network that is needed for early adopters, and then encourage private firms and consumers to take up green vehicles.

"Green public fleets" can also play an important demonstration effect in the commercialisation phase of AFVs, as they enable potential users to witness how green vehicles compare with conventional gasoline- and diesel-powered vehicles in terms of performance, reliability and other characteristics. Thus, public procurement may contribute to breaking some of the psychological biases against green vehicles. It can also help to overcome information asymmetries.

At the same time, using public procurement to foster consumer uptake of green vehicles can be a double-edged sword. It could be the case that the vehicles purchased through a government programme do not deliver on the expected performance, safety and cost-effectiveness. Or, even if the technical characteristics of the vehicle do live up to their expectations, public officials in charge of procurement may not have the adequate capacity to manage the programme to ensure that the demonstration effects are maximised. This could dent consumers' willingness to experiment with AFV technologies. Therefore, a failed demonstration programme may provoke a backlash against green vehicles.

The risks inherent in using public procurement as a demonstration tool call for thorough evaluations of the impacts of these programmes on consumer confidence vis-à-vis green vehicles and the resulting uptake. This could entail, for example, undertaking surveys of public perceptions of green vehicles following a public procurement programme, at the level of central government or local authorities. The impact of the demonstration effect induced by public procurement purchases of green vehicles for both individuals and commercial fleets could be assessed by controlling for other factors through econometric techniques (provided that sufficient and good-quality survey data is available). However, currently such evaluations are largely absent across OECD countries.

Policy practices

Many OECD countries are using public procurement as a tool for demonstration and deployment of green vehicles. For example, as part of its Electromobility Programme (ELMO) the government of **Estonia** has launched a demonstration programme, whereby it purchased 507 Mitsubishi iMievs by selling to the company unused Assigned Amount Units (AAUs) of CO_2 under the EU Emission Trading Scheme. The vehicles are owned by the Ministry of Social Affairs of Estonia, but then assigned to local municipalities and put at the disposal of social workers. As these public officials often deliver social services in rural and isolated villages, the programme has the objective to demonstrate that EVs can work for a wide range of drivers and in very diverse geographic areas.

France experimented with public procurement to promote EVs as early as the 1990s. A formal agreement between the French government, the two main carmakers Renault and PSA, and Electricité de France aimed at bringing the stock of EVs to 10 000 vehicles by the year 2000. As part of this strategy, 10% of the new vehicles purchased for the public fleet were to be electric (*i.e.* at least 1 000 vehicles) (ADEME, 2010). One year later, the target was increased to 20% for government agency fleets of at least 20 vehicles (Hasčič and Johnstone, 2011). No formal evaluation was carried out on the effects of the public procurement programme on consumer uptake. However, a simple review of new passenger car registration statistics shows that the intended target of 10 000 vehicles by 2000 was largely missed, as the cumulative number of newly registered EVs in the period 1994-2001 was only 7 059 units. ADEME (2010) gives the following reasons for this underachievement: the high cost of vehicles; the very limited range (80 km); the lack of charging infrastructure; and technical constraints with the batteries (*e.g.* long charging period).

More recently, the French government reintroduced a programme of public purchase of EVs, including for state enterprise fleets (*e.g.* La Poste, Box 9) for demonstration purposes. It is expected that more than 20 000 vehicles will be procured for the public sector in the next four years.[38] Crist (2012) questions the rationale for subsidising these purchases, since these fleets are generally operated in conditions favourable to the use of EVs, and their operators have the financing capacity to make the upfront capital investments needed without assistance.

[38] Personal communication with the Ministry of Economy, Finance and Industry of France.

Box 9. Public Procurement of EVs in France: the case of *La Poste*

The French Mail ("La Poste") currently has the largest industrial fleet in France, with over 50 000 vehicles. In December 2011, it announced the purchase of 10 000 electric cars by 2015, in addition to some thousands of electric quad bikes and 10 000 e-bikes. This procurement programme will give *La Poste* the largest fleet of EVs in the world. Over 1 600 EVs will already be delivered to mailmen in 2012.

Preparations for the purchase were launched in 2010, and involved a preparatory study, co-ordination and consultation with different stakeholders, and the drawing of the technical details of the tender. In October 2011, the decision was made that Renault and Peugeot would supply the the EVs to *La Poste*.

Source : *La Poste* (2011).

One of the pillars of **Japan**'s strategy to develop AFVs, started in the early 1970s, was market support (along with RD&D support and standardisation). Public procurement was one of the main instruments implemented to foster the development of the market for green cars. Under the 1995 Environment Conservation Programme, the central government announced that it would replace 10% of public vehicles with low-emission vehicles (LEVs) by 2000, and again in 2001 a new programme was put in place to replace all government vehicles with LEVs by 2004. These public procurement programmes were designed to be technologically neutral: they covered HEVs and BEVs, but also NGVs (but the Environment Ministry expected that 60% of these LEVs – roughly 4 000 vehicles – would be HEVs). Also the larger prefectural governments implemented public purchasing programmes in favour of BEVs (and thus targeted a specific fuel and a specific technology) in 1993 (Åhman, 2006).

The aim of all these programmes was to achieve 100 000 BEVs and 170 000 LPGVs by 2000. However, these first procurement programmes did not meet the targets, neither at the central nor at the prefectural levels, as only a few BEVs were in use in 2000. The main reason for the failure in meeting the targets seems to be that agencies and local governments found it unaffordable to purchase costlier low-emission vehicles in a time of deep economic stagnation as experienced by Japan in the 1990s (Åhman, 2006).

Among the more recent efforts to promote the diffusion of green vehicles through public procurement in Japan, the Green Purchasing Law of 2000 includes also motor vehicles among the 17 categories of products covered by the legislation. The green purchasing system led to all official vehicles having been replaced by low emission vehicles by the end of fiscal year 2004, and prevented significant amounts of CO_2 emissions until 2009, the latest fiscal year for which data is available (Table 7).[39]

[39] The total budget allocated for the public procurement programme is not known; therefore it is not possible to assess the extra cost incurred by the government to purchase green vehicles rather than conventional vehicles for the public fleet. In terms of pure avoidance of CO_2 emissions induced by the programme, taking the fiscal year 2003 as an example, it can be noted that a similar impact on global CO_2 emissions could have been obtained for less than EUR 250 000 by buying and cancelling emission allowances in the EU ETS. Of course, a full cost-effectiveness analysis should also take into account the impact of the demonstration effect of the programme on private individuals' purchases of green vehicles, and the resulting reduction in CO_2 emissions.

Table 7. Amount of CO2 emissions prevented (tons-CO2)

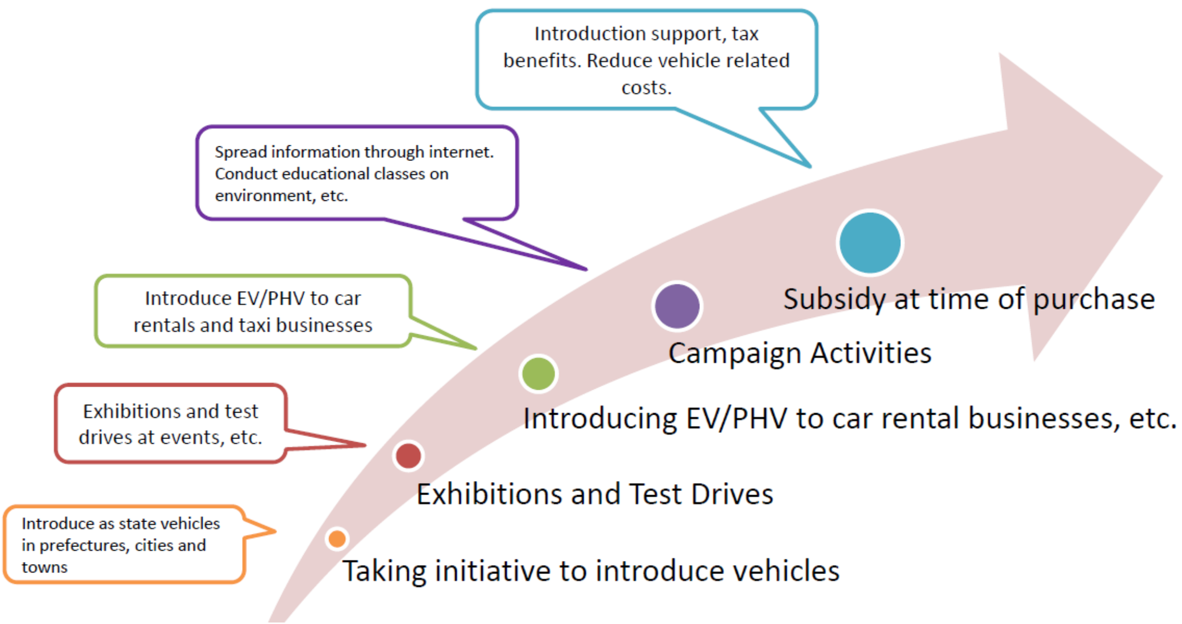
Year	Amount prevented (yearly)	Amount prevented (total)
FY2003	3 186	15 929
FY2004	2 483	12 415
FY2005	2 051	14 358
FY2006	1 223	8 563
FY2007	856	5 995
FY2008	848	5 934
FY2009	1 431	10 014

Note: The usage of the vehicle is estimated at 5 years for vehicles purchased in FY2003 and FY2004, and at 7 years for vehicles purchased in all other FYs.

Source: Japan's Ministry of Environment press releases "Evaluation for the reduction of environmental burdens by government's effort through the promotion of greener procurement", issued in FY2005-11. Available at: http://www.env.go.jp/policy/hozen/green/g-law/kakonooshirase.html.

Green public procurement requirements do not apply at the local level in Japan; however, many local authorities have voluntarily implemented the measures (Capozza, 2011). In addition, the Next Generation Vehicle Strategy of 2010 identifies public procurement at the local level as the first step in the chain of activities needed to foster initial demand for EVs (Figure 23).

Figure 23. Creating initial demand for EV/PHV in towns



Source: METI, 2010a.

The **United States** has been using public procurement to accelerate the diffusion of alternative transportation solutions since the early 1990s. In 1992, the Energy Policy Act (EPAct) required that 75% of new LDVs acquired by certain federal fleets must be AFVs, as well as that certain state government and alternative fuel provider fleets acquire a specific percentage of AFVs. Subsequently, the Clean Cities Programme was created in 1993 to provide informational, technical and financial resources to EPAct-regulated fleets and voluntary adopters of AFVs. The United States public procurement scheme for AFVs is designed to be technology neutral as it includes HEVs, FCEVs, but also energy-efficient conventional propulsion technologies. It also allows blending with biofuels (U.S. Department of Energy, 2011b).

More recently, other OECD countries have introduced public procurement of AFVs. In 2011, **Italy** passed legislation to implement the EU Directive on Green Public Procurement in the transport sector. The law establishes an obligation for both public administrations and public transport operators to use criteria related to energy consumption, CO_2 emissions and air pollution when purchasing vehicles for road transport. The design of the programme is technologically-neutral, as it covers different types of alternative fuels (not only EVs, but also CNG, LPG and biofuels).[40]

Korea has also had a Green Procurement Law ("Act on the Promotion of the Purchase of Environment-friendly Products") since 2005 and, as part of the 2008 Hybrid and Fuel-Cell Powered Vehicles Plan, has promoted the use of hybrid vehicles through the purchase of hybrid cars by government agencies for official use. The 2010 *Strategy for Green Car Development* reinforced this objective further by setting the target that 50% of vehicles purchased for the public fleet located in the capital area should be AFVs by 2013.[41]

As part of its 2011-15 Electric Mobility Action Plan, the government of the **Netherlands** is assessing the feasibility and financial implications of purchasing EVs for the public fleet, by field-testing 26 EVs.[42]

In the **United Kingdom** the government's Low Carbon Vehicle Public Procurement Programme (LCVPPP) is currently providing funding to support the trial of over 200 electric and low-emission vans in a range of public fleets. The programme has three main objectives: allow for the collection of real life data about the vehicles' performance and usage; helping to drive ongoing technological development; and demonstrate the existing capabilities of green vehicles.[43]

In addition, a new Government Buying Standard (GBS) for transport was published in November 2010, and became mandatory for central Government departments in February 2011. An *ex ante* impact assessment of the revised standards found that the benefits following the introduction of the preferred option (*i.e.* update and align GBS with the EU Green Public Procurement Transport Requirements, plus additional proposed considerations to further the sustainability benefits) would outweigh the costs (Table 8).

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40 Personal communication with the Ministry of Economic Development of Italy.

41 Personal communication with the Ministry of Knowledge Economy of Korea.

42 Personal communication with the Ministry of Economic Affairs, Agriculture and Innovation of the Netherlands.

43 Personal communication with the United Kingdom Department for Business, Innovation and Skills.

Table 8. Cost-benefit analysis of revised "Government Buying Standards" specifications for Transport Products and Services

	Low (GBP million Present Value)	High (GBP million Present Value)
Costs		
Administrative burden	0.044	0.095
Financial costs	0.000	7.042
Total cost	**0.044**	**7.137**
Benefits		
Avoided GHG emissions from reduced vehicle emissions	1.172	1.465
Air quality benefit – avoided damage costs from emissions	2.867	4.589
Financial fuel savings	3.887	4.858
Avoided GHG emissions through reduced waste and to landfill/increased recycled content	0.109	0.543
Avoided energy costs	0.351	1.753
Avoided waste management costs	0.006	0.030
Total benefits	**8.392**	**13.247**

Source: DEFRA (2010).

Also in the United Kingdom, the Prince of Wales's Corporate Leaders Group on Climate Change and the Department for Business, Innovation and Skills launched three Joint Public–Private Low Carbon Procurement Compacts for new, "low to zero carbon goods and service. The "Down to Zero" Compacts bring together major public and private sector customers to demonstrate to potential suppliers that there is a substantial and organised market demand for cost-effective and low-carbon solutions in three areas, including transport. As part of the process, a market sounding phase is designed to gauge the interest and capacity of the supply chain to deliver the solutions in response to unmet needs identified by customers. This is a form of catalytic procurement, as the government (both at the central and local level) is only one of the leading customers for the innovative goods and services (The Prince of Wales's UK Corporate Leaders Group on Climate Change and Department for Business, Innovation and Skills, 2012).[44]

[44] The signatories to the Low to Zero Carbon Transport Procurement Compact are: Anglian Water, Bedford College, Birmingham City Council, BSkyB, BT, EDF Energy, Government Procurement Service, Johnson Matthey, B&Q, Lex Autolease, The Rotherham NHS Foundation Trust, Wakefield and District Housing (WDH), and Wiltshire College.

Lessons learned

The inventory of selected initiatives analysed in this report shows that although public procurement has significant potential for fostering the development and deployment of green vehicles, there are also some important challenges. For example, the public sector may lack the capacity to design and implement purchasing programmes that are oriented to stimulating eco-innovations in the transportation sector. This issue may be even more acute at the sub-national level, as municipalities and regions often lack procurement-specific knowledge and personnel. However, as shown in the policy cases, many public procurement programmes for low-emission vehicles are often carried out at the city level (*e.g.* United States, Japan). These schemes will need to consider the capacity of the public sector to ensure effective implementation.

Moreover, using public procurement to support marked development of green cars runs the risk of inefficient policies and distortion of the competitive process, including in the international context. The policy cases show that the empirical basis for assessing whether procurement of low-emission vehicles is a more cost-effective way to achieving the set innovation and environmental goals than market-based instruments or other supply- or demand-side policies is largely lacking. This underscores the importance of collecting and analysing evidence on the impact of procurement on innovation in AFVs, on adoption in the market and on CO_2 emissions and air pollution reduction.

5.2 Performance-based regulations and standards

Rationale for the instrument

Performance-based regulations and standards can be designed to foster improvements in environmental performance of motor vehicles. They may do so by: defining the scope of energy efficiency and environmental performance; setting the performance target (*e.g.* minimum limit of fuel economy or maximum limit of CO_2 emissions); and introducing a penalty in the case of non-compliance. Implementation of fuel economy standards and emission-control regulations for road vehicles can accelerate dissemination, if the standards are well-crafted (OECD, 2010d). Performance-based regulations and standards should be set by taking into account well-to-wheel calculations of the energy efficiency of vehicles. They can have an important impact on the production of "green" electricity or hydrogen, as well as the usage of non-ICE engines or very CO_2-efficient ICE engines.

Performance regulations and standards can play an important role in encouraging competition between specific fuels or propulsion technologies and in avoiding irreversible effects that could lead to lock-in. Governments should design fuel economy regulations so that they are technology neutral, and ensure that they foster continuous innovation by allowing flexibility in achieving the outcomes rather than by supporting specific solutions.

However, when a technology is already locked in (arguably the case for the road transport system based on gasoline- and diesel-powered internal combustion engines), performance regulations and standards may not be sufficient to bring about more radical innovations. In some cases, this has led regulators to turn performance regulations and standards into *de facto* technology mandates. For example, a regulation may require that a certain number of vehicles sold (as percentage of total sales) have to meet fuel economy or GHG emission standards which are so stringent that they can only be met by one type of propulsion technology. This is risky: if regulators underestimate technology development, they may set a performance standard that is not stringent enough to reap the potential environmental benefits. But if regulators overestimate the technological potential, the stringency of the standard could place too heavy a cost burden on manufacturers, relative to the resulting emission reductions and environmental benefits (Bedsworth and Taylor, 2007).

Performance-based regulations and standards can also help to change consumers' norms and habits vis-à-vis green cars, as well as overcome information asymmetries, by highlighting the improved fuel economy and environmental performance of an AFV relative to less efficient and more polluting options.

Finally, by setting a performance target, fuel economy or emission-reduction standards can enhance regulatory certainty for carmakers and investors, especially if governments commit for a long-term horizon. To this effect, the introduction and potential revisions of the standards should be communicated clearly and transparently to all interested stakeholders (*e.g.* automobile manufacturers and users).

Performance-based regulations and standards should be set on the basis of data reflecting the typical usage of vehicles. Current emission cycles, such as the New European Driving Cycle (NEDC) or the Federal Test Procedure (FTP) in the United States may not reflect accurately the typical usage of green cars. Actual in-use fuel economy performance can be up to 25% worse than the tested values. This divergence can be due to several factors: test cycles are not representative of all types of driving; some technologies (*e.g.* air conditioning) are not tested; vehicle maintenance (*e.g.* after-market parts such as tyres, are not always as good as those tested); driving behaviour; and traffic and road surface conditions (Tam, 2011). Either performance measurements using traffic simulations or stochastic tests to measure performance of vehicle types in real-life usage should be required to adjust the performance ratings of vehicle series.

Policy practices

Several OECD and some non-OECD countries have adopted performance standards to improve the energy efficiency of vehicles, with heterogeneous approaches (Table 9) leading to different impacts on fuel economy and GHG emissions (Figures 24 and 25). More countries, including Brazil, India, Mexico and South Africa, are expected to introduce similar measures in the future (An, Earley and Green-Weiskel, 2011).

Average fuel economy levels vary from approximately 6 litres (L) per 100 km for the least fuel-intensive end of the spectrum (India) to over 9 L/100 km at the most fuel-intensive end (the United States). Average new LDV global fuel economy improved at a rate of 1.7% between 2004 and 2008.[45] While some countries and regions are improving their fuel economy considerably (*e.g.* European Union), others are quickly becoming less fuel efficient (*e.g.* China, Brazil, Mexico, India) (International Energy Agency, 2012).

[45] Average of 21 countries and sample of cars examined by the Global Fuel Economy Initiative.

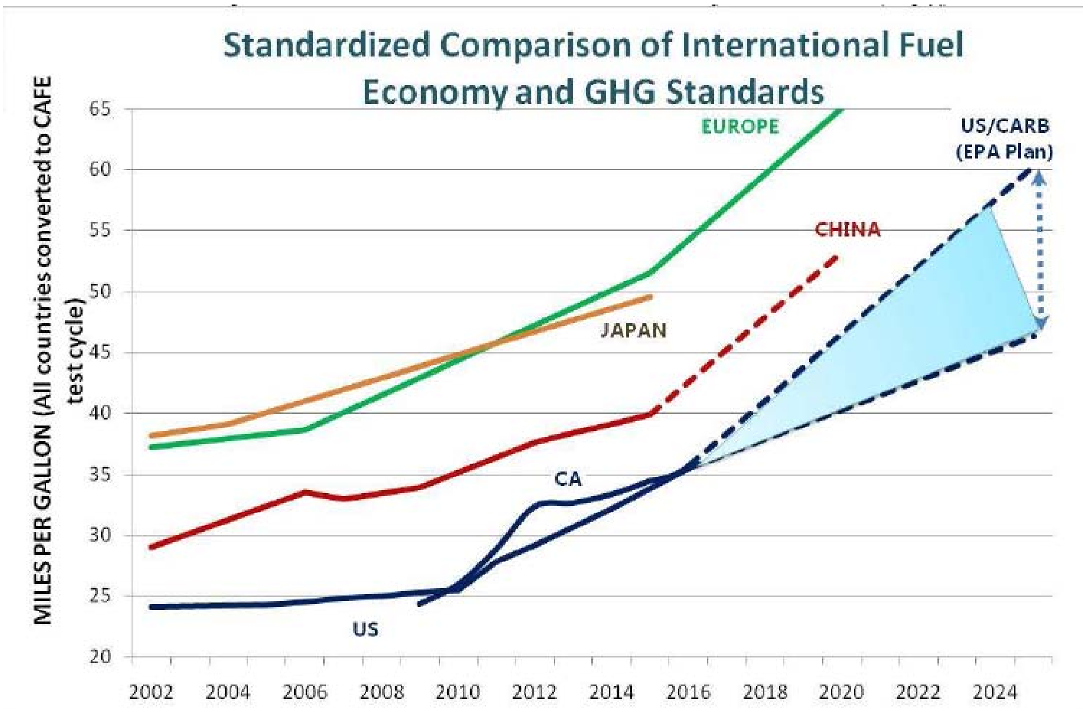
Table 9. Fuel economy and GHG emission standards for vehicles in selected countries

Country/region	Type	Measure	Implementation
United States	Fuel	Mpg	Mandatory
California	GHG	g/mile	Mandatory
European Union	CO_2	g/km	Voluntary, mandatory as of 2012
Japan	Fuel	Km/l	Mandatory
China	Fuel	L/100-km	Mandatory
Canada	Fuel	L/100-km	Voluntary
Australia	Fuel	L/100-km	Voluntary
Korea	Fuel or GHG	Km/l or g/km	Mandatory

Source: An, Earley and Green-Weiskel (2011).

Figure 24. Standardised comparison of international fuel economy standards (mpg)

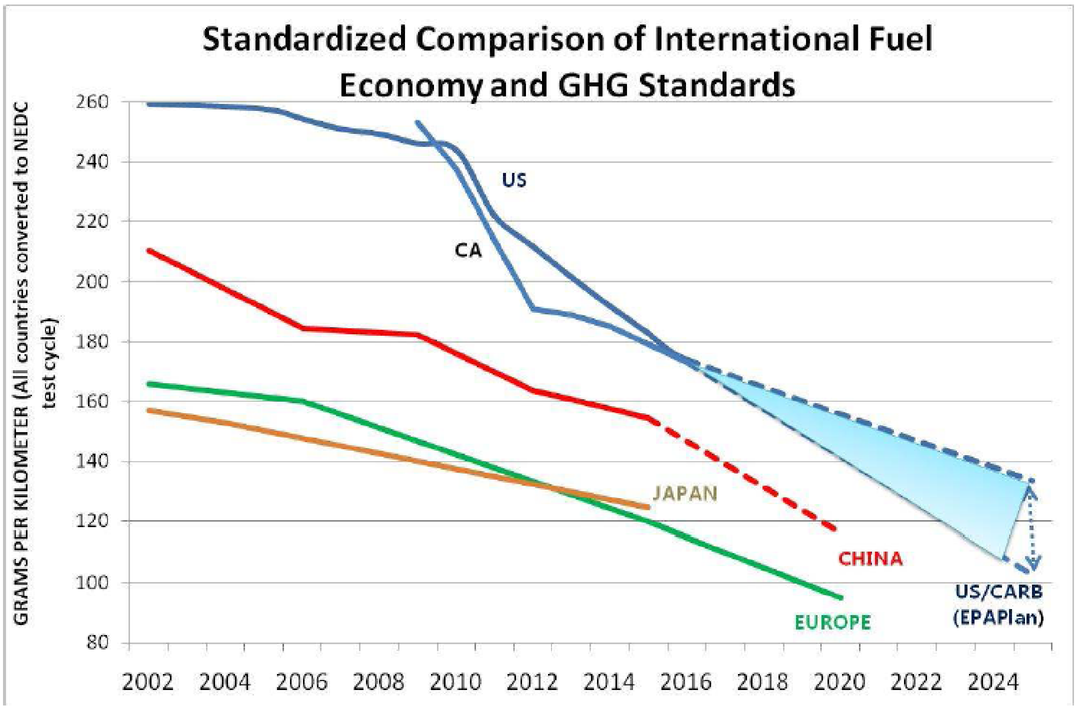
2002-24



Source: An, Earley and Green-Weiskel (2011).

Figure 25. Standardised comparison of international fuel consumption standards based on GHG emissions (gCO2/km)

2002-24



Source: An, Earley and Green-Weiskel (2011).

United States

The Corporate Average Fuel Economy (CAFE) Standards

Performance standards can be either mandatory or voluntary. Until recently, mandatory approaches were rare. One notable example is the United States' Corporate Average Fuel Economy (CAFE) set of standards, enacted in the Energy Policy Conservation Act (EPCA) of 1975 and first applicable to 1978 models, largely in response to the 1973-74 oil embargo. These standards regulate fuel efficiency expressed in miles per gallon, as opposed to limiting CO_2 emissions as is the case in the EU as well as California and other US States (Morrow *et al.*, 2010).

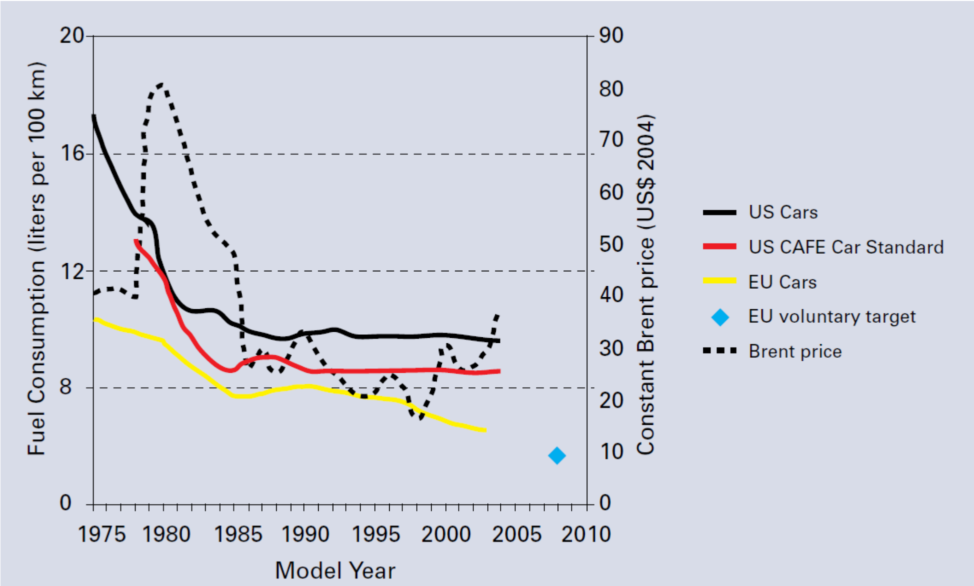
For many years car fuel economy was unchanged and the truck fuel economy standard rose only slightly in the United States. In 2007, the Energy Independence and Security Act (EISA) mandated the National Highway Traffic Safety Administration (NHTSA) to set standards achieving 35.5 miles per gallon (mpg) for the 2017 model year (MY) by 2020. Finally, in 2011 the government and a number of major carmakers reached an agreement on a fleet-wide average 54.4 mpg target by 2025, marking a significant increase in regulatory stringency. While the 2017 MY CAFE standard represents a 30% increase from the 2010 average, the 2025 MY standard will lead to a 54% improvement from the 2017 MY target (PWC, 2011).

A relatively high degree of stringency is an important condition for inducing more innovation (Ashford, Ayers and Stone, 1995). This is independent of whether the standard is mandatory or voluntary, as a comparison between the CAFE set of standards and the previous EU voluntary standards[46] illustrates (Figure 26). In the United States, the fuel economy standard remained unchanged since 1990 until the recent amendments to the legislation, and this lack of stringency was reflected in a comparatively slower rate of improvement in vehicle fuel efficiency. In the EU, there has been a continuous improvement in vehicle fuel efficiency since 1975, driven in part by relatively more stringent (though voluntary) targets than those set in the United States.[47]

A mandatory standard based on fuel economy improvements, like the CAFE, is technologically neutral by design. However, if the standard is characterised by a high enough degree of stringency, incremental innovations in the dominant technology (*i.e.* gasoline- and diesel-powered ICE) will not be sufficient to meet the target by the set date. PWC (2011) argues that while carmakers can rely on existing technologies such as hybrids, direct injection and turbocharging to achieve the 2017 MY goal, improvements in current technologies, but also more radical innovations, will be required to reach the 2025 MY target.

Figure 26. Stringency of performance standards in the US and the EU, and impacts on fuel efficiency improvements

1975-2004



Source: BERR (2008).

California's approach to vehicle low-emission standards

Within the United States, California has been a leader in promoting stringent emission vehicle standards. In 2002, the state adopted legislation (Assembly Bill 1493) directing the California Air Resources Board (CARB) to achieve the maximum feasible and cost-effective reductions in GHG emissions from light-duty vehicles. Consequently, CARB adopted regulations (known as "Pavley regulations", from the name of the person who sponsored the Assembly bill) requiring manufacturers to reduce emissions, expressed as grams of GHG per mile, effective with 2009 models. The emission standards become increasingly more stringent through the 2016 model year. CO_2 emission rates are

46 EU emission standards were made mandatory in 2009 – see further below for more details.

47 Fuel taxes and prices also played an important role in shaping these developments.

expressed as CO_2 equivalents to account for emissions of all GHG (CO_2, N_2O, CH_4, HFCs) from vehicles. The regulation provides manufacturers with the flexibility of meeting these standards through a combination of reducing tailpipe emissions of CO_2, N_2O and CH_4, and receiving credits for systems demonstrated to mitigate fugitive emissions of HFCs from vehicle air conditioning systems (CARB, 2008). A second set of more stringent standards ("Pavley II") is scheduled to enter into force effective with 2017 models, with the aim of meeting the requirement of reducing GHG emissions to 80% below 1990 levels by 2050.[48]

The GHG emission standards are to be integrated into the low emission vehicle (LEV) programme, which was introduced in 1990 and has focused on reducing emissions of oxides of nitrogen, non-methane organic gases (NMOG), and carbon monoxide (Bedsworth and Taylor, 2007). Unlike the CAFE standards, the Pavley standards do not apply separately to cars and trucks. While federal CAFE standards aim at reducing fuel consumption, California's standards target GHG emissions directly. Since CO_2 emissions and gasoline use are nearly proportional, these limits raise the fuel economy requirements for manufacturers in the states adopting the limits (Goulder, Jacobsen and van Benthem, 2012).

These regulations prompted a series of legal disputes between the state of California, carmakers and the federal administration. Finally, in 2009 the Environmental Protection Agency (EPA) granted a waiver to California to implement its GHG emission standards for MYs 2009-2016 vehicles.

In January 2012, the CARB approved a new emission-control programme for model years 2017 through 2025 ("Advanced Clean Cars" programme), which combines the control of smog, soot-causing pollutants and GHG emissions in a single package of requirements. The CARB estimates that by the time the rules will be fully implemented in 2025, new automobiles will emit 34% fewer global warming gases and 75% fewer smog-forming emissions (CARB, n.d.).

Following California's lead, 14 other states approved the adoption of legislation to establish limits on GHGs per mile from light-duty vehicles.[49]

Interaction between federal standards and state-level standards

In 2009, the EPA and the U.S. Department of Transportation (DOT) proposed a new joint regulation for GHG emissions and fuel economy for light-duty vehicles. Subsequently, and in order to solve the issue of diverging federal and state-level regulation, it was announced that the CAFE standards would be merged with the California standards. The EPA and the NHTSA[50] developed harmonised light-duty fuel economy and GHG emission standards for vehicles built in MYs 2012-16 (released in April 2010) and then for MY 2017 and beyond (announced on 1 October 2010). Combined with the standards already in effect for MYs 2012-16, as well as the MY 2011 CAFE standards, the proposed standards would result in MY 2025 light-duty vehicles with nearly double the

48 This target was established in 2005 by Executive Order S-3-05. The other main piece of legislation is the 2006 Assembly Bill 32 (Nuñez and Pavley), which mandates a reduction in GHG emissions to 1990 levels by 2020.

49 Arizona, Connecticut, Florida, Maine, Maryland, Massachusetts, New Jersey, New Mexico, New York, Oregon, Pennsylvania, Rhode Island, Vermont, and Washington. In addition, Delaware and Illinois planned to adopt the Pavley rules (An, Earley, & Green-Weiskel, 2011; Goulder, Jacobsen and van Benthem, 2012).

50 NHTSA has the authority of proposing fuel economy requirements under the Energy Policy and Conservation Act, while EPA can regulate GHG emissions under the Clean Air Act.

fuel economy, and approximately one-half of the GHG emissions compared to MY 2010 vehicles (EPA and NHTS, 2011).

The merging of the federal standards with state-level standards goes in the direction of solving emission leakage derived from the interactions between the federal CAFE standards and the state-level Pavley regulations. Goulder, Jacobsen and van Benthem (2012) found three sources of interactions:

1. *The state-level standards induce offsetting emissions impacts in the states that do not adopt the limits*. Auto manufacturers exceed the overall federal average fuel economy requirements by selling more efficient vehicles in the states with stricter environmental regulations. Thus, they can change the composition of their sales outside the Pavley states, and sell cars with lower levels of fuel economy. The adjustments in non-adopting states' car markets would offset about 74% and 65% of the emission reductions in the adopting states' car markets under Pavley I and II, respectively.

2. *Leakage may occur from the new car to the used car market.* Regulation is likely to increase the price of new cars. Therefore, scrap rates will decline, as the number of households deciding to retain their used cars for longer periods (instead of purchasing new cars) will increase. Used cars tend to be less fuel efficient than new cars, hence the emission leakage. It is estimated that the adjustments in the used car market offset 8% and 5% of the reductions from new cars in the adopting states under Pavley I and II, respectively. This effect becomes much larger (18%–27%) when the number of states adopting Pavley regulations increases.

3. *More stringent state-level regulations can induce technological spillovers and reverse leakage effects.* More stringent regulations can induce additional investments in fuel-saving technologies in the states that adopt such standards. These investments can produce positive spillovers also in other states. However, only very high levels of technological spillovers would yield significant reductions in nationwide gasoline consumption or GHG emissions.

Overall, costs per avoided tonne of emissions are approximately twice as high when offsetting emission increases from new cars sold in non-adopting states and from used cars are taken into account. This would reinforce the view that state-level performance standards are costly measures relative to their environmental effectiveness. At the same time, it can be argued that, in spite of the leakage, more stringent emission regulations at the state level can induce eco-innovations and prompt the emergence of more cost-effective federal standards (Goulder, Jacobsen and van Benthem, 2012).

The Zero Emission Vehicle (ZEV) Regulation: performance standard and technology mandate

The design of the "Zero Emission Vehicle" (ZEV) regulation of California is quite unique, as it combines a performance standard – zero emissions – with a sales mandate to carmakers (Bedsworth and Taylor, 2007). It represents an example of a performance standard that is nominally technology neutral, but is in fact technology forcing. Although the CARB formally allowed carmakers to choose whatever technology they saw appropriate to meet the ZEV targets, EVs were the only feasible option when the mandate was conceived in 1990 (Calef and Goble, 2007).[51] The ZEV requires that carmakers maintain ZEV-certified vehicles as a percentage of total vehicles sold in California (initially, 2% by 1998, increasing to 5% in 2001, and 10% in 2003 and after). Automobile manufacturers can be fined by the CARB up to USD 5 000 for each violation.

51 . Different emission standards established by the CARB applied to four categories of vehicles: Transitional Low-Emission Vehicles (TLEVs), Low-Emission Vehicles (LEVs), Ultra Low-Emission Vehicles (ULEVs), and Zero-Emission Vehicles (ZEVs).

The CARB has ensured ongoing monitoring of the policy, both in terms of the achievement of the original objectives, and the state of the art of technological progress (especially as regards the battery). Based on these assessments, it was decided to maintain the mandate in its original form in 1992 and 1994, but at the end of 1998 the CARB decided to amend the mandate and introduce a new category of extremely clean cars that were not ZEVs and that could receive partial ZEV (PZEV) credits. The creation of this new standard reflected the advancement of technology in gasoline, hybrid and other AFVs, such as CNG vehicles (Calef and Goble, 2007).

Ongoing monitoring of the evolution of the technology as well as of the technical and commercial challenges can enable flexible and continuous adaptation of the policy to current conditions. For example, the CARB again amended the legislation in 2001, requiring that by 2003 only 2% of the cars would have to be pure ZEVs (*i.e.* battery or fuel cell EVs), while 6% could be PZEVs (*i.e.* low-emitting gasoline-powered ICEs), and 2% could be met using advanced-technology PZEVs (ATPZEVs), *i.e.* HEVs and NGVs. Therefore, regulators aknowledged the potentially important role that could be played by improvements in the fuel efficiency of conventional ICEs, and the emergence of hybrid vehicles (which had unexpectedely benefitted from the advances in battery technologies; Calef and Goble, 2007).

Finally, having reviewed again the policy in 2009, the CARB proposed that efforts concentrate on helping to move the pre-commercial pure ZEV technologies (BEVs, FCEVs, PHEVs, hydrogen ICEs) from demonstration to commercialisation in 2015 (Hasčič and Johnstone, 2011). The 2009 ZEV review raised the overall standards for PZEVs to 11% for 2009-11 model years, 12% for 2012-14 model years, and 16% for 2018 and beyond. Pure ZEV requirements are 2.5% for 2009-11, 3% for 2012-14, and 4% for 2015-17 (Zachmann *et al.*, 2012; Hasčič and Johnstone, 2011).

The CARB claims that, in spite of the critics, the ZEV regulation has proven to be successful, as nearly 2 million Californians are driving partial zero and advanced technology partial zero emission vehicles (PZEV and ATPZEV), which are 80% cleaner than the average 2002 model year car. The regulation has also spurred the diffusion of "near-zero emission" vehicles, with 400 000 hybrids on California's roads (CARB, 2011).

An assessment of the future potential of the ZEV standards carried out by the International Council on Clean Transportation (ICCT) shows that the key objective for the near term is to ensure that the programme provides steady, sustainable progress. In the long run, the ZEV programme can be seen as a transitional arrangement to foster investment in a broad range of technologies for low-carbon vehicles, in order to meet the increasingly stringent future fleet average while leaving the way open for other technical solutions. The review also finds environmental benefits, in terms of reduced air pollution and GHG emissions, but also for water pollution, water consumption and waste (ICCT, 2011).

At the same time, Bedsworth and Taylor (2007) find that although the ZEV programme has resulted in environmental benefits at least as large as those associated with the orginal structure of the programme, these benefits have been achieved mainly through continued but unanticipated improvements in conventional vehicles.

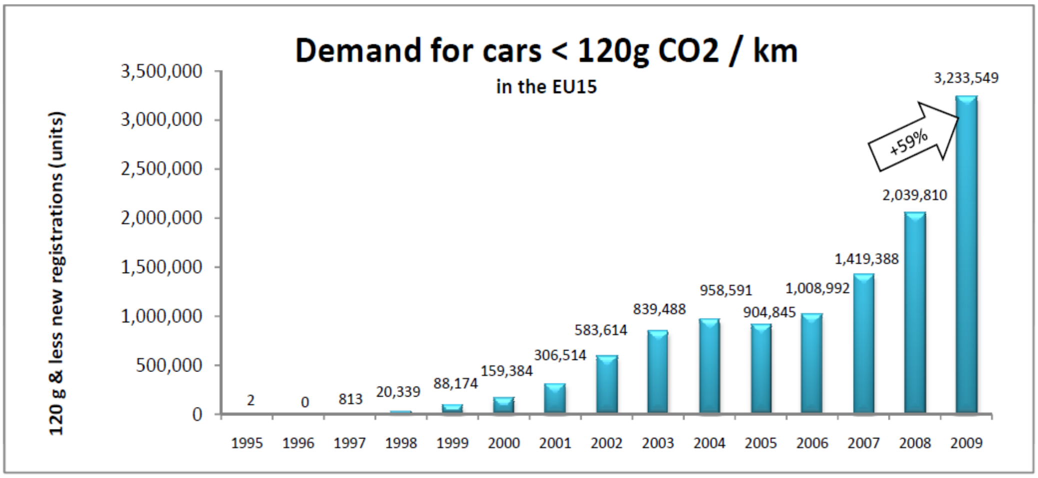
The innovation-inducing effects of the ZEV programme have also been mixed. For example, patenting data show an initial technology push by industry in response to the mandate, but as the programme was amended over time, this relationship weakened. Rather, the available data suggest that the CARB was responding to emerging trends in technology developments (*e.g.* in HEV and FCEV technologies) when it amended the mandate. At the same time, there is evidence of positive spillovers, for example in battery technology for use in HEVs, and in the market and infrastructure development (Bedsworth and Taylor, 2007).

The EU emission performance regulation

The EU performance regulation for CO_2 emissions in the car industry represents an interesting example of how the stringency and flexibility of an instrument can evolve over time. As part of its 1995 Community Strategy to reduce CO_2 emissions from cars, the EU obtained voluntary commitments from the automotive industry. In 1998 the European Automobile Manufacturers' Association (ACEA) adopted a commitment to reduce average CO_2 emissions from new sold cars to 140 grams per kilometre (g CO_2/km) by 2008. In the following year, the Japanese Automobile Manufacturers' Association (JAMA) and the Korean Automobile Manufacturers' Association (KAMA) declared the same commitment to be achieved by 2009. In conjunction with the other pillars of the strategy (a labelling scheme and fiscal incentives), the voluntary commitments contributed to the increase in demand for low-carbon vehicles in the period (Figure 27).[52]

Figure 27. Registration of new low-carbon passenger vehicles

1995 - 2009



Source: ACEA (2010).

Although substantial progress was made towards achieving the voluntary target, by 2008 the passenger vehicle fleet average CO_2 emissions reached 155 g CO_2/km instead of the 140 g CO_2/km target. Thus, the EU decided in 2009 to introduce additional measures, setting a short-term target of 130 g CO_2/km by 2012 and a long-term target of 95 g CO_2/km by 2020 on a fleet-average basis. A regulation replaced the previous efforts based on the voluntary commitments from the industry. In the case of non-compliance, manufacturers have to pay a penalty ("excess emission premium").

In addition to this basic framework, the standard employs some mechanisms – "limit value curve", "pooling", "phase-in", "super credits", "E85 extra credits", and "eco-innovation" – to create flexibilities and incentives for the automobile industry to adopt or invest in new green technologies, while ensuring fair competition.

52 The steep increase in international oil prices also contributed to these developments.

The CO_2 emissions performance target of each manufacturer is calculated on the basis of its average vehicle weight. Manufacturers have the right to create a pool with others in order to be monitored as one entity for the purpose of achieving their targets. The “pooling” mechanism aims to provide flexibility for manufacturers to meet the targets set by the regulation. In addition, the standard has a “phase-in” schedule during the period 2012-14. Both the "pooling" and the "phase-in" arrangements provide the manufactures with additional flexibility.

Data on CO_2 emissions from passenger cars show that emissions are decreasing in the EU-27 overall (EEA, 2011). Average emissions were 140.3 g CO_2/km in 2010, 5.4 grams less than in the previous year. This is the second largest annual decline since the monitoring scheme began in 2000 (Table 10). The introduction of the CO_2 emission standard is considered to have been one of factors contributing to this improvement, together with the steep increase in international oil prices and consumers' preference for smaller and cheaper vehicles induced by the economic crisis.

Table 10. Average CO2 emissions from new passenger cars by fuel type

2000-10

g CO_2/km	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
All fuels	172.2	169.7	167.2	165.5	163.4	162.4	161.3	158.7	153.6	145.7	140.3
Petrol	177.4	175.3	173.5	171.7	170	168.1	164.9	161.6	156.6	147.6	142.6
Diesel	160.3	159.7	158.1	157.7	156.2	156.5	157.9	156.3	151.2	145.3	139.3
AFV	208	207.4	179.2	164.7	147.9	149.4	151.1	140	137	125.8	125.7

Source: EEA (2011).

Japan

After earlier experimentation with voluntary commitments, in 1998 Japan included motor vehicles (gasoline passenger vehicles and diesel freight vehicles) in its Top Runner Programme. The programme sets energy efficiency targets based on a sales-weighted average. It requires manufacturers or importers to satisfy the fleet-average energy efficiency targets for regulated products within the target year. Energy efficiency targets are determined by considering the best performances available on the market ("top runners") and potential technological improvements at the time of target-setting. In addition, the programme sets the different targets within a single product range based on the size or capacity of the product as well as its technology type. Furthermore, targets are regularly reviewed and normally tightened when the target year is reached, or if the target is achieved earlier.

In 2007, new fuel efficiency standards entered into force, with 2015 as the target year for passenger vehicles. Manufacturers and importers will need to achieve the average fuel efficiency levels, calculated as the harmonised weighted average of the fuel efficiency levels by the number of shipped vehicles. The standards are expected to result in a 23.5% improvement in the fuel efficiency of passenger vehicles by 2015, compared to 2004 levels (OECD/IEA, 2010).

In case of non-compliance, the Ministry of Economy, Trade and Industry (METI) can impose a fine, but so far actual energy efficiency improvements have been higher than the targets in all product categories. For gasoline passenger cars, energy efficiency increased by 22.8% in the period 1995-2005 (fully meeting the initial target), and during the same period energy efficiency of diesel freight vehicles improved by 21.7% (largely exceeding the original 6.5% target) (METI, 2010b).

However, it is not clear to what extent the Top Runner Programme contributed to the energy efficiency improvements. In the case of passenger vehicles, improvements have resulted in part from market demand (*e.g.*consumers choosing more energy-efficient, and hence more cost-effective, products) and from technological improvements in response to consumer demands (which may have happened even in the absence of the standards). The increase in vehicle fuel efficiency that started in 1997 (*i.e.* before passenger cars were included in the Top Runner Programme) partially bears out the skeptics' argument.

But even accounting for these caveats, Kimuna (2010) argues that the standards have been successful in accelerating the trend of energy efficiency improvements in passenger vehicles. For example, manufacturers reported that the Top Runner Programme contributed to shift their priorities in favour of fuel efficiency improvements: developments might have happened anyway, but they would have taken longer in the absence of the standards.

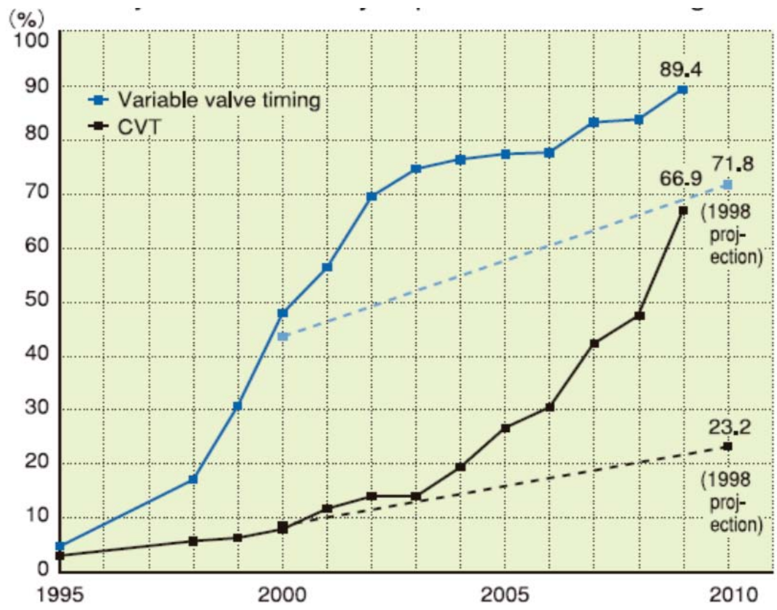
According to the Japanese Automobile Manufacturers Association (JAMA), a number of important technologies improving fuel efficiency in motor vehicles (*e.g.* variable valve timing and continuously variable transmission) were adopted faster than was originally projected, as a result of the Top Runner Programme (Figure 28).[53]

One of the main arguments in favour of the Top Runner approach is that it ensures flexibility and technology neutrality, as the requirements based on energy performance give car manufacturers the freedom to develop their own solutions. However, Nordqvist (2006) argues that the programme focuses on encouraging incremental innovation rather than breakthrough innovation. For example, hybrid vehicles are excluded from the analysis for setting the energy efficiency targets, as conventional ICEs could not meet the efficiency level that hybrid technologies can provide.

53 ICE cannot directly deliver constant levels of power at different rotational speeds: they need transmission systems to convey the engine power to the wheels. The transmission involves energy losses, the significance of which depends on the transmission technology in use. Automatic transmissions are about 85% efficient. Continuously variable transmissions (CVT) systems are not as efficient as manual transmissions, but can reach efficiencies of around 90% to 93% (International Energy Agency, 2009).

Figure 28. Adoption rate of fuel efficiency improving technologies in passenger cars in Japan

1995-2010



Note: CTV = Continuously Variable Transmission.

Source: JAMA (2010).

It may prove difficult to apply the design of the Top Runner Programme to other countries, since the success of the approach has depended crucially on the Japanese market structure. The Japanese market is dominated by a limited number of domestic producers. All these producers have high technology competency, could accept strict standards (because none would be excluded from the market), had incentives to develop energy efficient products to increase competitiveness with foreign producers, and complied with the standards without strict sanctions (Kimuna, 2010).

Other OECD and non-OECD countries

In 2003, the government of **Australia** reached an agreement with the automotive industry on a voluntary target for new petrol-operated passenger cars by 2010, which represented an 18% improvement in the fuel efficiency of new vehicles between 2000 and 2010. Subsequently, the Federal Chamber of Automotive Industries (FCAI) and the Australian Greenhouse Office (AGO) commenced preparatory work for the development of a national average carbon emissions (NACE) target, which would also incorporate larger four-wheel drive and light commercial vehicles, as well as other fuels, including diesel and LPG. No agreement was reached on the NACE target. FCAI adopted a voluntary target of 222 g CO_2/km by 2010. The NACE rating for new passenger cars in 2007 was 226 g CO_2/km (OECD/IEA, 2012). The government has announced that it will introduce mandatory CO_2 standards for new passenger and light commercial vehicles by 2015 (NTC, 2012).

According to official reporting from the Australian National Transport Commission, in 2011, the national average CO_2 emissions from new passenger and commercial vehicles was 206.6 g/km, *i.e.* a 2.8% reduction from 2010. In 2010, Australia's CO_2 emissions from new passenger vehicles were 46% higher than in the EU (205 g/km compared to 140 g/km) (NTC, 2012).

In 2010, **Canada** issued a draft regulation to limit GHG emissions from passenger cars and light trucks from model years 2011 to 2016, with the intention of keeping the flexibility to harmonise its regulations with possible future actions from the US government to address GHG emissions from vehicles. The Canadian government anticipated that the average GHG emission performance of the 2016 Canadian fleet of new cars and light trucks would be 153 g CO_2/km (169 g CO_2/km under the New European Driving Cycle), representing an approximate 20% reduction compared to the new vehicle fleet that was sold in Canada in 2007. However, An, Earley and Green-Weiskel (2011) consider that Canada should be able to achieve a lower average emissions level than that which the government has anticipated, given that its average fleet size is smaller than in the United States. Based on these assumptions, Canada should be able to achieve a fleet-average of 141 g CO_2/km (154 g CO_2/km under the New European Driving Cycle) by 2016.

In 2009, **Korea** announced a proposal for a combined fuel economy and GHG emissions target of 17 km/L, or 140 g CO_2/km respectively, for model year 2015 (An, Earley and Green-Weiskel, 2011).

In **China**, the National Development and Reform Commission established mandatory fuel efficiency standards for passenger cars in 2004. The standards were implemented in two phases: Phase 1 took effect in 2005 for passenger vehicles and Phase 2 in 2008 for light-duty vehicles. The standards classify vehicles into 16 categories based on vehicle weight.[54] Standard values are set for each category. In addition, there are different standard values for manual transmissions and automatic transmissions. Manufacturers must get the vehicle type they want to market certified to comply with the standards. The standard values are maximum allowable limits for each vehicle type, not the limits for the fleet average of the categories (OECD/IEA, 2012). New Phase 3 standards will be fully effective by 2015, and the Chinese government is considering a new fuel economy target for 2020 (An, Earley and Green-Weiskel, 2011).

According to calculations of the China Automotive Technology and Research Centre (as reported in An, Earley and Green-Weiskel, 2011), 26.6 billion litres of gasoline will be saved between 2008 and 2016 through the implementation of the new Phase 3 standards, and 63.3 million tonnes of CO_2 emissions will be avoided. Of course, the validity of these calculations depends crucially on the assumptions, for example as regards developments in fuel prices.

Although performance-based regulations and standards are expected to have a positive impact on fuel economy, as the purchasing power of countries grows, so do vehicle sales. In China, the share of new large vehicle registrations increased from 2005 to 2008. Thus, on average, fuel economy worsened, although the fuel standard introduced in 2005 helped limit this effect. India, Indonesia and Mexico showed similar trends, although they do not have performance-based regulations yet (International Energy Agency, 2012).

In **India,** minimum fuel efficiency standards were to be established for all vehicles under the 2008 "Integrated Energy Policy" (An, Earley and Green-Weiskel, 2011). In May 2011, it was reported that a Corporate Average Fuel Economy (CAFE) standard would be introduced, giving auto manufacturers until 2015 to improve fuel economy by about 18% (Hindustan Times, 2011).

Lessons learned

The inventory of initiatives reviewed in this report shows that performance-based approaches across OECD and non-OECD countries employ very wide and diverse combinations of mechanisms,

[54] Such a system gives carmakers little incentive to improve energy efficiency by reducing the weight of the vehicles.

such as: target-setting for average-fleet performance (Japan's Top Runner Programme and the EU's CO_2 emission regulation); "super credits" for overachieving performers, pooling of manufacturers to be monitored as one entity, and eco-innovation certification schemes (EU's CO_2 emission regulation); and gradual increase of voluntary targets and shift to mandatory targets (EU's CO_2 emission regulation).

Some of the cases reviewed also illustrate the importance of designing performance regulations so that they induce continuous efforts and behavioural change of carmakers and drivers, without locking them in any particular technological pathway. The continuous review of targets and performance testing methods, as in Japan's Top Runner programme, is one approach to addressing this challenge.

The impacts of performance regulations and standards on market development for green cars are likely to be highly technology specific. This implies that considerable industry-specific expertise will be required in public bodies as a pre-requisite for the design and implementation of such instruments. Regulators may need to consult widely with the industry and other relevant stakeholders to design effective regulations, as was done in many OECD countries.

The governance of setting and administering performance regulations and standards can be crucial in determining their effectiveness. In particular, in the context of "nested regulations" between different levels of government, policy makers should be aware of the importance of vertical co-ordination. Emissions leakage has been traditionally analysed in the context of producer relocation or incomplete regulation,[55] but can also emerge as a consequence of nesting state-level within federal regulations, or national regulations within supranational regulation (Goulder, Jacobsen and van Benthem, 2012).

Challenges also exist in evaluating the cost-effectiveness and specific effects of performance-based approaches. To gauge the appropriateness of regulatory policy targeted at a specific sector, analysts need to be able to assess whether the market would introduce the appropriate level of technology in the absence of the regulation or standard. And even in cases where regulation does spur innovation, regulation-based policy might be cost-ineffective overall. For example, in the cases of fuel economy or emission reduction regulations presented here, it is not always clear if other measures (*e.g.* market-based instruments) would have delivered more cost-effective fuel economy technologies, thus making regulation redundant.

It can also be difficult to isolate the specific effects of regulation from other influences, including the simultaneous impact of other policies or exogenous factors. For example, while CO_2 emission reduction regulations may have certainly contributed to the rapid increase in demand for low-carbon vehicles, the steep rise of international oil prices has also played a crucial role in this respect. A study undertaken in the United States found that, as gasoline prices increased, consumers purchased smaller, more efficient vehicles. The inverse was true when gasoline prices decreased, with an increase in the share of SUVs (International Energy Agency, 2012).

One argument that is often given against imposing tight fuel economy or emission regulations is that they can be too burdensome and represent an excessive cost for automakers. Measuring the

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55 Leakage from producer relocation occurs when a regulation, by raising costs of production to manufacturers in a given state or region, causes producers to move to another state or region. Incomplete regulation may lead to leakage when, for example, pollution regulation applies to only a subset of factories, and production at regulated factories can be substituted for unregulated production (Goulder, Jacobsen and van Benthem, 2012).

compliance costs of performance regulations is not straightforward, in the absence of transaction prices, and because carmakers have an incentive to over-report their costs. It is generally believed that such costs are high. However, Anderson and Sallee (2011) estimate that tightening the fuel economy CAFE standard in the United States by one mile per gallon in recent years would have cost domestic automakers between USD 9 and USD 27 in profit per vehicle. These estimates are much lower than previous attempts to measure these costs.

5.3 Technology-based regulations and standards

Rationale for the instrument

Technology-based regulations and standards set out the specific characteristics of a product, process or production method, such as its size, shape and design. They affect innovation by setting technical specifications for ensuring interoperability, securing minimum safety and quality, achieving variety reduction and providing common information and measurement. The standardisation of technical specifications for converging technologies is a key to accelerating their successful deployment. In the environmental context, technology regulations and standards impose on the emitters the use of specific abatement technologies. Hence, the use of technology regulations and standards can contribute to redress some of the failures that are preventing green vehicles from being widely adopted by consumers.

Existing command-and-control regulatory frameworks may end up serving incumbent technologies (although they may not necessarily have been designed for that purpose), notably conventional fuels and propulsion systems in the case of road transport. This relates to health and safety standards or refuelling infrastructure, among other things (Sustainable Energy Ireland, 2008). Therefore, policy makers may need to review the existing framework to identify gaps in standardisation and regulation that may result from the emergence of new technologies and systems, as well as areas where regulations and standards may need to be adjusted to enable the emergence of these technologies.

Technology regulations and standards can enable the emergence of positive network externalities by ensuring interoperability. Thanks to a common standard, the owner of a car enjoys indirect network benefits: the owner may not care about the size of the network *per se*, but wants to enjoy the good service of the network and a competitive supply of spare parts (Swann, 2010). In the case of BEVs and PHEVs, interoperability is a key aspect in the establishement of an interface between the vehicle and electric grids, both in private and public charging stations. A significant level of compatibility is required to ensure that the different models can access the grid in their home country as well as in neighbouring ones, in order to allow exports and trade and to avoid costly and inefficient proprietary systems (OECD, 2011e).

Along the same lines, standardisation can facilitate the deployment of the necessary charging infrastructure. In the best of scenarios, an international plug-in charging infrastructure would be deployed based on internationally agreed compatibility standards regarding vehicle–electricity grid interconnectivity, as well as technical safety and compatibility standards in terms of plug-in equipment and recharging protocols.[56] For pure BEVs, a battery-swapping business model (as an alternative or complementary solution to plug-in charging) would require international compatibility standards for interconnectivity between the car and battery-swapping system. Technical compatibility and safety

[56] In practice, it can be expected that standards are developed at the continental/regional level. However, the international option is more likely to facilitate the deployment of cost-effective electromobility solutions at the global level and could also help to avoid trade barriers.

standards could also be set for smart metering (vehicle-to-grid power flow, day/night price differentials, restricted/priority charging during peak demands) (IEA, 2009).

In addition, standarisation and the resulting interoperability provide private sector operators with a stake in the manufacturing of green vehicles and investment in refuelling infrastructure with long-term certainty and predictability as to the government commitment to sustainable road transport.

Competition among different product designs, technological solutions and business models during a proliferation period contributes to ensuring that the most efficient and desirable solution will emerge that could later become a standard on the market (OECD, 2011e).[57] Setting very specific technical standards too early may go against the principle of technological neutrality, and stifle innovation. However, the nature of the barriers preventing the development and diffusion of green vehicles may justify a minimum level of standardisation at a sufficiently early stage.

Finally, technology regulations and standards can contribute to changing some negative opinions of consumers vis-à-vis green vehicles, and overcome information asymmetries. At present, there is no established and agreed metric for describing EVs and for comparing their performance and costs in a rigorous manner. Specific measurement criteria should also be defined and introduced for the safety of EVs, taking into account features such as driving profiles, weight, parking locations or connection with the electricity grid. For example, determination of the energy efficiency of EVs requires test cycles that reflect energy consumption under different, realistic driving conditions, and consider that EVs and PHEVs employ two different primary energy sources in two distinct driving modes. Technology standards can increase the knowledge of consumers and their confidence in the reliability of EVs, and reduce the information gap between car manufacturers and drivers by providing easily comparable metrics.

Confidence in the reliability of EVs can also be enhanced through technical safety standards for battery disposal and recycling, in order to avoid hazardous impacts from used batteries.

Policy practices

Ideally, there should be internationally agreed uniform standards for connecting vehicles to charging stations. In reality, different standards are emerging across the world. This may bring some degree of uncertainty to the deployment of charging infrastructure. Currently, several standards exist: an international standard for sets of electrical connectors and charging modes for EVs developed by the International Electrotechnical Commission (IEC 62196/Mennekes); the J1772 standard developed from the American Society of Automotive Engineers (SAE); and the CHAdeMO standard in Japan (for fast charging).[58] While CHAdeMo is the *de facto* fast-charging standard and is being rolled out

57 However, there are examples of technologies having become the international standard although they were not necessarily the best available option. For example, observers of the competition between JVC VHS and Sony's Betamax to become the industry standard for videocassette recorders generally attribute the victory of the former to JVC's strategy, rather than to any inherent superiority of the VHS format (Besen and Farrell, 1994).

58 "CHAdeMO" is an abbreviation of "CHArge de MOve", equivalent to "charge for moving", and is a pun for "O cha demo ikaga desuka" in Japanese, meaning "Let's have a tea while charging". The standard was set up by an association of TEPCO, Toyota, Nissan, Mitsubishi, Fuji Heavy Industries (*i.e*. Subaru) with the aim of becoming a global standard. The association now has 170 regular members and 192 supporting members. Members include carmakers (*e.g*. Peugeot-Citroen PSA), component suppliers (*e.g*. Bosch), utilities (*e.g*. ENEL, E.ON) and charger manufacturers (*e.g*. Aker Wade, AeroVironment) from all over the world (Squatriglia, 2010).

globally, regional fast-charging standards are also being developed in North America and Europe. In the European Union, European automobile manufacturers issued a common recommendation in September 2011 to standardise the charging of electrically chargeable vehicles, with full implementation for new vehicle models from 2017. As announced by the Ministry of Industry and Information Technology in November 2010, China will also issue a unified standard for charging electric vehicles (Cleantech, 2011b).

At the international level, the United Nations Economic Commission for Europe (UNECE) has been promoting standardisation of environmental and energy-related aspects of green vehicles (hybrid, electric, hydrogen and fuel-cell technologies), as well as safety considerations, in the framework of the World Forum for the Harmonisation of Vehicle Regulations (WP.29). As regards environmental and energy-related aspects, it adopted regulations on measurement of maximum speed, measurement of power, measurement of the emission of carbon dioxide and fuel consumption and the measurement of electric energy consumption and electric range. With respect to safety, regulations were adopted on frontal collision for EVs, protection of occupants in the event of frontal collision, protection of the occupants in the event of a lateral collision, approval of BEVs with regard to specific requirements for the construction, functional safety and hydrogen emissions. The Forum also attempted to develop a single assessment criterion for the definition of environmentally friendly vehicles. However, this activity is currently on hold, due to different market situations and consumer needs, varying prioritisation of environmental needs in different regions, the availability of several environmental parameters, and doubts over the pursuit of a single scoring approach to define the vehicle.[59]

International efforts are underway also for the standardisation of systems and devices for the production, storage, transport, measurement and use of hydrogen. These include the work on internationally accepted safety codes and standards for on-board hydrogen storage and refuelling devices. Developing international design codes for refilling stations could also ease the infrastructure roll-out (International Energy Agency, 2012). The main international forum in this area is the Technical Committee of the International Standardisation Organisation (ISO/TC 197) for hydrogen technologies.

Finally, command-and-control regulations have also been used extensively to encourage the use of biofuels, in the form of renewable fuel standards and mandatory blending requirements. Policy support is given in over 50 countries (International Energy Agency, 2012). In the OECD context, mandates or targets up to 10% are in place in several countries (Table 11).

59. http://www.unece.org/fileadmin/DAM/trans/doc/2011/wp29/WP29-155-16e.pdf.

Table 11. Biofuel blending mandates and targets in the OECD

Country	Mandate	Target
Canada	Biodiesel Ethanol	
Korea	Biodiesel	
Belgium	All biofuel	
Italy	All biofuel	
Czech Republic	Biodiesel Ethanol	
Netherlands		Biodiesel All biofuel
United Kingdom		Biodiesel All biofuel
Australia	Biodiesel Ethanol	
Austria	All biofuel	
Finland	All biofuel	
Poland	All biofuel	All biofuel
Germany	All biofuel	
Spain	All biofuel	
Sweden	Biodiesel Ethanol	
France	All biofuel	

Source: International Energy Agency (2012).

In the **United States** the Energy Policy Act of 2005 required the introduction of a Renewable Fuel Standard (RFS) Programme, which entered into force on 1 September 2007. The Energy Independence and Security Act of December 2007 increased and expanded the standard. By 2022, 36 billion gallons of renewable fuels must be used per year. A certain percentage of the renewable fuel blended into transportation fuel must be cellulosic biofuel, biomass-based diesel, and advanced biofuels. In addition to these federal requirements, renewable fuel standards and mandatory blending requirements exist in 12 states.[60]

In the **European Union**, the 2003 Directive on the promotion of the use of biofuels and other renewable fuels for transport mandated Member States to ensure that the minimum share of biofuels

60 Florida, Hawaii, Iowa, Louisiana, Massachusetts, Minnesota, Missouri, Montana, New Mexico, Oregon, Pennsylvania, and Washington.

sold on their markets was 5.75%. On 1 January 2012, the 2003 requirements were repealed by a 2009 Directive on the promotion of the use of energy from renewable sources. Biofuels should contribute to a reduction of at least 35% of GHG emissions in order to be taken into account. From 1 January 2017, their share in emission savings should be increased to 50%. Legislation also specifies the criteria that biofuels must meet in order to be qualified as "sustainable".[61]

Mandatory biofuel blending requirements are in place in several non-OECD countries, notably Brazil (mandates for biodiesel and ethanol varying from 5% to 25%), China (mandate for ethanol at 10%); Paraguay (mandate for biodiesel and target for ethanol); Indonesia (mandates for biodiesel and ethanol and targets for biodiesel and ethanol at 15% and 20%, respectively); Thailand (mandate for biodiesel); Colombia (mandates for biodiesel and ethanol at 5% and 10%, respectively, and target for biodiesel at 20%); and India (International Energy Agency, 2012; Rajagopal and Zilberman, 2007).

Lessons learned

The reviewed initiatives in the area of standardisation for alternative fuels and propulsions technologies highlight two important challenges for policy makers: getting the right timing of standardisation and the international dimension of standardisation.

Getting the right timing of standardisation is an important challenge for policy makers and other actors. Procedures in standard bodies can be slow and bureaucratic, and can be held up by large players. Involvement by the government may contribute to shortening the standardisation process by bringing together all the relevant stakeholders and facilitating co-operation among them. Standards should not be introduced too early as this could shut out alternative (and potentially better) options and go against the principle of technology neutrality, but early enough to create interoperability and positive network effects. For example, specific barriers in markets for EVs may justify some degree of standardisation at a sufficiently early stage in order to reduce uncertainty. In addition, late standard setting may lead to wastage of financial resources and duplication of efforts. At the same time, any standardisation at an early stage should not be excessive, and leave room for experimentation that allows producing information and real innovation.

Another challenge relates to the international dimension of standardisation. International co-operation can play an important role in diffusing green car technologies across countries, for example by having one internationally agreed uniform standard for connecting vehicles to charging stations. Although standardisation efforts are ongoing at international level and in multilateral fora, different standards are emerging around the world and this may bring some degree of uncertainty to the deployment of the charging infrastructure. Efforts are underway to harmonise standards at the regional/continental level: for example, France and Germany have set up a joint working group to solve the issue of diverging standardisation. In the European Union, European automobile manufacturers issued a common recommendation in September 2011 to standardise the charging of electrically-chargeable vehicles, with full implementation for new vehicle models from 2017.

5.4 Price-based measures

Rationale for the instrument

Price-based measures can play a fundamental role in tackling one of the main entry barriers for green vehicles, *i.e.* the high cost relative to conventional ICE-powered vehicles. They can address this

[61] See Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources.

barrier by raising the price of the most pollutant and energy-inefficient vehicles, *e.g.* through taxation, or by lowering the price of cleaner fuels and propulsion technologies, *e.g.* through tax credits and direct subsidies. In so doing, these measures can either be technology neutral, or favour specific fuels or technologies.

Price-based measures may also contribute to changing norms and habits of consumers and overcoming information asymmetries. Buyers of a new car should have a clear view of the anticipated annual mileage, the future price of fuel, and how the second-hand value of the car is affected by their choice. In addition, buyers should be able to discount future costs (Kågeson, 2012). However, this information is often not available, and even when it is, buyers may not be able to process it correctly. Price-based measures can help to put consumers in a better position to make a rational decision.

Taxation of relatively more polluting fuels and propulsion technologies can also correct the unpriced negative environmental externalities caused by road transport. Dings (2012) notes that it may not be enough to set one carbon price throughout the economy, for example by including transport in an emission trading scheme. A single instrument could be inadequate because climate policy is more regional than global, and political concerns of carbon leakage constrain carbon prices in the most exposed sectors. In this context, what may happen in practice is that carbon prices in sheltered sectors (*e.g.* transport and building) will often be higher than in exposed ones.

Policy practices

There are two main categories of price-based measures:

- *Fiscal and financial incentives*. These can take the form of direct subsidies through financial transfers to buyers or users of green vehicles, or tax incentives.

- *Fiscal and financial disincentives.* They include taxes and charges that aim at changing the relative prices of inputs (fuel taxes, CO_2 taxes, and taxes on energy carriers) and the price of outputs (depending on the point of incidence: tax on the purchase, ownership or usage of a vehicle) (Hasčič and Johnstone, 2011).

Fiscal and financial incentives

Many OECD and non-OECD countries have introduced a wide range of fiscal and financial incentives and disincentives, mostly in their vehicle purchase/registration tax schemes, to foster the purchase of green cars.

In **France**, since 2007 a "Bonus-Malus" scheme (*i.e.* a fee/penalty on inefficient vehicles and a rebate/reward on efficient vehicles, also called "feebate") has provided a combination of financial incentives and disincentives to any new car buyer, depending on the vehicle’s CO_2 emissions. This one-time purchase tax (subsidy) levies a Malus ranging between EUR 200 and EUR 3 600, or provides a Bonus ranging between EUR 300 and EUR 5 000. In addition, there is a “super bonus” of EUR 200 which consists of an additional premium paid in case of the disposal of an old vehicle (more than 15 years old) and the purchase of a new green car.

Cost-benefit analyses of the Bonus-Malus and evaluations of its impacts on the environment show mixed results. From a budgetary perspective, the scheme accumulated a deficit of EUR 1.25 billion in the period 2008-10, with a further deficit of EUR 245 million expected in 2011. This, in addition to the cost of the "prime à la casse" (EUR 1.2 billion) which was part of the stimulus package in response to the economic crisis, led the French Supreme Audit Institution to put in doubt the budgetary sustainability of the scheme (Cour des Comptes, 2011).

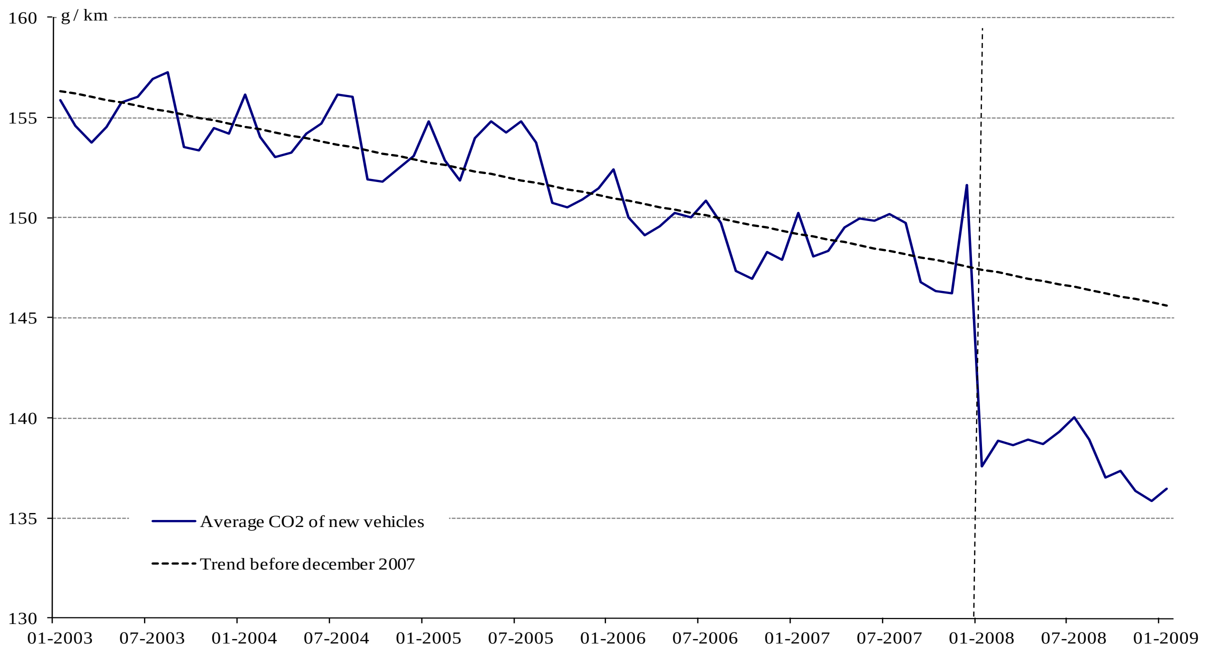
As regards the effectiveness of the Bonus-Malus, the share of new vehicles emitting less than 120 g CO_2/km doubled in a few months after its entry into force. The announcement of the introduction of the scheme resulted in a one-off increase of CO_2 emissions in December 2007, an effect caused by consumers bringing forward purchases of more polluting vehicles. But CO_2 emissions plummeted in January 2008, with a steep decrease relative to the previous trend (Figure 29).

Using an exhaustive dataset of car registrations and a recent transportation survey which provides information on individual journeys, D'Haultfoeuille, Givord and Boutin (2011) estimate a model that relates car choice and mileage. They show that in the short term (*i.e.* between March and May 2008) the Bonus-Malus scheme caused an increase in total CO_2 emissions of 168.4 kilotonnes per quarter, *i.e.* a 1.2% increase. This effect was mainly caused by an increase of sales of new vehicles: all other things being equal, total new vehicle sales at the beginning of 2008 were estimated to be 13% higher than they would have been in the absence of the Bonus-Malus, resulting in a 232 kilotonnes increase in CO_2 emissions per quarter (Table 12) (INSEE, 2012). Even in the long run, the policy has a large negative impact, as the feebate leads to an increase in automobile equipment, inducing more car use emissions. This effect largely overcomes the composition effect stemming from changes in car choices (D'Haultfoeuille, Givord and Boutin, 2011).

In addition, the Bonus-Malus was found to benefit domestic automotive production only partially: the scheme incentivises sales of smaller, more efficient (and less expensive) cars, whose production has been heavily offshored by French carmakers to other countries (*e.g.* Slovenia, Czech Republic and Turkey) (MINEFI, 2008).

Figure 29. CO2 emissions of new vehicles (g/km) in France

January 2003–January 2009



Source: D'Haultfoeuille, Givord and Boutin, 2011.

Table 12. Decomposition of the Bonus-Malus effect (kt CO2 per quarter)

March–May 2008

	Short-term, 2008 scheme
Composition effect ("greening of the vehicle fleet")	-80.4
Rebound effect (increase in kilometres travelled per vehicle)	6.1
Emissions due to the production of additional vehicles	232.1
Total size of vehicle stock in circulation	10.4
Total increase in kt	**168.2**
Total increase in % of emissions	**1.2**

Source: INSEE (2012).

The **United States** federal government offered a tax credit to light-duty HEVs based on an individual model's fuel efficiency (fuel economy credit) and fuel savings (conservation credit) under the Energy Policy Act of 2005. The fuel economy credit was allowed up to USD 2 400, based on efficiency gains over the 2002 model year city fuel economy, while the conservation credit was allowed up to USD 1 000, based on lifetime fuel savings. The credit was designed to be phased out after a manufacturer sold 60 000 qualified vehicles.

In 2009, a new scheme of green car incentives was introduced as part of the American Recovery and Reinvestment Act, offering much more generous incentives to PHEVs and EVs. Under the new scheme, buyers of PHEVs or EVs benefit from a tax credit of USD 2 500 to 7 500, depending on the equipped battery size. The credit begins to be phased out for each manufacturer after 200 000 qualified vehicles have been sold by that manufacturer. In addition, until 2011, qualified PHEVs conversions were also eligible for a tax credit for 10% of the conversion cost, not to exceed USD 4 000. A tax credit of up to 10% of the cost of qualified low-speed EVs, electric motorcycles, and three-wheeled EVs, not to exceed USD 2 500, was available until 2011.

As part of a broader initiative to support advanced vehicles, and in order to make them more affordable, in March 2012 the United States administration proposed to amend the tax credit along these lines: expand the eligibility of the credit to a broader range of advanced vehicle technologies; increase the amount from USD 7 500, up to USD 10 000; make the credit available at the point of sale, so that consumers can benefit from it when they purchase the vehicle rather than when they file their taxes; remove the cap on the number of vehicles per manufacturer eligible for the credit and, instead, decrease and eventually eliminate the credit towards 2020 (The White House, 2012).

In addition to the federal tax credit, many state and local governments offer additional tax incentives or cash rebates along with various non-monetary benefits such as unrestricted access to high occupancy vehicle (HOV) lanes, free parking and exemptions from emission testing.[62] For instance in

[62] Many of these instruments are described in the OECD/EEA database on instruments used for environmental policy (www.oecd.org/env/policies/database).

California, PHEVs meeting specified state and federal emissions standards and affixed with a California Department of Motor Vehicles Clean Air Vehicle sticker are allowed to use HOV lanes regardless of the number of occupants in the vehicle. Cash rebates are also available through the Clean Vehicle Rebate Project (CVRP) for the purchase or lease of qualified PHEVs. The rebates offer up to USD 2 500 for light-duty zero emission and PHEVs that the CARB has approved or certified. Special parking spaces are reserved to PHEVs or EVs that display a valid state-issued zero-emission vehicle (ZEV) sticker and are connected for electric charging purposes.

Several other countries have introduced incentive schemes:

- In **Belgium**, electric cars benefit from a tax deduction of 30% of the purchase price, up to EUR 9 000 in 2011 and EUR 9 190 in 2012. An additional measure provides for a tax deduction of 40% of the investment for the installation of a charging station outside private houses (up to EUR 250 in 2011 and 2012). Further tax incentives are given at the regional level, both in Flanders and in Wallonia.[63]

- In **Canada**, several incentive schemes exist at provincial level. For example, Ontario established an Electric Vehicle Incentive Programme in 2010, with incentives from CAD 5 000 to CAD 8 500 for the purchase or lease of highway-capable PHEVs or BEVs (OECD, 2011e).

- In **Estonia**, private, commercial and public buyers of fully electric passenger cars are eligible to receive an incentive of 50% of the vehicle price. The maximum amount of the grant is EUR 18 000 per car (in addition to EUR 1 000 for setting up a Mode 3 home charger). The EV can be purchased in any EU country, but second-hand vehicles are not eligible. The financial envelope allocated to the scheme allows incentives for 500 EVs.[64]

- In **Italy,** in 2011 the government offered incentives for the conversion of gasoline-powered engines to LPG and methane-powered engines. At the end of April 2011, EUR 23.4 million worth of incentives had been requested, for the conversion of 45 308 LPG engines and 5 474 methane engines. In addition, holders of EVs are exempted from the motor vehicle ownership tax for a period of five years, after which EVs are taxed at the 25% rate applied to non-electrically powered vehicles in the same category.[65]

- As part of its *Next Generation Vehicle Strategy 2010*, **Japan**'s government earmarked USD 356 million in the budget of fiscal year 2011 for installation of infrastructure but also incentives for purchasing EV and PHEV. Part of this financial envelope aimed at subsidising half of the difference between the price of an EV or PHEV and their base vehicle models.[66]

- In **Korea**, the 2010 *Strategy for Green Car Development* foresees the introduction of a Bonus-Malus scheme and other incentives for consumers to purchases green vehicles in

63. Personal communication with the Federal Public Service Economy, SMEs, Self-employed and Energy of Belgium.

64 Personal communication with the Ministry of Economic Affairs and Communications of Estonia.

65 Personal communication with the Ministry of Economic Development of Italy.

66 Personal communication with the Ministry of Economy, Trade and Industry of Japan.

2012. In addition, a tax incentive of up to KRW 3.1 million per vehicle is offered for the purchase of an HEV.[67]

- In the **Netherlands**, a package of tax measures introducing incentives for energy efficient vehicles was submitted to Parliament in June 2011. It is proposed that a 0% rate is applied to all vehicles with CO_2 emissions of 50 g/km or lower, a standard currently met only by pure EVs and some range-extended EVs and PHEVs. All fuel-efficient cars are exempted from the Motor Vehicle Tax (MRB) until 2014, but vehicles with emissions of 50 g CO_2/km and lower will be exempt until 2015, in practice giving EVs an advantage over other fuel-efficient propulsion technologies. Finally, criteria for exemption from the Private Motor Vehicle and Motorcycle Tax (BPM) will gradually become stricter, so that the exemption will remain fully in effect until 2018 only for EVs, PHEVs and range-extended EVs.[68]

- In **Norway**, incentives to promote the use of EVs include: exemptions from the first-time registration tax, VAT and road tolls; reduction of the annual motor vehicle tax; and the ability to use lanes otherwise reserved for public transport (OECD, 2011i).

- In 2010, **Portugal** introduced financial incentives specific to electric propulsion: EUR 5 000 for the first 5 000 buyers of light-duty EVs; EUR 1 500 for scrapping an old vehicle and acquiring an EV.[69]

- In 2012, the government of **Spain** confirmed the regulatory framework for incentives for EV purchases introduced in 2011, and fixed the maximum budgetary allocation at EUR 10 million. The Ministry of Industry, Energy and Tourism will subsidise 25% of the sale price of the vehicle (before taxes), up to EUR 6 000 for individual users and fleets, and up to EUR 30 000 for large vehicles (*e.g.* buses). If the vehicle does not include the battery, the individual subsidy can go up to 35% of the sale price (Ministry of Industry, Energy and Tourism of Spain, 2012).

- In the **United Kingdom**, the government, through the Office for Low Emission Vehicles (OLEV), made GBP 300 million available over the lifetime of the current Parliament for a Plug-In Car Grant (PiCG) for ultra low-emission vehicles. Motorists purchasing an eligible vehicle (of which there are currently ten, from different manufacturers) can receive a grant of up to 25% of the cost of the vehicle, capped at GBP 5 000. This grant is designed to bring the whole-life cost of low-carbon vehicles in line with similar sized traditional vehicles, thereby removing cost as a barrier to low-carbon vehicles ownership. In line with the Government's general approach to emissions reduction, the grant is technology neutral. This is to remove the risks of government "picking winners" in terms of low-carbon technologies and means that all forms of low-carbon vehicles are available to consumers through the grant (although hydrogen-fuelled vehicles are currently less available on the open market than plug-in hybrid-electric and battery electric vehicles).[70]

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67 Personal communication with the Ministry of Knowledge Economy of Korea.

68 Personal communication with the Ministry of Economic Affairs, Agriculture and Innovation of the Netherlands.

69 Personal communication with the Ministry of Economy and Employment of Portugal.

70 Personal communication with the Department for Business, Innovation and Skills of the United Kingdom.

- In **China**, in June 2010 the Ministry of Finance launched a clean transportation pilot subsidy programme in five cities (Shanghai, Shenzhen, Hangzhou, Hefei and Changchun). Buyers of full EVs are eligible to receive up to RMB 60 000 and buyers of PHEVs are eligible to receive RMB 50 000. In addition, nationwide direct incentives of RMB 3 000 are offered for buyers of vehicles with 1.6 litre engines or smaller and consuming 20% less gasoline than current standards (Cleantech, 2011b).[71] The "Development Plan of energy-saving and new energy automotive industry (2012-20)" adopted by the State Council executive meeting on 18 April 2012 foresees to start a pilot programme to grant financial support for private purchases of new energy-efficient vehicles (Guide to P.R.C. Government Agencies, 2012).

While in most OECD countries vehicle tax incentives (and also disincentives) favouring green cars are based on CO_2 emissions, since 2009 **Israel** has differentiated the vehicle purchase tax on the basis of the vehicles' broader environmental performance. The tax is calculated as a percentage of the vehicle pre-tax price (83%), net of a rebate based on a "green index" (or "green score"), so that in practice the effective tax rate for the lowest emission category of vehicle is 40%. What makes Israel unique in the OECD context is that the "green index" is calculated according to emissions of local pollutants (carbon monoxide, hydrocarbons, nitrogen oxides and particulates) in addition to CO_2 emissions (OECD, 2011j).

Reduced vehicle tax rates apply to electric and hybrid cars (10% and 30%, respectively) (OECD, 2011j). In April 2012, the Ministry of Finance announced that as of 1 June the purchase tax rate on BEVs will be reduced from 10% to 8% in 2012-13, and the purchase tax rate on HEVs will stay at 30% in 2013, instead of increasing to 45%, as originally planned. The tax rate on emission-free vehicles will then increase to 10% in 2014 and 30% in 2015-19, and then increase to the base rate of 83% (net of the incentive calculated on the basis of the "green index"). In the case of HEVs, the increase to a 45% rate will occur in 2014, followed by a further increase to 60% in 2015 before reaching the 83% rate (net of the "green index" benefit) in 2016. In addition, a special tax rate of 20% was introduced that will apply on purchased PHEVs until the end of 2013, and gradually increase to 30% in 2014, 45% in 2015 and 60% in 2016 (before being taxed at the full rate as of the beginning of 2017). Emission-free vehicles will be taxed at the full rate of 83%. Tables 13 and 14 show the evolution of the rates before and after the new legislation entered into force. The cost of the incentives was estimated at NIS 130 million (Ministry of Finance of Israel, 2012).

[71] The government reportedly declared that the incentives will be reduced once 50 000 green cars are sold.

Table 13. Tax rates on electric and hybrid vehicles before the 2012 reform in Israel

<table>
<tr><th>Years</th><th>Emission-free</th><th>Hybrid</th><th>Conventional</th></tr>
<tr><td>2009-2012</td><td rowspan="3">10%</td><td>30%</td><td rowspan="5">83% net the tax benefit according to the green score</td></tr>
<tr><td>2013</td><td>45%</td></tr>
<tr><td>2014</td><td>60%</td></tr>
<tr><td>2015-2019</td><td>30%</td><td rowspan="2">83% net the tax benefit according to the green score</td></tr>
<tr><td>2020</td><td>83% net the tax benefit according to the green score</td></tr>
</table>

Source: Ministry of Finance of Israel (2012).

Table 14. Tax rates on electric and hybrid vehicles after the 2012 reform in Israel

<table>
<tr><th>Year</th><th>Emission-free</th><th>Plug-in</th><th>Hybrid</th><th>Conventional</th></tr>
<tr><td>2009-2011</td><td>10%</td><td>-</td><td>30%</td><td rowspan="6">83% net the tax benefit according to the green score</td></tr>
<tr><td>2012-2013</td><td>8%</td><td>20%</td><td>30%</td></tr>
<tr><td>2014</td><td>10%</td><td>30%</td><td>45%</td></tr>
<tr><td>2015</td><td>30%</td><td>45%</td><td>60%</td></tr>
<tr><td>2016-2019</td><td>30%</td><td colspan="2" rowspan="2">83% net the tax benefit according to the green score</td></tr>
<tr><td>2020</td><td>83% net the tax benefit according to the green score</td></tr>
</table>

Source: Ministry of Finance of Israel (2012).

Perhaps unsurprisingly, several studies find that financial incentives have had a positive effect on the adoption of green vehicles. However results are mixed, especially with regard to the cost-effectiveness of incentives, and gasoline prices appear to play a more important role overall. For example, Gallagher and Muehlegger (2011) estimate how hybrid sales respond to state-level incentives, rising gasoline prices, and access to carpool lanes in the United States. They show compelling evidence that demand for the highest fuel economy vehicles rises most with gasoline prices. Based on their estimates, increasing the average gasoline price by 20% over the period 2000-06 (equivalent to increasing a state's gasoline tax by 36 cents per gallon and increasing average fuel economy savings from driving a hybrid vehicle by USD 85 per year) would increase hybrid vehicle sales an equivalent amount to a USD 330 sales tax waiver.

Estimating the effect of provincial tax rebates for HEVs in Canada, Chandra, Gulati and Kandlikar (2010) argue that tax incentives may not be the most effective way to encourage consumers to switch away from fuel-inefficient vehicles, at least in the short to medium term. On the one hand, tax rebates had a positive and significant effect on the market share of HEV vehicles: 26% of the hybrid vehicles sold during the rebate programme is estimated to be attributable to the rebate. In addition, less fuel-efficient vehicles were crowded out as a result of the rebate. On the other hand, the average cost of reducing carbon emissions from these programmes was estimated to be USD 195 per tonne. The authors acknowledge that the relatively high cost of saving fuel or reducing carbon emissions can be justified based on the following considerations: incentives can accelerate technological diffusion and favour economies of scale in production; HEVs can be associated with reductions in local air pollutants; and increased uptake of HEVs thanks to subsidies can generate positive network externalities. Although none of these positive spillovers are found to be large enough to offset the cost of the rebates in Canada, these conclusions may differ if the analysis were applied to other countries.

Diamond (2009) tests the relationship between adoption of HEVs and a variety of socio-economic and policy variables using a cross-sectional time-series analysis of HEV registration statistics over time from US states. He finds a strong relationship between gasoline prices and hybrid adoption, but a much weaker relationship between incentive policies and hybrid adoption.

The result of Gallagher and Muehlegger (2011) also highlight the crucial importance of instrument design, as the type of incentive offered is as important as the generosity of the incentive: sales tax waivers are associated with more than a tenfold increase in hybrid sales relative to income tax credits. These results seem to suggest that a feebate at the time of purchase may be more effective at encouraging the purchase of high fuel economy vehicles than a fuel economy-based registration or emission testing fees. In addition, a feebate can be designed to be revenue neutral.

Consumers have a tendency to put a greater value on the immediate costs and savings than on the future savings. Diamond (2009) points out that changes to incentives in the form of tax waivers appear to have had more impact than changes in incentives in the form of rebates or tax credits, because tax waivers affect the upfront cost that the consumer has to pay for the products (or would be effective immediately after the purchase), while rebates or tax credits may take longer to get back.

One could also wonder if subsidies are needed at all. Comparing conventional vehicles models with their electric counterparts marketed in France, Crist (2012) found that owners of EVs studied can expect to pay EUR 4 000 to EUR 5 000 more than a fossil-fuelled passenger car over the vehicle's lifetime under typical use scenarios (30-35 km/day, 365 days/year). However, a higher use scenario (*e.g.* that of a delivery van travelling 90 km a day during weekdays) would save its owner about EUR 4 000 over the vehicle's lifetime. Hence, people travelling longer daily (fleets, deliveries, taxis) would likely already benefit from EVs, even without the purchase subsidies, which would then be superfluous.

There is also a concern over "rebound effects" with the diffusion of fuel-efficient cars. If the use of vehicles cost less, people may drive them more often or for longer distances, or drive larger cars. A number of studies discuss potential rebound effects of subsidies for HEVs, but most of them conclude that these effects are almost negligible. For example, de Haan, Peters and Scholz (2007) conducted surveys with Swiss buyers of the Toyota Prius 2 hybrid car since its market entry in 2004 and, as a control group, 250 Toyota Corolla and 250 Toyota Avensis buyers. They concluded that any rebound effect was not detected and the increase in vehicle length (used as a surrogate for car size) from the previously owned cars was even lower for buyers of hybrid vehicles compared to the control group.

The issue of the equity of public support to consumers for purchasing green vehicles also deserves some attention. Tax credits and subsidies may end up being highly regressive, as the majority of purchasers of EVs are young, affluent and educated males purchasing a second vehicle, and many early adopters would purchase an AFV regardless of the incentives. It has been argued that financial incentives for EVs may only reward those who need them the least, as they were likely to have purchased EVs anyway and that consumers buy EVs based on a general image of a "good vehicle" rather than on a detailed cost-benefit analysis or government incentives (Diamond, 2009; Chandra, Gulati and Kandlikar, 2010).

Assessing the costs of incentives to foster the use of EVs against the benefits in terms of emissions reductions in Norway, *Econ Pöyry* (2009) (as reported in OECD, 2011i) estimated that the subsidies provided exceeded EUR 2 500 per tonne of CO_2 emissions avoided, indicating that the incentives provided are considerably higher than those in other sectors, and raising questions as to whether the benefits of the package exceed the cost.

Another issue with fiscal and financial incentives is that they can end up favouring specific technological solutions and create or enhance a lock-in, although it is very difficult for policy makers to know in advance which option will be the most efficient and effective. For example, improvements in the energy efficiency of ICE still have a significant untapped potential to reduce emissions and pollution, and such a potential may not be exploited fully if too strong incentives are given to alternative propulsion technologies. In order to avoid this, incentives could be designed so as to give equal treatment to all competing technologies, for example by providing the same benefit to any reduction by one unit of energy or one gram of CO_2 (Kågeson, 2012). For instance, fuel taxes can achieve this.

At the same time, implementing technology-neutral incentives is not always possible. Public resources are finite, and cannot be spent on all innovations. In addition to general incentives that apply to all technological options, a case can be made for more targeted support to certain promising alternative fuels and propulsion technologies. However, such selective treatment should only be given to technologies that can be reasonably expected to have a steep learning or experience curve (*i.e.* costs should be expected to come down at a fast pace due to economies of scale and scope) (Azar and Sandén, 2011; Kågeson, 2012).

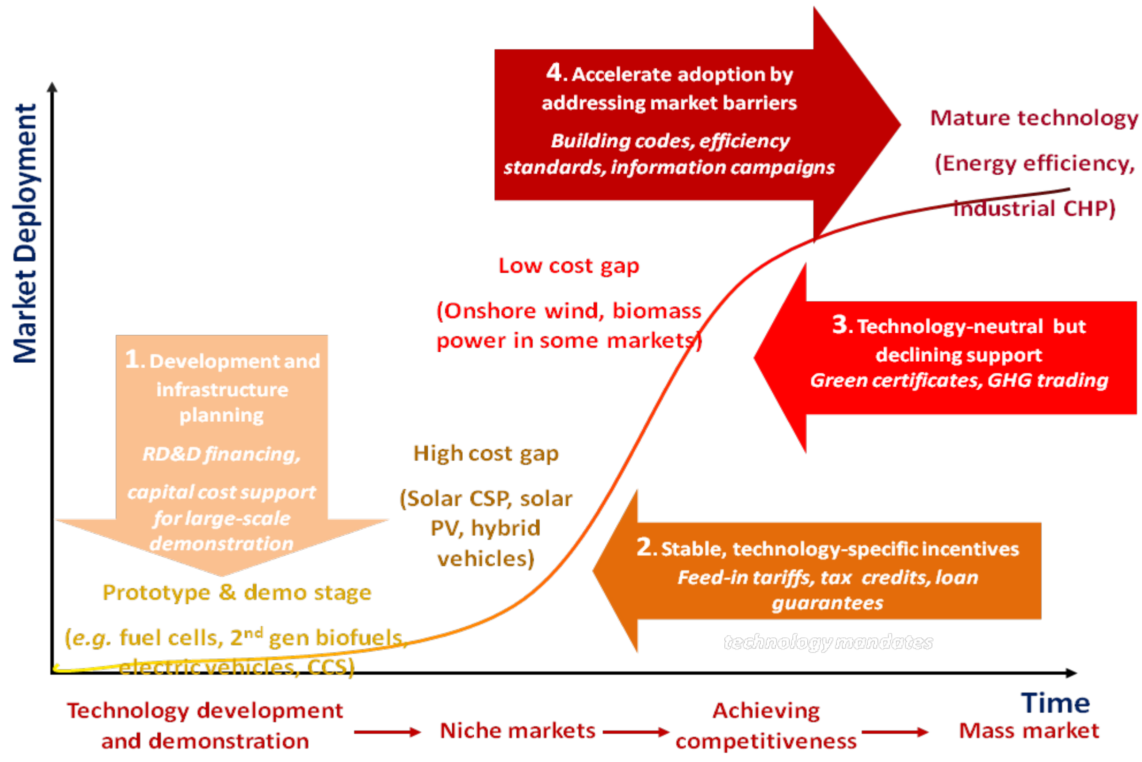
Of course, policy makers should remain alert to the risk that support becomes captured by vested interests and gives rise to opportunities for rent seeking. In order to avoid this problem, and the resulting lock-in effects, incentives could be limited in time and volume, for example by including a sunset clause. Ongoing monitoring will be required, and this can imply the discontinuation of a scheme if the results of evaluation show that the technology is not delivering what was originally expected.

Another potential problem with incentives is that they can reduce policy predictability and certainty for the private sector, especially in times of constrained public finances. Investors and manufacturers will make plans over a full cycle of new car models, based on current rules. However, if an incentive proves to be too burdensome for the government budget, or if a new government has different political priorities, schemes may be scrapped, or amended in favour of other propulsion technologies. The same could happen if the results of an evaluation of the incentive scheme proved it to be inefficient or ineffective, in which case policy makers should weigh the cost of reducing predictability and certainty for the industry against the benefit of eliminating or modifying an instrument that is not meeting its objectives. Communicating clearly and up-front the reasons for possible future changes to policy instruments can contribute to policy predictability.

Overall, policy experiences from OECD countries reveal the crucial importance of the timing and sequencing of financial and fiscal incentives. Policy makers should send clear signals that price incentives will not disappear suddenly, while avoiding the exposure to large potential subsidy costs. One option suggested by the IEA (2011b) is to allocate an annual limit on incentive expenditures, and keep that amount each year through a predefined period (*i.e.* a decade), reducing the amount per vehicle as sales rise. This has the benefit of automatically lowering the support level per vehicle as sales increase.

Most OECD countries give consumers a higher level of incentives in the first period of the schemes, while gradually decreasing them in following years. The arrangement has the clear objective of providing a strong pull at a stage of market deployment in which costs are high and the technology is still surrounded by uncertainty (Figure 30). Once costs decrease and AFV technologies gain acceptance in the market, subsidies are typically phased out. However, in some OECD countries the level of financial incentives was increased and the number of vehicles covered by the scheme enlarged (*e.g.* the United States), or the phasing-out of fiscal disincentives was lengthened (*e.g.* Israel), possibly because it was deemed that pricing measures were not yet having the expected impact. Finally, the IEA (2012) notes that levelling the cost of ownership of EVs via incentive programmes is a key component of government policies to scale up deployment. However, it remains to be seen whether the current incentive levels, USD 5 000 to 7 500 per vehicle in most OECD countries, are sufficient to achieve this. Falling battery and vehicle costs may also give a contribution in this respect.

Figure 30. Timing and sequencing of energy technology policy



Source: OECD (2011f).

Fiscal and financial disincentives

Fuel taxes

Fuel taxes generate an incentive to buy fuel-efficient vehicles. Although fuel tax regimes were originally designed to raise public revenues, they have proven to be an effective part of the mix of climate change policies. For example, fuel demand and CO_2 emissions would have been much higher in the absence of the existing high fuel taxes in Europe (Coria, 2012). An advantage of fuel taxation is that it affects both the choice of car and driving behaviour (Kågeson, 2012).

Gasoline prices – in purchasing power parity (PPP) terms – have increased two to fivefold in most OECD countries between 1978 and 2008 (and as much as sevenfold in Turkey). In 2000, consumers in India and Thailand paid by far the highest price (on a PPP basis), followed by those in Hungary and the Slovak Republic. The lowest prices were observed in the United States, Brazil, China, and Canada. In the period 2000-08, prices generally rose (except for Hungary and the Czech Republic), with the highest absolute increases recorded in Turkey, Portugal and Japan, and the highest percentage increases in the United States, Japan, Portugal and Canada. Similar developments were observed for automotive diesel prices (Hasčič and Johnstone, 2011).

Fuel taxes as an instrument to promote "cleaner" road transport have been criticised for allegedly creating a disproportionately bigger financial burden on poorer households. Evidence on the regressivity of fuel taxes comes primarily from cross-sectional surveys, showing that low-income families spend a larger fraction of their annual income on gasoline than high income families.

However, Coria (2012) notes that, according to recent research, the choice of the methodology to assess the regressivity of fuel taxes is crucial in determining the distributional impacts. In any case, regressivity can be alleviated through interventions targeted at households that are hit most adversely.

For example, Ščašný (2012) finds that such equity concerns may not be justified, at least in the Czech Republic, as the share of fuel expenditures in total expenditures in the Czech Republic is almost uniform across income groups. Therefore, fuel taxes are neither strongly progressive nor strongly regressive.

Studying the distributional impacts of fuel taxes in seven European countries (France, Germany, the United Kingdom, Italy, Serbia, Spain and Sweden), Sterner (2012) finds some very weak evidence of regressivity, which leads him to the conclusion that fuel taxes are approximately proportional. However, fuel taxes are actually characterised by progressivity in low-income countries, where a smaller share of the population has access to cars and thus fuel taxes are more equivalent to a tax on luxury goods.

Vehicle taxes

In many OECD countries there are two main categories of taxes on motor vehicles: one-off taxes that are levied when the vehicles are first registered; and recurrent taxes that one has to pay (*e.g.* annually) in order to possess and/or use the car. Increasingly, such taxes are levied on the basis of the amount of CO_2 that vehicle categories emit on average per kilometre driven. In some countries, the tax rate differentiation is based directly on the certified CO_2 emissions of a vehicle type, while in other countries the tax rate depends on the certified fuel efficiency. Table 15 gives an overview of OECD countries that differentiate tax rates on the basis of CO_2 in one-off taxes and recurrent taxes on motor vehicles.[72]

Table 15. CO_2-related tax differentiation in motor vehicle taxes

CO_2-related tax differentiation in one-off taxes	CO_2-related tax differentiation in recurrent taxes
• Austria • Belgium - Wallonia • Canada • Denmark • Finland • France • Ireland • Netherlands • Norway • Portugal • Spain • United States	• Denmark • France (big polluters) • France (company cars) • Germany • Ireland • Portugal • Sweden • United Kingdom

Source: OECD based on Braathen (2012).

In the **United Kingdom**, a new vehicle excise duty (VED) was introduced in 2001, so that all vehicles registered for the first time were placed into one of four bands based on their levels of CO_2 emissions. A fifth band was announced in the 2002 budget, a sixth in 2003, and a seventh in the 2006 budget. In addition, in 2006 the VED rate for the lowest emitting cars was reduced to zero. In the 2007 budget, the rate for the vehicles emitting the highest level of CO_2 was increased significantly. Within each band, there is a discount rate for using cleaner fuels, although a gram of CO_2 is harmful to climate and the environment regardless of whether it is emitted from a diesel-powered vehicle, or a natural gas vehicle, or a vehicle powered by biofuels.

The 2008 budget introduced a further reform of the VED scheme. All vehicles were placed in one of 13 new bands, reflecting their CO_2 emissions more accurately and putting a significant increase of rate on those vehicles in the higher band. This new system increased the number of bands for high-emission vehicles and set lower tax rates for AFVs. Duty rates for new cars (when they are first registered) are set in a way that the difference between the least and the most emitting vehicles is stressed, sending a strong signal to consumers about the environmental implications of their car purchase.

Evaluations of the impact of the VED scheme on consumer behaviour and emission reduction have produced mixed results. A 2003 assessment conducted on behalf of the Department of Transport showed that the VED had a minimal impact: differences between the bands were not high enough to be considered in the decision-making process. Even after the 2008 reform, critics pointed to a number of shortcomings of the system. First, rising VED rates on cars that have already been purchased is unlikely to influence drivers' behaviour, as the tax does not depend on the kilometres travelled. Second, the differentials between VED bands are considered to be too small to be effective, and the projected carbon savings are far less than they were expected to be (The House of Commons of the United Kingdom, 2008).

72 For comparisons of CO_2-related tax rate differentiation in motor vehicle taxes, see www2.oecd.org/ecoinst/queries/MotorVehicleCO2.htm.

Similar schemes have been introduced in other OECD countries, with some evidence pointing to positive results, although the cost-effectiveness of the measures is often uncertain. For example, in **Sweden** an environmental excise duty on cars was introduced in 2006. The duty rates depend on CO_2 emissions and on the fuel type, with lower rates for cars powered by alternative fuels. The rate is higher for diesel-powered vehicles, because the fuel tax rate on diesel is lower than on petrol, and because requirements concerning the emissions of local pollutants (such as NOx) are less stringent in the case of diesel-powered vehicles. Therefore, the incentive to choose a low emission vehicle is much larger in the case of diesel-powered cars. Since July 2009, clean cars have been exempt from this tax for the first five years. This measure replaced the EUR 1 000 subsidy for private clean car buyers. The result is that low emission diesel cars are more subsidised than low emission petrol cars or alternative fuel cars, although the higher rate on diesel-powered cars was meant to compensate for environmental effects and fuel tax differences (Beser Hugosson and Algers, 2012).

Borup (2009) and Beser Hugosson and Algers (2012) show that the environmental excise duty contributed to an increase in sales of clean cars as a share of new cars, from less than 5% in 2005 to more than 40% in 2010. This increase was mainly driven by sales of E85 (ethanol)-capable vehicles, although their share of new clean vehicles decreased from 53% in the period January–September 2009 to 31% in the period January–September 2010. Although this represents a positive development, E85-capable vehicles mainly run on petrol when the price relation is unfavourable to biofuels, therefore their contribution to CO_2 mitigation will only be successful if price relations make consumers choose the alternative fuel. The share of diesel-powered vehicles also increased significantly, mainly at the expense of sales of petrol-fuelled cars.

However, it is difficult to disentangle the effects of exogenous factors (*e.g.* evolution of international oil prices) from the impact of the fiscal disincentive. In addition, the duty was introduced in parallel with other measures (including fiscal and financial incentives, other fiscal disincentives such as the congestion charge, and green public procurement). No assessment was carried out of what the effect of the environmental excise duty would have been, had the measure been introduced in isolation.

In 2008, **Ireland** introduced a carbon-differentiated vehicle registration tax (VRT) system. Vehicles are categorised in seven bands on the basis of their CO_2 emissions, and individuals pay a higher VRT the higher the emission intensity of the vehicle purchased, with rates ranging from 14% to 36%. The same system of bands also applies to the motor tax (*i.e.* the annual circulation tax, ACT), so that the annual tax ranges from EUR 104 for the least carbon-intensive vehicles to EUR 2 100 for the most carbon-intensive vehicles (Hughes-Elders, 2010).

Following the introduction of the scheme, the share of energy-efficient cars in new car sales increased steeply, in parallel with a decrease in sales of less efficient vehicles. This contributed to a drop of average CO_2 emissions of new cars by more than 30 g/km since the introduction of the scheme (Hughes-Elders, 2010).

Using a discrete choice model,[73] Giblin and McNabola (2009) assessed the impact of the carbon-differentiated VRT and ACT system on the behaviour of new vehicle purchases, and consequently on CO_2 emissions and government revenues. They predicted a reduction in CO_2 emission intensity of 3.8% from petrol cars and 3.6% from diesel cars, and a 3% reduction in total CO_2 emissions from

73 In a discrete choice model, decision makers choose among a set of alternatives, whereby alternatives are mutually exclusive, exhaustive and finite.

private transport.[74] However, these results in terms of CO_2 reduction do not take into account the potential rebound effect. A shift of 6% from petrol-fuelled to diesel-fuelled car ownership was also predicted. Furthermore, the ACT was found to have a larger impact on CO_2 emissions intensity reduction than the VRT, which may be due to the fact that, when purchasing a new vehicle, the price is quoted inclusive of VRT and as such is not seen by the purchaser as an extra cost.

In terms of overall costs, the introduction of the measures was found to result in an annual revenue loss of EUR 191 million for the public exchequer. However, Giblin and McNabola (2009) argue that the cost savings in terms of public health improvements and carbon credits may outweigh this loss. At the same time, Hughes-Elders (2010) reports that the yield from the VRT dropped sharply in 2008 and especially in 2009 and 2010, because of: the economic crisis; the reduction of new car prices; and the decrease in the effective average VRT rate applied under the new system.

Also in the Irish case, it is difficult to assess the impact of the pricing measure. The carbon-differentiated VRT scheme was introduced at the same time as a new car labelling system, which makes it more complicated to isolate the effects of one initiative compared to the other.

One common problem with carbon-differentiated vehicle taxation schemes is that they have notches (*i.e.* discrete boundaries), which can give rise to a number of questions: why should a hybrid vehicle pay a lower duty than a conventional vehicle with the same test carbon emissions? And why should new vehicles be taxed in bands, rather than as a continuous function of the relevant parameter (*i.e.* the level of CO_2 emissions)? (Schipper, 2012). In addition, Sallee and Slemrod (2010) provide evidence that automakers respond to notches by manipulating fuel economy ratings so as to just qualify for more favourable treatment. Using data for the United States Gas Guzzler Tax,[75] they find that welfare benefits from such manipulations are negative.

The same set of issues can also be raised with regard to feebates (*e.g.* the French Bonus-Malus). Setting fees and rebates according to a stepwise schedule can be less effective than a continuous feebate, as there is little incentive to improve the performance of vehicles that are not close to the next step, and there is more uncertainty about the value of adding technology to future vehicles (ICCT, 2010).

In addition to highlighting the difficulties of isolating the effects of fiscal disincentives from other related measures when evaluating the impact of carbon-differentiated vehicle taxation, the examples of the United Kingdom, Sweden and Ireland also points to the importance of ongoing monitoring of commercial and technological developments. The timing and sequencing of vehicle taxation should reflect such developments. As automobile manufactures improve the energy efficiency of their vehicles over time and the market evolves accordingly, policy makers may consider tightening the stringency of fiscal disincentives, in order to ensure that the measures continue to contribute to CO_2 emissions reduction.

74 This amounts to a 0.16 Mt CO_2 reduction. For comparison, by 2010 vehicle engine efficiency improvements were expected to deliver reductions of 0.48 Mt of CO_2, and modal shifts to public transport were targeted to deliver a reduction of 0.78 Mt of CO_2.

75 The Gas Guzzler Tax was introduced in 1978 with the CAFE programme, and penalised cars with lower fuel economy. The amount of the tax is notched in fuel economy, so vehicles with small ratings differences may be subject to discretely different taxes (Sallee and Slemrod, 2010).

Road usage taxes and congestion charges

Road usage taxes may impact the overall volume of traffic, but they are unlikely to provide incentives for reducing per-unit fuel consumption and CO_2 emissions, as their main objective is to encourage a modal shift away from personal transport (in addition to raising funds for road maintenance). An innovative scheme was introduced in the **Netherlands**, which imposed a tax on road usage (kilometres driven annually) applying a differentiated tax rate which varies by the type of vehicle reflecting its CO_2 emissions (Hasčič and Johnstone, 2011). However, the scheme has since been abandoned.

Congestion charging is another instrument that can contribute to shifting consumer preferences towards green vehicles. It has been introduced in London, Stockholm and Singapore, with different approaches. These experiences show that a successful congestion charging scheme can be defined as one that works technically and reduces congestion, is acceptable, and generates net socio-economic benefits. Congestion charges potentially raise substantial amounts of revenue, but the systems are costly to run as well. Emphasising revenue neutrality may be an important requirement for getting public and political support, but transparency and accountability in revenue use is at least as importance for acceptance (OECD/ITF, 2010).

Lessons learned

Developing instruments based on pricing is a complex task for policy makers, since they often require highly technical knowledge on particular technologies to set the right support level and administrative skills to design incentives and disincentives that lead to a behavioural shift of targeted consumers. This requires experience, which takes time to build.

Cost-effectiveness considerations are particularly important for pricing measures, given the potentially high costs that they can entail for public exchequers. When formulating cost-benefit analyses, it is necessary to measure the returns to supported adoption of green vehicles in terms of additional environmental goods (*e.g.* CO_2 emissions and air pollution reduction) versus the subsidy costs to the taxpayer.

The effectiveness of price-based instruments may also depend on learning effects. When these are limited, incentives may fail to trigger the adoption of green vehicles, or it may take too long for AFVs technologies to become competitive. On the other hand, when learning effects are high, incentives may not be necessary because the diffusion would have happened anyway. If the target product or technology does not have a vision to be "economically competitive" at some point in the future, it should not be supported (Kalish and Lilien, 1983). Only AFVs technologies that are likely to experience steep cost reductions should be supported. Policy makers need to find a "sweet spot" at which subsidies are effective in triggering adoption and widespread diffusion without wasting public funds on consumers who would have adopted the products involved anyway (Cantono and Silverberg, 2009).

Another main challenge for pricing instruments is to produce a shift in consumer behaviour by increasing awareness of the long-term benefits of green vehicles. Consumers rarely count the full costs and benefits of their purchasing decisions, but instead focus on the immediate costs and are influenced by individual emotions, other people's behaviour, habits and the use of mental shortcuts which help to make a quick decision (Policy Studies Institute, 2006). Consumers also have a tendency to put a greater value on the immediate costs than on the future savings. For instance, tax waivers typically have a greater impact than rebates or tax credits, because tax waivers affect the upfront cost immediately, as shown by the experience with these measures in the United States, Canada and other OECD countries.

Price-based measures run some other risks. For example, they can end up focusing AFV innovations along relatively narrow lines, resulting in inefficient decisions of producers, investors and consumers. There is also a risk of "picking the wrong winners and losers" by providing direct or indirect incentives and/or disincentives in sectors or technologies on which policy makers do not have full information. Moreover, there is a danger that providing early financial or fiscal support to a technology might stymie further innovations.

The issue of equity is also important. Tax credits and subsidies may end up being highly regressive, and only reward those who need them the least. In addition, fuel and vehicle taxes may create a disproportionately big burden on poor households, although the evidence does not seem to support this argument.

As shown by the cases analysed in this report, some evaluations of the efficiency and effectiveness of these schemes were carried out in OECD countries. Overall, these assessments produced mixed results; in particular, they cast doubt over the cost-effectiveness and budgetary sustainability of incentive schemes. Price-based measures can play a role in the overall policy mix, but have some limitations in the current context of growing fiscal constraints across OECD countries.

5.5 Support for commercialisation

Rationale for the instrument

Electric drive trains and fuel cells are among the technologies that are often considered to be too risky to attract debt finance and thus critically depend on other sources of finance, such as venture capital for their commercialisation (Ghosh and Nanda, 2010). Governments may need to support financially the commercialisation of innovative fuels and propulsion technologies, thus contributing to overcoming high entry costs and lock-in failures.

In addition, newcomers and new business models often play a crucial role in the development of green vehicles and their diffusion in the market, for example battery manufacturers in the case BEVs, or providers of innovative business models. Therefore, governments may consider introducing initiatives to encourage the availability of venture capital for the creation and growth of new firms.

Policy practices

In 2010, **France** created the programme *Investissements d'Avenir* ("Investments for the future"), which has among its objectives the support to innovation in automotive technologies that contribute to the goal of reducing CO_2 emissions. The programme is designed to go beyond demonstration by providing companies with support to pilot new technology into the experimental phase and validate it prior to commercialisation (IEA IA-HEV, 2011).

In the **Netherlands**, the 2011-15 Electric Mobility Action Plan foresees the establishment of an Innovation Fund to improve the access to capital for companies that invest in innovations, by means of innovation credits, by giving guarantees to financial intermediaries and by participating in investment funds.[76]

In the **United States**, the Department of Energy provides loan guarantees through the Loan Guarantee Programme to eligible projects that reduce air pollution and GHG, and supports early commercial use of advanced technologies (including biofuels and AFVs). Therefore, the programme does not target R&D projects. The Department of Energy may issue loan guarantees for up to 100% of the amount of the loan for an eligible project (U.S. Department of Energy, 2011c).

In the **European Union**, the TEN-T Annual Call 2012 gives prominence to so-called "market-sided innovations", *i.e.* new technologies (in particular those that use alternative fuels) that are ready for deployment, with initial results due by end of 2013.

In **China**, more than RMB 100 billion will be invested to facilitate the development of the entire PEV industry value chain and commercialisation of PEVs in the decade 2010-20. Of this amount, RMB 30 billion will be invested in the commercialisation of EVs, and RMB 20 billion will be invested in the commercialisation of HEVs and PHEVs (Accenture, 2011ab). The Ministry of Finance issued a policy statement announcing government participation in venture capital funds that are investing in clean technologies, including AFV technologies (Wang, 2011).

Lessons learned

Complete evaluations of the impact of government support to financing commercialisation of green vehicles are largely lacking, possibly because many of these initiatives are quite recent. Therefore, it is not fully clear what constitutes best practice in this area.

However, some lessons can be drawn from recent OECD work on the role of policies to drive markets for eco-innovation, and provide some guidance to policy makers on how to avoid mistakes made in other sectors (OECD, 2012e). For example, government intervention should attract and complement private financing, not crowd it out. The main challenge in this respect is for governments to attract large sums from private sector sources using a relatively small amount of public funds. In addition, a portfolio approach should be applied for risk mitigation, so that overall risks and returns are aligned. It also means that policy makers should consider employing a broad range of financial instruments including debt and equity. Independent, transparent and accountable management of funds may go a long way in ensuring better performance of government support. Finally, financial instruments should be implemented in combination with other demand-side policies, as market certainty and strong demand can lower the costs of financial transactions and ease the mobilisation of private investment in eco-innovation.

Generally, evaluations of programmes in support of commercialisation of eco-innovations highlighted positive outcomes in terms of mobilisation of private funds as well as employment creation. However, concerns over the management and effectiveness of these programmes have been raised: doubts exist over the role of third-party certification in shaping financial institutions' decision-making processes; the procedures to obtain government loans are often lengthy and costly; and government support may distort incentives and provide the wrong signals to the industry. Project failures may also cast a negative light on accountability and screening procedures.

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[76] Personal communication with the Ministry of Economic Affairs, Agriculture and Innovation of the Netherlands.

Analysing company-, regional- and national-level determinants of high-growth financing in the cleantech sector (including energy efficiency and transportation), Criscuolo and Menon (2012) do not find any significant correlation between public investment loans or financing and the amount of private financing of innovative ventures. However, this does not mean that government financing could not represent a possible solution to the financing gaps in the cleantech sector. This financing gap arises because the level of investment required by the cleantech sector is on average much larger than in other sectors and because the time span of cleantech projects from the seed to the scaling up phase is much longer than the average life of a venture capital fund.

5.6 Infrastructure provision

Rationale for the instrument

By supporting the provision of refuelling infrastructure, governments can tackle the important network externalities that prevent the creation of markets for green cars, as well as provide private operators with an incentive to invest.

The results of real-life test trials and experience with deployment of EVs show that most consumers charge their vehicles at their residence and under-utilise public charging infrastructure. In addition, private sector operators are increasingly entering this market. However, public intervention could be justified in providing fast charging infrastructure, also in order to tackle the range anxiety of drivers.

Policy practices

Many OECD countries are supporting infrastructure deployment:

- **Canada** is deploying charging stations for EVs in partnership with Better Place (see Box 4). Infrastructure is being deployed mostly at the provincial level. In 2009, Vancouver's council mandated charging infrastructures for electric cars in new homes. This completes an ordinance calling for 10% of parking spots in new condominiums and multi-unit residential complexes to be fitted with 240V charging stations. It was decided to focus on basic home access to fast electric charging, so as to give potential consumers of electric cars an easy and simple way to charge their vehicles overnight (OECD, 2011e).

- The governments of **Denmark** and **Israel** are also deploying charging and battery swapping infrastructure in partnership with Better Place (see Box 4).

- **Estonia** is deploying a countrywide network of EVs fast-charging infrastructure to complement the use of private slow-charging stations. Eventually, it will be possible to find a fast-charging station within a 25 kilometre-distance in each direction.[77]

- In **France,** in response to a Green Book issued by Senator Louis Nègre in spring 2010, efforts are underway to deploy both private and public charging infrastructure for EVs. In April 2010, the French government, carmakers and 13 “collectivités territoriales” (local authorities) signed a charter through which they agreed to co-operate to put in place charging infrastructure. The government has launched a call for expressions of interest to finance

[77] Personal communication with the Ministry of Economy and Communications of Estonia.

demonstration projects on charging infrastructure deployment (*e.g.* test runs and best practices on how to put in place the stations and on how to protect them).[78]

- In **Germany**, the National Development Plan for Electric Mobility (2010-20) targets the development of the necessary infrastructure for a large-scale introduction of EVs. Charging infrastructure investment was part of the economic stimulus package ("Konjunkturpaket II") implemented in January 2009 (IEA IA-HEV, 2011).

- The government of **Italy** is promoting the deployment of refuelling infrastructure, not only for electricity, but also for other alternative fuels (biofuels, methane and LPG).[79]

- In **Japan**, part of the USD 356 million earmarked in the fiscal year 2011 budget to clean vehicles deployment is dedicated to installation of charging infrastructure. More specifically, half of the price of the charger is subsidised.[80]

- The government of **Korea** plans to deploy 5 000 public charging stations for EVs by 2014, and support the installation of commercial stations through public financing. It will also provide financing for the establishment of hydrogen fuelling stations which will use by-product hydrogen, land-filled gas, LPG or LNG.[81]

- The government of the **Netherlands** is planning to roll out charging infrastructure for EVs gradually. In specific geographic areas, infrastructure will be deployed slightly in advance of EVs commercialisation. Incentives will be given to viable innovative charging technologies (*e.g.* rapid chargers, battery swapping and inductive charging). In addition, the government adopted a recommendation to launch projects involving applications for smart grids for electric transport.[82]

- In **Portugal**, the Mobi.E project, undertaken in co-operation with 25 municipalities, should lead to a network of 1 300 slow-charging and 50 fast-charging stations to be installed by the end of 2012.

- In the **United Kingdom**, the government released a plug-in vehicle infrastructure strategy in June 2011. The strategy also sets out steps being taken to remove regulatory barriers, such as planning laws, to make it easier for the recharging infrastructure to be installed at home and in workplaces. It also proposes to include a policy on infrastructure in the National Planning Policy Framework, in order to encourage local authorities to foster the deployment of recharging infrastructure in new homes, workplaces and retail developments. The government is supporting Plugged-In Places (PiP), a match-funding scheme which is being run in eight pilot areas (covering a large part of the United Kingdom) with business consortia and public sector partners to support the installation of a recharging infrastructure. These pilot schemes will also provide data about how drivers use and recharge their vehicles,

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78 Personal communication with the Ministry of Economy, Finance and Industry of France.

79 Personal communication with the Ministry of Economic Development of Italy.

80 Personal communication with the Ministry of Economy, Trade and Industry of Japan.

81 Personal communication with the Ministry of Knowledge Economy of Korea.

82 Personal communication with the Ministry of Economic Affairs, Agriculture and Innovation of the Netherlands.

building the necessary evidence base to shape the design of the national recharging infrastructure.[83]

- In the **United States**, the American Recovery and Reinvestment Act of 2009 supports the deployment of more than 22 000 charging points for EVs in more than 20 cities across the country (IEA IA-HEV, 2011).

- In the **European Union**, funds have been made available under the annual TEN-T calls for infrastructure studies with the possibility of integrated pilot deployment contributing to the decarbonisation of transport. These provisions concern also the build-up of alternative fuel infrastructure on the TEN-T network (European Commission, 2011).

Outside the OECD membership, the government in **China** is funding the construction of charging stations and battery recovery networks in five cities (Shanghai, Shenzhen, Hangzhou, Hefei and Changchun). In January 2011, the government announced a plan to install at least 10 million car parking spots for EVs by 2020 (Cleantech, 2011b).

Lessons learned

The timing and sequencing of infrastructure deployment is crucial. As highlighted by the IEA (2011b), sufficient recharging infrastructure should be in place not only for the initial wave of vehicles (*e.g.* a few thousand within a country, through 2012) but also for the second phase of the market ramp-up (*e.g.* potentially up to hundreds of thousands or even a few million vehicles through 2015-20). In addition, as shown by the experience of the Netherlands, it may be appropriate to support the installation of refuelling/charging infrastructure in advance of AFV deployment, in order to avoid a potential "chicken-and-egg" problem. Well-designed public-private partnerships may provide the most promising approach to developing the necessary infrastructure.

Deployment of public charging infrastructure poses some specific challenges. It needs to fit the specific needs of urban customers, and be budget neutral for cities. The related business model must be simple to implement. Concretely, this implies that charging stations should be installed where other services are provided (*e.g.* in parking lots) and charging methods should be universal (interoperability is key in this respect). However, the overall revenue model of public infrastructure deployment is still surrounded by a high degree of uncertainty. It can be expected that the initial investment and the daily operations of the networks may need separate funding patterns, and private investment could be needed to complement public initiatives (Paturet, 2012).

The results of a test trial with drivers in Japan show that fast-charging infrastructure can go a long way in overcoming range anxiety. Before the installation of a DC fast charger in the area, drivers were reluctant to use EVs, although they knew that the range of the batteries could cover the area fully. After the fast charger was installed, monthly driven mileage increased significantly, from 203 miles to 1 472 miles travelled. Fast charging can be an efficient and effective solution for refuelling an EV in a public location (where drivers are not willing to wait for a long time), while it is too costly for private charging (*e.g.* at home or at the office, where the time of refuelling is less important). Governments can put in place a number of measures to promote deployment of fast charging infrastructure, as it was done in Japan with subsidies and tax incentives, but also changes in the electricity supply regulation and in the fire protection regulation to eliminate divergences at the local level (Aoki, 2012).

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[83] Personal communication with the Department of Business Innovation and Skills of the United Kingdom.

The approach adopted in Estonia allows the government to procure the full infrastructure solution (including the chargers, the operating system and the related services) at once and with a single operator. Location and connection of charging stations are negotiated centrally, and this makes it easier to plan and execute the roll-out. The government may eventually exit the single operator/single network management system business model through privatisation.

Smart grids will play a key role in facilitating the deployment of the charging infrastructure. Smart grid technologies make it possible for EVs to proliferate without overloading the electric supply industry. Thanks to smart grids, EVs may be useful for matching intermittent solar and wind power supplies to demand, soaking up excess off-peak power supply and feeding power back into the grid when needed (Morgan, 2012). The Dutch experience underscores the importance of developing the smart grids that are needed to accommodate and balance the changing patterns of energy production and distribution, due to the increasing use of renewable sources and the decentralisation of electricity generation.

5.7 Information-based measures

Rationale for the instrument

Access to high quality, reliable information is an important factor in enhancing consumer' confidence and strengthening markets for environmentally friendly products, including green cars. However, information asymmetries exist in markets for green cars: a certain ambiguity around the availability, performance and safety of AFVs may reinforce consumers' preferences for conventional vehicles, for which information is more abundant and readily available. And even when full and reliable information on green vehicles does exist, it may be too time-consuming and costly for potential buyers to obtain. In order to overcome this market failure, governments can also implement measures aimed at enabling individuals to make more informed choices, such as labelling and consumer education and awareness raising.

Policy practices

Labelling

In **Australia**, since 2001 all new light vehicles sold are required to display a fuel consumption label on the windscreen, giving details of how many litres of fuel the vehicle uses to travel 100 kilometres in city-cycle driving. Since 2009 a new version of the label has been required in showroom vehicles. This new label adopts the UNECE Regulation for the calculation of fuel consumption and CO_2 emissions. It includes additional consumption information – the combined, urban and extra-urban consumption – as well as the combined CO_2 value. Thanks to the additional information, the new label highlights the higher fuel consumption of many vehicles when driven in urban conditions, which is a piece of information that tends to be masked when the label only displays a single combined number (OECD/IEA, 2010; UNEP, n.d.).

Chile introduced a fuel economy labelling scheme in January 2011, the first country in South America to do so. The label was voluntary until September 2011, when it became mandatory for all lightweight vehicles. The label provides consumers with information on CO_2 emissions in grams emitted per kilometre driven, fuel efficiency in kilometres per metre (highway, city, and mixed) and emission compliance standards (UNEP, n.d).

Japan introduced a fuel efficiency labelling system in 2004 (and amended it in 2006) in connection with the Top Runner Programme. The labelling scheme allows to identify if the vehicle is "fully compliant", "plus 5%", "plus 10%" or "plus 20%" higher than the fuel economy standard (OECD/IEA, 2010).

In **Korea**, a labelling system was introduced in 2008, obliging carmakers to show CO_2 emission levels for new vehicles manufactured for the domestic market. Labels on new vehicles must be displayed on vehicle windows and indicate fuel economy and CO_2 emissions, in km per litre and CO_2 released per km (OECD/IEA, 2010).

New Zealand introduced legislation on labelling in 2008. The fuel economy information is specific to a vehicle and is based on the fuel consumption of that vehicle as established by independent testing. Fuel economy information labels must be displayed on new and used passenger cars at the point of sale. The fuel economy information is expressed as: *i)* fuel cost per year; *ii)* fuel economy rating out of 6 stars; and *iii)* fuel economy, in litres per 100 km (OECD/IEA, 2010; UNEP, n.d.).

The **United States** has had the longest running fuel economy/consumption labelling programme. Every new car and light truck sold is required to have a fuel economy sticker label, listing the city, highway and combined miles-per-gallon estimates (OECD/IEA, 2010; UNEP, n.d).

In the **European Union**, Directive 1999/94/EC requires dealers in new passenger cars to provide potential buyers with information on vehicle consumption and CO_2 emissions. The information must be displayed on the car's label, on posters and other promotional material, and in specific guides. The fuel economy label must be attached to the windscreen of all new passenger cars at the point of sale. The label must be clearly visible, and contain an estimate of fuel consumption and of CO_2 emissions. In 2007, the European Commission published the results of a review of the Community Strategy to reduce CO_2 emissions from cars, and proposed to promote the purchase of fuel efficient vehicles by improving vehicle labelling, among other measures (European Commission, 2007). In 2012-14, the Commission plans to present the results of a study looking at the state of implementation of legislation on car CO_2 labelling and consider the need for a review (European Commission, 2011).

The EU directive leaves Member States a significant degree of freedom in designing the labelling scheme. Two main comparison methods have been adopted: *i)* the absolute comparison method in which the energy efficiency/CO_2 classes (six or seven in number) are defined by fixed values (*e.g.* Austria, Belgium, Denmark, France, Germany, Portugal and the United Kingdom); and *ii)* the relative comparison method, in which the energy efficiency classes are related to the stock average (*e.g.* the Netherlands, Spain).[84] The absolute comparison system is the easiest to understand for consumers. The EU directive does not require comparative information, and developing a consistent and fair method for relative comparison proved to be a contentious task, especially with the car manufacturing industry (World Energy Council, 2008).

Fuel economy labelling systems for motor vehicles are also in force in some non-OECD countries. Since 2010, **India** has had a labelling system for new cars. Originally the system was voluntary, but became mandatory for all new vehicles in 2011. In 2008, **South Africa** introduced a standard fuel economy and CO_2 emission testing and labelling system for new passenger cars at dealerships. The system is based on the one used in the European Union (UNEP, n.d.).

Consumer education and awareness raising

The following initiatives have been implemented in OECD countries:

84 Switzerland also applies a relative comparison method.

- In 2009, **Australia** introduced an online portal called "Living Greener" (www.livinggreener.gov.au) with the aim of enabling ready access and, therefore, greater uptake of environmental programmes for sustainability (including in personal transport) by Australian households. The portal is designed to be a single, central and user-friendly hub with links to sectoral information tools such as the Green Vehicle Guide (GVG). Launched in 2004, the GVG is an Internet database providing model-specific fuel consumption and CO_2 emissions data, as well as separate ratings for GHG and air pollution performance, and an overall star rating. Consumers can also calculate annual fuel costs and CO_2 emissions of individual models (OECD/IEA, 2010).

- In **Canada**, free advice is provided to households (through the "ecoENERGY for Personal Vehicles" programme) and business (through the "ecoENERGY for Fleets" programme) on how to make vehicle use more energy efficient. Both programmes were launched in 2007 (OECD/IEA, 2010).

- As part of the "Vehicle Fuel Consumption" project, in 2006 the Ministry of Transport of **New Zealand** launched a Fuel Saver website (www.fuelsaver.govt.nz/), which includes information on vehicle emissions, and guidance on how to calculate fuel expenses and how much can be saved (OECD/IEA, 2010).

- **Mexico** has introduced a website (www.ecovehiculos.gob.mx) that allows consumers to check the fuel economy of specific vehicles (UNEP, n.d.).

- In the **United States**, federal law requires auto dealers to have copies of gas mileage guides available on the showroom floor. The DOE and the EPA maintain a Fuel Economy Guide (www.fueleconomy.gov/), providing consumers with detailed information about mileage per gallon, carbon footprint, and air pollution scores of passenger cars and trucks. The guide has been updated annually since 2000. It also lists model year vehicles that are fuel economy leaders, both overall and by vehicle class, including hybrid vehicles and flexible-fuel vehicles (for blending with biofuels). The website is complemented by a Green Vehicle Guide (www.epa.gov/greenvehicles/) which is updated annually with the latest vehicle models on the market. Each vehicle is given an environmental score on a scale from 0 to 10, with 10 being the best, based on emission levels and fuel economy values. The best environmental performers receive the SmartWay designation, which means the vehicle scores well on both Air Pollution and Greenhouse Gas. The Green Vehicle Guide website allows side-by-side comparisons for up to three vehicles and searches that can be customised based on user choices (OECD/IEA, 2010; UNEP, n.d.).

- In addition to labelling, the **European Union**'s Directive 1999/94/EC (as amended by 2003/73/EC) requires setting up a fuel consumption and CO_2 emission guide, as well as displaying posters in car showrooms and including fuel consumption and CO_2 emissions data in promotional material. The fuel economy guide must be produced at national level at least once a year, and must include a list of the ten most fuel-efficient new car versions in terms of their CO_2 emissions by fuel type. Consumers must be able to obtain the guide both at the point of sale of the dealer and from a designated body within each Member State; an electronic version is also made available by the Commission on the Internet (Europa, 2010).

Lessons learned

As the inventory of policy initiatives presented in this report shows, several OECD countries have introduced vehicle labelling schemes to encourage the purchase of more fuel-efficient cars. In isolation, labelling schemes are unlikely to lead to significant fuel efficiency improvements, but they can be tied effectively to other instruments, such as tax incentives and subsidies (Hasčič and Johnstone, 2011; UNEP, n.d).

Evidence shows that automakers sometimes manipulate vehicle fuel economy in response to presentation notches created by rounding rules in fuel economy label regulations. For example in the case of the United States, automakers are required to report fuel economy ratings as integers, and the test results are rounded off, with the rounding cut-off at every 0.5 MPG. Therefore, automakers have an incentive to manipulate the ratings around these presentation notches, if consumers value fuel economy and use rounded integers when they make their purchasing decisions. The results of Sallee and Slemrod (2010) show that automakers do perform such manipulations, and consumers put a high value on fuel economy.

Education may also play an important role in steering users' behaviour towards sustainable consumption and in raising awareness of what consumers can do to reduce the negative environmental impact of their car purchase and usage patterns. In addition, the benefits of an EV need to be communicated clearly to the potential purchaser, also since the high initial price of the battery requires a longer-term perspective about the associated expenses (IEA IA-HEV, 2011).

5.8 Networks and partnerships

Rationale for the instrument

Government can play an important role in facilitating industry co-ordination, and co-ordination between industry and other stakeholders. In addition to network externalities affecting the demand side, the literature has underlined the importance for companies to engage in relationships and strategic alliances with actors across the production chain (customers and suppliers), as well as collaboration networks with research institutions (Carrillo-Hermosilla, del Río Gonzalez and Könnöla, 2009; Montalvo, 2008). Weak interaction among companies and other actors may hinder eco-innovations.

Transaction costs and co-ordination failures are particularly acute in the development of green vehicles, as there are a large number of technological trajectories. Networks and partnerships can facilitate co-operation and optimise the use of resources (*e.g.* knowledge, finance) among a variety of actors.

Policy initiatives

Networks and partnership to foster the development and diffusion of green vehicles have been implemented in several OECD and also non-OECD countries:

- In **Belgium**, a Belgian Platform on Electric Vehicles brings together the federal government, regional and local authorities, the private sector and other relevant stakeholders. The platform produced a number of position papers and recommendations for the deployment of EVs in Belgium, including on charging infrastructure, consumer uptake, public and private fleets, life cycle of the vehicles, technological developments for batteries, and the role of the public sector for demonstration of the performance of the vehicles. [85]

- In **Canada**, a multi-stakeholder organisation, Electric Mobility Canada, was set up to promote all forms of EVs. It associates firms from the car industry (Ford, GM), utilities (Hydro Quebec, Manitoba Hydro), major fleet users (private companies, government agencies and others), universities and research organisations (OECD, 2011b). In 2009, it released an Electric Vehicle Technology Roadmap for Canada in partnership with the government (Natural Resources Canada), with the aim to provide a vision for electric mobility in 2018.

- In **Germany**, the Electric Mobility Summit held in Berlin on 3 May 2010 led to the establishment of the National Platform for Electromobility, bringing together all the relevant stakeholders from government, industry and society. Seven high-level working groups were created to discuss major issues relating to electric mobility. Their proposals led to the adoption by the federal government of the 2011 *Electric Mobility Programme* (Ramsauer, 2011).

- In **Japan**, a "Strategy Study Group on the automobiles contributing to the renaissance of the Japanese economy" was set up, consisting of executives of the automotive industry, the materials and parts industry, academic experts and other relevant stakeholders. The Group produced a report outlining a vision for energy-efficient vehicles, among other recommendations.[86]

- In the **Netherlands**, the government established the Formula E-Team as a collaboration of Dutch trade and industry, institutes and administrations. The Formula E-Team is an important feature of the governance of the Dutch Electric Mobility Action Plan 2011-15. It brings together all the relevant partners and stakeholders to advise the government at high level and therefore provides a long-term vision. A complementary public-private task force is responsible with dealing with more practical, day-to-day issues related to vehicles, charging and paying systems, and roll-out in municipalities.[87]

- In **Portugal**, creation of knowledge networks is one of the activities of the Mobi.E programme. For example, the Knowledge Society Agency (UMIC) under the Ministry of Education and Science has facilitated partnerships in the field of electric mobility among the Carnegie Mellon Portugal Programme, the MIT- Portugal Programme, the Centre of Excellence and Innovation in the Automotive Industry (CEIIA), INTELI (Innovation Centre), several laboratories and research centres, and enterprises associated with the Mobi.E programme.[88]

- In the **United Kingdom**, in 2007, the government created a "Low Carbon Vehicles Innovation Platform" under the Technology Strategy Board, with funding from several

85 Personal Communication with the Federal Public Service Economy, SMEs, Self-Employed and Energy of Belgium.

86 Personal communication with the Ministry of Economy, Trade and Industry of Japan.

87 Personal communication with the Ministry of Economic Affairs, Agriculture and Innovation of the Netherlands.

88 Personal communication with the Ministry of Economy and Employment of Portugal.

departments (Department for Transport, Department of Energy and Climate Change, Department for Business, Innovation and Skills, the Technology Strategy Board and the Engineering and Physical Sciences Research Council). Since its launch, the platform has delivered a wide range of research projects targeted at low- and ultra low-emission vehicle technologies, with match-funding from the private sector. The platform is also implementing a demonstration project, trialling over 340 electric and plug-in electric cars in 8 locations around the United Kingdom.[89]

- In order to facilitate a broad market penetration of electric vehicles, the **European Union** supports a European demonstration project within the Green Car Initiative of the 7th Framework Programme for Research and Technological Development. The "Green eMotion" project (www.greenemotion-project.eu) has been selected following an open call for proposals within the EU. Forty-three partners from industry, the energy sector, electric vehicles manufacturers, municipalities as well as universities and research institutions are participating in this demonstration project, which should contribute to the development of a market for electromobility in Europe. The project has a total budget of EUR 42 million, and is funded by the European Commission with EUR 24 million.[90]

- In **China**, an Electric Vehicle Industry Alliance consisting of 16 central state-owned enterprises and led by the State-owned Assets Supervision and Administration Commission of the State Council (SASAC) was created in 2010. The alliance's medium to long-term goal is to master the core technology for electric vehicles and build internationally competitive Chinese electric car brands (*People's Daily Online*, 2010).

Lessons learned

Networks and partnerships to foster the development and diffusion of green vehicles in OECD countries have different structures and modus operandi (*e.g.* multi-stakeholders platforms; knowledge networks; high-level working groups; operational and technical task forces). Their outputs range from producing strategic visions for the decarbonisation of transport to solving operational and technical issues in putting in place the right framework conditions and infrastructure required for AFVs deployment.

Formal evaluations of the impact of networks and partnerships on market development of green vehicles are generally lacking. However, anecdotal evidence emerging from the experience in OECD countries seems to suggest that they have often provided key governance structures for co-ordinating diverse actors in a complex environment.

5.9 Summary of policies to foster market development for alternative fuel vehicle technologies

Table 16 summarises the main demand-side policy instruments presented in this report, and the barriers they address, as well as examples from OECD and non-OECD countries.

89 Personal communication with the Department for Business, Innovation and Skills of the United Kingdom.

90 Personal communication with the Directorate-General for Mobility and Transport (DG MOVE) of the European Commission.

Table 16. Summary of policies, barriers and examples from OECD and non-OECD countries

Policy instrument	Barriers/failures addressed	Examples from OECD and non-OECD countries
Public procurement	• Low returns to R&D • Network externalities • Norms and habits • Information asymmetries	• Estonia: public procurement of EVs for social workers. • France: public procurement of EVs for state enterprise fleets. • Japan: Green Purchasing Law and procurement of EV/PHVs in prefectures, cities and towns. • United States: EPAct AFVs purchasing requirements for federal, state governments and alternative fuel providers fleets. • Italy: Green Public Procurement Law. • Korea: Green Procurement Law and AFVs purchasing requirements in: 2008 Hybrid and Fuel-Cell Powered Vehicles Plan; 2010 Strategy for Green Car Development. • The Netherlands: potential purchasing of EVs for the public fleet in the 2011-15 Electric Mobility Action Plan. • United Kingdom: Low Carbon Vehicle Public Procurement Programme (LCVPPP).
Performance-based regulations and standards	• Entry barriers and technology lock-in • Norms and habits • Information asymmetries • Policy unpredictability and regulatory uncertainty	• United States: federal CAFE standards. • California (and other US States): Pavley regulations and ZEV technology mandate. • EU: CO_2 emission regulation. • Japan: Top Runner Programme. • Australia, Canada, Korea, China and India: emission performance regulations.
Technology-based regulations and standards	• Network externalities • Barriers to competition • Norms and habits • Inadequate infrastructure • Policy unpredictability and regulatory uncertainty • Information asymmetries	• United States, EU, Japan: Standardisation of charging infrastructures. • UNECE: International standardisation of environmental, energy-related, and safety aspects of green vehicles. • Several OECD and non-OECD countries: Renewable fuel standards and mandatory blending mandates or targets for biofuels.

Table 16 Summary of policies, barriers and examples from OECD and non-OECD countries (cont'd)

Price-based measures	• Barriers to competition • Norms and habits • Perverse subsidies and preference to incumbents • Information asymmetries • Environmental externalities	• Fiscal and financial incentives: Bonus-Malus in France; incentives in the United States, Belgium, Japan, Korea, Canada, Estonia, Italy, the Netherlands, Portugal, Spain, United Kingdom, Norway, Israel, China. • Fiscal and financial disincentives: fuel taxes; one-off CO_2-based vehicle taxes (France, Portugal, Spain, Finland, Austria, Ireland, Netherlands, Belgium – Wallonia, Norway, Canada, Denmark, United States); recurrent CO_2-based vehicle taxes (Denmark, Germany, Ireland, Portugal, Sweden, United Kingdom, France – for big polluters and company cars); vehicle taxation based on CO_2 emissions and emissions of local pollutants (Israel); road usage tax (Netherlands) and congestion charges (London, Stockholm, Singapore).
Financing for commercialisation	• Barriers to competition	• United States: Department of Energy Loan Guarantee Programme. • EU: TEN-T. • France*: Investissements d'Avenir*. • The Netherlands: Innovation Fund. • China: government participation in clean-tech VC.
Infrastructure provision	• Network effects • Inadequate infrastructure	• Support to infrastructure deployment in the following countries and regions: Canada, Estonia, France, Germany, Israel, Denmark, Italy, Japan, Korea, the Netherlands, Portugal, United Kingdom, United States and European Union.
Information measures	• Norms and habits • Information asymmetries	• Labelling: United States, EU, Australia, Chile, Japan, Korea, New Zealand, India, South Africa. • Consumer education and awareness-raising: EU, Australia, Canada, New Zealand, Mexico, United States.
Networks and partnerships	• Network effects	• Canada: Electric Mobility Canada. • Germany: National Platform for Electromobility. • Japan: Strategy Study Group on the automobiles contributing to the renaissance of the Japanese economy. • The Netherlands: Formula E-Team. • Portugal: Mobi.E networks. • United Kingdom: Low Carbon Vehicles Innovation Platform. • EU: Green eMotion. • China: Electric Vehicle Industry Alliance.

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LIST OF ABBREVIATIONS

AAU	Assigned Amount Units
AC	Alternate current
ACEA	European Automobile Manufacturers’ Association
ACT	Annual circulation tax
AFV	Alternative Fuel Vehicle
AGO	Australian Greenhouse Office
ATPZEV	Advanced technology partial emission vehicle
BEV	Battery Electric Vehicle
BPM	Vehicle and motorcycle tax
BRT	Bus rapid transit
CAFE	Corporate Average Fuel Economy
CARB	California Air Resource Board
CH4	Methane
CNG	Compressed natural gas
CO	Carbon monoxide
CO2	Carbon dioxide
CVRP	Clean Vehicle Rebate Project
CVT	Continuously variable transmission
DC	Direct current
DOE	Department of Energy
DOT	Department of Transportation
EISA	Energy Independence and Security Act
ELMO	Electromobility programme

EPA	Environmental Protection Agency
EPAact	Energy Policy Act
EPCA	Energy Policy Conservation Act
ETS	Emission trading scheme
EV	Electric vehicle
EVI	Electric vehicle initiative
FCAI	Federal Chamber of Automotive Industries
FCEV	Fuel cell electric vehicle
FTP	Federal Test Procedure
g CO2/km	Gram of CO2 per kilometre
GBS	Government buying standard
GHG	Greenhouse Gas Emission
GPP	Green public procurement
GVG	Green Vehicle Guide
HC	Hydrocarbon
HEV	Hybrid electric vehicle
HFC	Hydrofluorocarbon
HOV	High occupancy vehicle
IA-HEV	Implementing Agreement for co-operation on Hybrid and Electric Vehicles Technologies and Programmes
ICCT	International Council on Clean Transportation
ICE	Internal Combustion Engine
ITS	Intelligence transporation system
JAMA	Japanese Automobile Manufacturers’ Association
KAMA	Korean Automobile Manufacturers' Association
kW	Kilowatt
kWh	Kilowatt hour

LCA	Life Cycle Analysis
LCVPPP	Low carbon vehicle public procurement programme
LDV	Light-duty vehicles
LEV	Low-emission vehicle
Lge	Litre per gasoline equivalent
LNG	Liquified natural gas
LPG	Liquified petroleum gas
MRB	Motor vehicle tax
Mtoe	Million tonne of oil equivalent
MY	Model year
N_2O	Nitrous oxide
NACE	National average carbon emissions
NEDC	New European Driving Cycle
NGV	Natural gas vehicle
NHTSA	National Highway Traffic Safety Administration
NMOG	Non-methane organic gas
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_X	Nitrogen oxides
NTC	National Transport Commission
OEM	Original equipment manufacturer
OLEV	Office for Low Emission Vehicles
Pb	Lead
PEM	Polymer electrolyte membrane
PHEV	Plug-in hybrid electric vehicle
PiCG	Plug-in Car Grant

PM	Particulate matter
PZEV	Partial zero emission vehicle
RD&D	Research, development and demonstration
REEV	Range extended electric vehicle
RFS	Renewable Fuel Standard
SASAC	State-owned Assets Supervision and Administration Commission of the State Council
SO_2	Sulphure dioxide
TCO	Total Cost of Ownership
TFC	Total final consumption
TLEV	Transitional low-emission vehicle
Toe	Tonne of oil equivalent
TPES	Total primary energy supply
TTW	Tank to Wheel
ULEV	Ultra low-emission vehicle
VED	Vehicle excise duty
VKT	Vehicle kilometres travelled
VOC	Volatile organic compounds
VRT	Vehicle registration tax
WTT	Well to Tank
WTW	Well to Wheel
ZEV	Zero-emission vehicle

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