# THE IMPACT OF ELECTRIC VEHICLES ON THE GLOBAL OIL DEMAND AND $CO_2$ EMISSIONS

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## ABSTRACT

Global oil demand will grow significantly in the future years, partially due to a doubling of the global vehicle fleet until 2050. Especially in the emerging economies the vehicle density is assumed to increase in the coming years. In this context, China and India play, due to their fast economic development and large populations, a dominant role. This growth in oil demand is, however, strongly dependent on the market penetration of alternative fuels and drive technologies. Even a small share of alternatives might have a considerable effect on crude oil prices. From the current perspective, the oil price is still high enough to make electric vehicles (EVs)[1] competitive to conventional internal combustion engine vehicles (ICEVs).

This development of the vehicle market and its impact on the oil price has significant influence on global energy scenarios in general. This paper focuses on the market potential of EVs in various relevant markets with respect to the technological development, prices and policies. Besides the analysis of the impact on oil demand, the $CO_2$ emission development based on national power plant portfolio and its usual electricity generation is analysed.

*Keywords: sustainable transport policy, electric mobility, transport energy demand, $CO_2$ emissions*

[1] The term EVs refers throughout this paper to battery (BEVs), plug-in hybrid (PHEVs), range extended (REEV or EREVs) and fuel cell (FCEVs) electric vehicles.

# 1. INTRODUCTION

The objective of globally reducing greenhouse gas (GHG) emissions, including those from the transport sector, is high on the international climate agenda. The transport sector, in particular road transport, is a major source of $CO_2$ emissions – 23% of the world $CO_2$ emissions in 2009 (IEA, 2011d). For example, in Europe (EU-27) transport is the only sector which increased its emissions in recent years (EC, 2010). In addition, the road transport sector is also a major consumer of crude oil, which creates, at the national level and especially in importing countries, concerns related to energy security. The trends in the road transport sector indicate that the world is thus facing two key global problems: energy demand growth and increasing emissions. Whereas the former will add enormous pressure on energy systems; the latter will lead to a greater concentration of anthropogenic GHG emissions in the atmosphere, prompting climate change. In an attempt to tackle this challenge from a transport sector perspective, various main solutions have been proposed. One of them is to improve vehicle technology, enabling the use of cleaner fuels and the deployment of alternative vehicles. In this regard, the electrification of the road transport sector emerges as a very promising pathway. A successful market penetration of EVs would therefore have important implications for global oil demand and the national energy systems as well as for the environment.

Transport energy use, dominated by road transport (mainly road passenger) and oil-based fuels, has more than doubled between 1971 and 2006 (IEA/OECD, 2009). In 2006, the world final energy consumption by the transport sector was 2,227 Million tonnes of oil equivalent (Mtoe), of which 94.5% corresponded to oil, representing 27.5% of the world total final energy consumption (TFC). In the same year, road transport consumed 1,625 Mtoe (72.9% of total transport energy use), with around 66% of the consumption taking place in OECD countries (IEA, 2008). The share of world total final oil consumption by the transport sector increased from 42.5% in 1973 to 61.7% in 2009 (IEA, 2011). According to IEA, there were around 800 million (passenger) light-duty vehicles[2] (LDVs) on the world's roads in 2006, which accounted for 47% of transport energy use (IEA/OECD, 2009, p. 113). Between 2000 and 2010, road transport energy consumption worldwide increased from 1,293 Mtoe to almost 1,700 Mtoe (IEA, 2012a).

Almost the entire global vehicle stock is based on ICEVs, which make use of oil fuels. Therefore, the road transport sector is currently dependent on a scarce, non-renewable source of energy, whose production is mainly concentrated in twelve countries[3].

The transport sector is a major contributor of local urban air pollution and noise. Common emissions of ICEVs are oxides of nitrogen ($NO_x$), volatile organic compounds (VOC), carbon dioxide ($CO_2$), carbon monoxide (CO), and particulate matters (PM), among others. In 2006, the transport sector emitted 6,444 Million tonnes (6.4 Gt) of $CO_2$ emissions, generating 23% of global energy-related $CO_2$ emissions. It is also responsible for 13% of greenhouse gas (GHG) emissions (IEA, 2008, p.392-393). The road transport sector accounts for 74% of total transport $CO_2$ emissions (IPCC, 2007, p. 325). In the last decade, road transport $CO_2$ emissions worldwide increased from 4.4 Gt in 2000 to 5 Gt in 2005 and 5.8 Gt in 2010 (IEA, 2012a).

[2] This category includes automobiles, light trucks, sport utility vehicles (SUVs) and mini-vans.
[3] The OPEC (Organization of the Petroleum Exporting Countries) held an 81.33% share of world crude oil reserves in 2010 (OPEC, 2011).

In the last two decades, governments have become increasingly aware of the risks of excessive GHG emissions and have attempted to put forward mitigation actions in the transport sector. For example, in Germany $CO_2$ emissions from road transport have decreased in the last decade (Umweltbundesamt, 2011). However, such actions have proved difficult to implement in the road transport sector, and results have so far been insufficient. The introduction of EVs means that local air pollution can be completely eliminated, and $CO_2$ and other adverse emissions potentially avoided.

There is a close relationship between population, income, transport activity and its related energy consumption and emissions (IPCC, 2000). According to UN projections, the world population is expected to increase from 7 billion inhabitants today to around 8.9 billion by 2050. Moreover, 60% of the world population will be living in urban areas by 2030, where 80% of the world's wealth will be concentrated (UN, 2004). Economic growth drives car ownership. Historic data from the US shows that the number of vehicle-miles driven between 1970 and 2006 has grown faster than vehicle registration growth and much faster than population growth (Sperling and Gordon, 2008).

Driven by population and economic growth, it is estimated that global transport activity will continue to grow steadily during the next four decades. In many emerging economies, it is expected that the currently low levels of car ownership will not last long. Personal transport activity by LDVs is expected to show a 1.7% average annual growth rate between now and 2050, exceeding 40 trillion passenger-km (pkm)/year by road by 2050 (WBCSD, 2004). Whereas there is evidence suggesting that car travel may have peaked in some OECD countries (ITF, 2012); the majority of growth in vehicle miles travel is expected to take place in emerging economies. The global implications of this increase in road transport activity, in terms of foreseeable energy needs and generated emissions, are enormously important for the future.

## Purpose, scope, and structure of our paper

This paper[4] seeks to investigate some of the potential energy and environmental impacts EVs may have. Thus the scope of the paper is solely EVs, without considering the potential of alternative modes of transport. The study focuses on various OECD countries (namely France, Germany, and the United States) as well as on three BRIC countries (namely Brazil, China, and India).

This paper is structured as follows: in Section 2, the potential development of the vehicle market, with a focus on EVs, is investigated. Section 3 presents key aspects for EVs, such as oil prices, electricity and vehicle carbon emissions. Section 4 examines the impacts of EVs on energy scenarios and the possible resulting $CO_2$ emissions. In Section 5, we reach our conclusions and provide policy recommendations.

[4] The paper is part of a doctoral study on energy scenarios, which aims at estimating the possible impacts EVs will have on global transport energy demand and related $CO_2$ emissions. For this purpose, a System Dynamics model and various scenarios will be developed at a later stage. The geographical coverage of this doctoral study will be further extended.

# 2. VEHICLE MARKET DEVELOPMENT – FOCUS ON ELECTRIC VEHICLES

## Global vehicle stock

In 2010, the global passenger LDV stock was 842 million (IEA, 2012a). Today, around one billion road motor vehicles (of which around 70% are cars) circulate on the world's roads (Wards, 2011). There are great differences in vehicle stock levels among countries and world regions. In 2005, 77.3% of the world passenger LDV stock (in total 714 Million vehicles) was in OECD countries (IEA/OECD, 2009). Projections show however that this huge vehicle stock gap between OECD and non-OECD countries will be narrower in the next decades (BP, 2012). Indeed, the share of the world passenger LDV stock in OECD countries had already decreased to 69.4% by 2010 (IEA, 2012a).
In terms of vehicle ownership rate, in 2005 there were 710 and 556 vehicles per thousand inhabitants in the United States and Germany, respectively; whereas in the same year the vehicle ownership rate for China and India was 11 and 6 vehicles per thousand inhabitants, respectively (IEA/OECD, 2009). According to the International Monetary Fund (IMF), real GDP annual growth rates in China and India are projected to be respectively 8.8% and 7.3% in 2013, and 8.5% and 8.1% in 2017 (IMF, 2012a). For example, in China there are very marked differences between regions in terms of GDP, with the coastal provinces of Guangdong, Jiangsu and Shandong representing a large share of China's GDP in 2010 (The Economist, 2012). It seems reasonable to assume that in the future an increasing portion of the Chinese population living in these wealthy regions will have a level of income similar to Western citizens[5]. Despite the rapid increase in vehicle stock in these countries, the ownership rate is expected to remain low by 2030 in comparison with most of the OECD countries (BP, 2012). By 2050, it is projected that car ownership per thousand people will be 645 in Brazil (surpassing the USA), 363 in China and 382 in India (Goldman Sachs (2004) in King (2007)).

## Income and vehicle sales

Due to the close relationship between income and vehicle ownership it is suggested that OECD countries, with high vehicle ownership, are approaching levels of vehicle market saturation. Indeed, the percentage change in passenger LDV sales between 2000 and 2005 was rather low (3%) in North America and even negative (-2%) in Europe. On the contrary, the percentage change in non-OECD countries ranged from 18% in Latin America to 73% in India and 319% in China (IEA/OECD, 2009). Considering the low ownership rates in these countries (compared with most OECD) and their large populations, it is expected that income growth – as it is currently happening – will continue to drive rapid motorisation. Based on assumptions concerning future trends in population, urbanisation and income, Dargay et al. (2007) project that the share of total vehicles owned in non-OECD countries will more than double (from 24% to 56%) between 2002 and 2030, with China owning the largest vehicle

[5] See also WBCSD (2004) for projections of real GDP per capita (purchasing power parity) until 2050 in various world regions.

stock (390 million by 2030). They also project that the world's total vehicle stock will grow to more than two billion vehicles by 2030 (Dargay et al., 2007).

Population and economic growth are driving global vehicle sales and vehicle stock growth. Indeed, rapid motorisation is taking place in many developing countries today. In 2011, the top-ten vehicle markets (measured in car and truck sales) were: China[6] (18.5 million), US (13m), Japan (4.5m), Brazil (3.6m), Germany (3.5m), India (3.3m), Russia (2.8m), France (2.6m), UK (2.2m) and Italy (1.9m). These countries represented about 71% of global vehicle sales that year[7] (ICCT, 2012b; ACEA, 2012).

## Vehicle market scenarios up to 2050

It is projected that the global vehicle fleet will continue to grow during the next four decades. However, there is a lot of uncertainty around the estimated size of this growth, as can be seen in Figure 1. As a rule of thumb, it can be said that the global vehicle fleet could double by the middle of the century, increasing from around 1 billion motor vehicles in 2010 to about 2 billion vehicles worldwide in 2050. Most of the growth is expected to happen in non-OECD countries, which currently have low levels of car ownership. In addition, since BRICS countries are experiencing rapid economic growth, it is not surprising to see that four of these countries are part of the top-ten markets in terms of vehicle sales. Figure 2 shows the projected passenger LDV stock development in the countries of our interest until 2050. The largest share of the world vehicle stock will be held by China, India and the USA. Remarkably, the expected growth in vehicle stocks of China and India during the next four decades is dramatically high. These six countries, which in 2010 represented 45% of the world vehicle stock, are projected to hold 48 to 61% of the global vehicle share[8] by 2050 (IEA, 2012a).

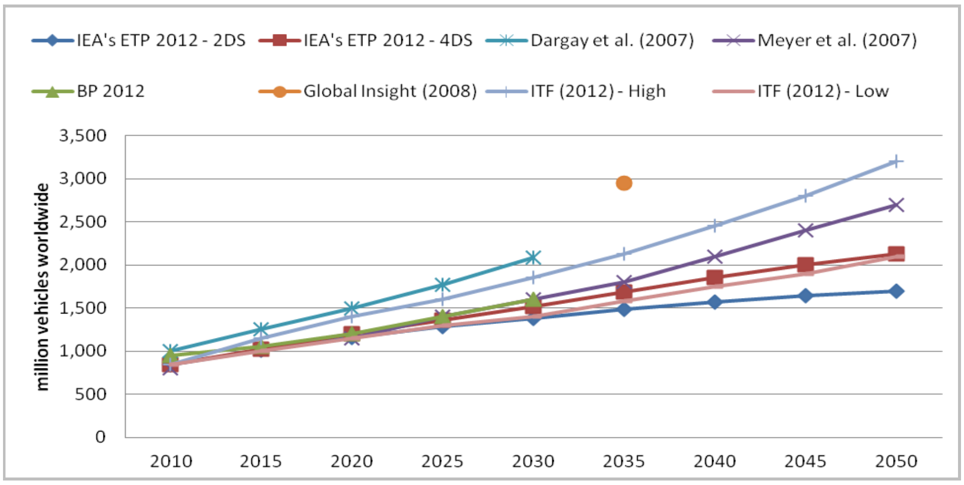


Figure 1 – Projected vehicle market scenarios (vehicle stock in million vehicles).
Source: Own work using various sources (indicated in the graph)

[6] China overtook the USA in vehicle sales in 2009.
[7] In 2011, 78.5 million vehicles were sold worldwide (ACEA, 2012).
[8] Own calculation, based on IEA data. Whereas the 48% share refers to numbers relating to the ETP's 4DS; the 61% figure is based on the 2DS.

## Alternative, improved vehicle technology and consumer acceptance

The world's vehicle stock is almost entirely powered by ICEVs, fuelled by gasoline or diesel. The former dominates the transport fuel market. In fact, over 80% of the world's LDVs were fuelled by gasoline in 2005 (IEA/OECD, 2009). There are however alternative fuel vehicles, such as natural gas[9] vehicles, autogas[10] vehicles, dual-fuel or flexi(ble)-fuel vehicles (FFVs) (with an ICE designed to run on more than one fuel), which may contribute to reduce the reliance on only gasoline fuel. In this context, biofuels are expected to play a much more important role in the future. For example in Brazil, the vast majority (over 90%) of new registrations are FFVs, running on gasoline mixed with ethanol or ethanol alone (IEA, 2012a). It is estimated that hybrid and other vehicles with advanced technology will account for almost 50% of all world LDVs by 2040 (ExxonMobil, 2012).

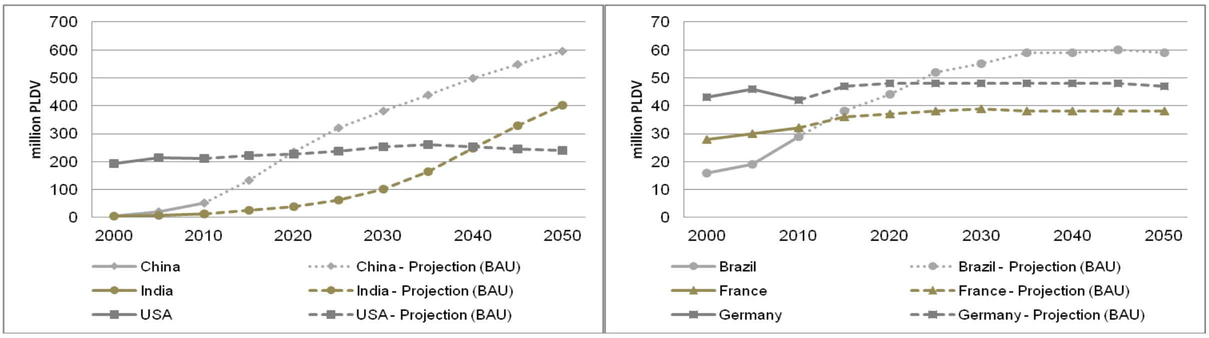

Figure 2 – Estimated passenger vehicle stock (millions) in selected countries. Source: Based on IEA (2012)

However, the real breakthrough in reducing road transport's dependency on oil fuels may be brought by battery electric vehicles (BEV), electric drive vehicles propelled by electric motor(s) powered by rechargeable battery packs. Whereas conventional gasoline vehicles only convert about 17% to 21% of the energy stored in gasoline to power at the wheels; BEVs convert about 59% to 62% of the electrical energy from the grid (US, 2012). Not only are EVs more energy efficient but, since the electricity that powers them can be created from renewable sources, they can also potentially generate zero emissions. And even with the current energy mix, EVs emit fewer emissions compared to ICEV for most countries – especially locally (Klopfert and Hecq, 2010).

The major challenge for BEVs to succeed is consumer acceptance. BEVs are able to meet already today the daily mobility needs of most road users, in terms of range in km on a single – e.g. overnight – charging (van Haaren, 2011). Moreover, the successful deployment of sufficient charging infrastructure – especially in an urban context – can help mitigate "range anxiety". However, given that the development of EV technology has not reached a maturity stage and the low sale figures obviate economies of scale, the cost of producing EVs is still high – especially due to the battery pack, representing a large portion of the total EV production cost. Thus the purchase price of EVs is significantly higher than of conventional vehicles, and is expected to be so during the next years. According to IEA, if EVs are to become competitive with conventional ICEVs, battery costs must be reduced from the current estimated range of US$ 500 to 800 per kilowatt-hour (kWh) of storage at high volume down to US$ 300 to 400 per kWh by 2020 (IEA, 2011b). The outlook for potential cost

[9] Usually Compressed Natural Gas (CNG).
[10] Liquefied Petroleum Gas (LPG).

reductions of EV battery packs is nevertheless promising. Element Energy (2012) indicates that current costs for a BEV of around US$800/kWh at pack level translate into a pack cost[11] of US$21,000. They estimate, under a baseline scenario, that this will drop to US$6,400 for a BEV with a range of 250km in 2030 (Element Energy, 2012).

Furthermore, costs comparisons between ICEVs and EVs should be made on the basis of total cost of ownership (TCO), where not only vehicle purchase costs but also operating costs throughout the vehicle's life are considered[12]. In particular, the expected future evolution of fuel relative prices, such as gasoline vis-à-vis electricity prices, will affect the TCO of different types of vehicles, favouring one type over the other.

In addition, new and cleaner technology can be supported during its initial market penetration through governmental economic incentives. For example, various European countries have provided and continue to provide tax incentives for EVs (see ACEA, 2010 and EIA, 2011).

In an international consumer survey, a substantial number of respondents indicated their willingness to either consider purchasing an EV or even become a first mover in its adoption. Particularly interested were respondents in China and India (Deloitte, 2011). In a preliminary survey about the main reasons for using EVs in France and Germany, French respondents pointed out the low electricity costs whereas German respondents expressed environmental concerns (Ensslen et al., 2012).

## EVs market scenarios in key countries

In 2012 the global EV fleet was over 180,000 vehicles (EVI, 2013). Forecasting market penetration of EVs is at this early stage of diffusion at least adventurous. Perhaps an indication is given by national targets set to achieve the IEA's 2-Degree Scenario (IEA, 2012a). Some countries have set national targets[13] for cumulative electric drive vehicles[14] up to 2015 and beyond[15] (CARS21, 2012; ICCT, 2011a; IEA, 2012a): China half a million by 2015 and 5 million by 2020, France 2 million by 2020, Germany[16] one million by 2020 and 6 million by 2030, India 6 million by 2020, as well as USA (California) one million by 2015 and one and a half million by 2020.

The possible evolution of EV sales over the next years is very uncertain. There are many predictions with differing estimates of new EV sales and the degree of estimate variability is high. Kay et al. (2013) consider that the mainstream estimates for market shares of new vehicle sales range from 5% to 20% for HEVs and 2% to 10% for EVs (all types) by 2020 as well as estimates ranging from 20% to 50% for HEVs and 20% to 50% for EVs by 2030.

By the year 2030, EVs should already play an increasingly important role, if the climate goals are to be met[17].

[11] For a 2012 medium sized BEV with a range of 150km. See Element Energy (2012) for comprehensive results. See also ICCT (2011b) for battery cost estimates from various analysts.

[12] See Kahn (2012), E-Mobil (2011), van Essen and Kampman (2011) and Fernandes Serra (2012) for examples of operating costs and TCO comparisons. ERA (2011) includes relevant information on EV market characteristics of nine European countries.

[13] In the case of Brazil, no clear electric vehicle target as been set yet. As we will see later, there are various reasons why electric vehicles do not seem a very attractive option in this country. Instead, greater use of biofuels is expected to occur.

[14] However, the extent to which these figures represent two, three or four wheelers remains unclear.

[15] Beyond 2035, it is expected that FCEVs will be playing a more important role.

[16] In addition to EVs, the German government aims at increasing the share of vehicles running on natural gas (BMU, 2011).

[17] This situation is reflected by IEA's BLUE Map scenario, which describes how energy technologies may be transformed by 2050 to achieve the global goal of reducing annual $CO_2$ emissions to half of 2005 levels. In this scenario, transport contributes to this overall reduction by cutting $CO_2$ emissions levels in 2050 to 30% below 2005 levels (IEA, 2011b).

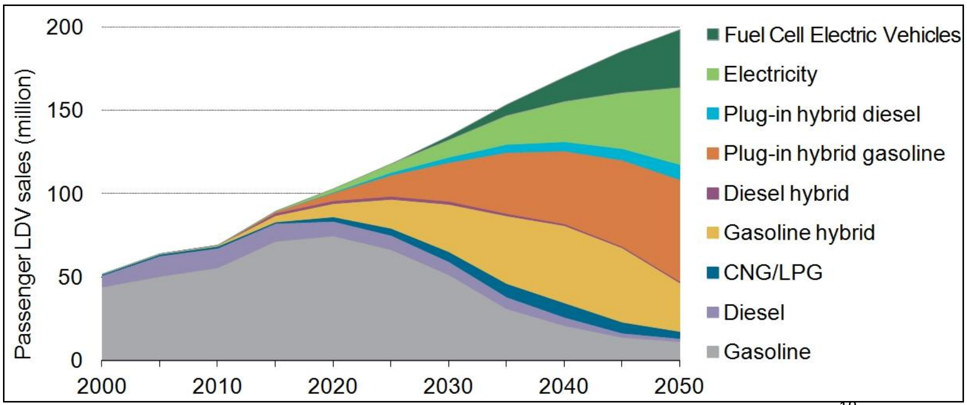


Figure 3 – IEA's projected cumulative global LDV sales 2000 - 2050, by type of technology[18]. Source: IEA (2012b)

Hence, the EVs could have a significant share in the future vehicle market and, therefore, have an influence on the oil demand.

# 3. OIL PRICES, ELECTRICITY GENERATION AND VEHICLE CARBON EMISSIONS

## Crude oil and fuel prices

Historic international crude oil prices have been characterised by an upward trend and (especially in recent years) high volatility. In the last decade, the crude oil spot prices went up considerably from around 20-30 US$/barrel in 2000 to approximately 100 US$/barrel[19] in 2011 (IEA, 2011a). High oil prices affect adversely oil importing countries and have negative economic effects on the society. This is mainly due to the missing alternatives and the corresponding dependency of transport on fossil fuel. In fact, among others Johansson and Schipper (2007) found that the car fuel demand with respect to fuel prices is inelastic (-0.7), even in the long-run. The introduction of an alternative, substitute vehicle fuel – e.g. electricity – can contribute to reduce to some extent this inelasticity.
Figure 4 shows substantial differences of gasoline, diesel and electricity prices in various countries in 2010. When fuel and electricity prices are converted into litres / kWh per km, gasoline and diesel costs still remain higher than electricity costs. The greater the annual mileage car users drive, the more expensive it is to operate conventional vehicles, which helps to improve the TCO of EVs[20].

[18] It is assumed that "electricity" refers to BEVs.
[19] In real prices, this development is, however, somewhat smoother.
[20] The issue of the rebound effect however should not be neglected, since lower operating (electricity) costs for EVs can lead to greater vehicle use (mileage) and corresponding energy use.

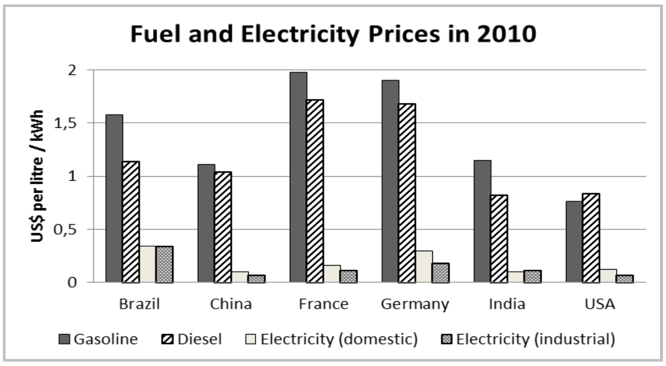


Figure 4 – Fuel (gasoline and diesel) prices at petrol stations and electricity prices in various countries in 2010.
Note: Electricity price data from 2010, except for the US (2009), Brazil (2011) and China (2012).
Source: Own work using World Bank (WB, 2012), IEA (IEA, 2012a) and Eurostat (EC, 2012) data

The way these prices will evolve in the future will also help determine the competitiveness of EVs and ICEVs. In this regard, the oil price development will play a key role[21]. The road transport sector can significantly influence oil prices under two possible scenarios. If transport continues to rely almost entirely on oil fuels to meet its energy needs, and since road transport demand and vehicle stock will continue to grow, it will likely drive international oil prices to an escalation in the future. If however, the road transport sector diversifies its sources of energy by increasingly incorporating electricity in its portfolio (representing a real alternative to gasoline and diesel fuels), it could in this way reduce its dependency on oil fuels. In this case, a clear market signal would be sent and the fact that a share of transport energy demand could (either realistically or hypothetically) switch from gasoline/diesel to electricity would probably lead to an oil price slowdown.

High oil prices have a large impact on the TCO and make EVs more attractive to own over ICEVs. The TCO components show that for EVs the main cost component is the investment (depreciation), i.e. in particular the battery (50% of cost per km), whereas for ICEVs the fuel price (with one third of cost per km) is most crucial. Therefore, decreasing battery costs and increasing fuel costs plays into the hands of EVs. Whereas the decrease in battery prices is more or less consensus (see e.g. Electrification Coalition, 2009 and McKinsey, 2012), the development of crude oil prices in the future is highly uncertain. According to the IMF, oil prices could even reach US$180-200 in 2021 (IMF, 2012b)[22]. There are many studies suggesting that future oil prices will increase significantly in the next decades. The existence of a wide range of scenarios and forecasts is an indication of the high level of uncertainty around oil prices. Additional oil price forecasts from various sources are shown in Keles et al. (2009, p. 66).

On the other hand, electricity prices will also be affected. The way electricity is produced influence electricity prices (cf. price comparison between Brazil and the USA in Figure 4). The impact on the TCO analysis is however not as strong as an increase in crude oil prices in this comparison. Generally, the crude oil price has a strong influence on the electricity price, as natural gas prices (and those of other fossil resources, too) are highly correlated, but the impact is not as strong due to other primary energy sources as nuclear and renewable energy. But, besides this influence, the electricity sector is faced with other price increasing influences in the midterm due to $CO_2$ mitigation and the integration of renewable

[21] Greater than the role of electricity prices, since the share in the TCO is higher.
[22] Oil price expressed in real 2011 US$.

energies (DIW, 2011). Therefore, the uncertainty of price development is not significantly lower, than the one from crude oil prices – even if in the long run renewable energies are seen as a helping hand in the far future to guarantee affordable electricity for mankind (Greenpeace, 2012). This leads in parallel to a decrease in $CO_2$ emissions. But in the midterm EVs might have even an increasing impact on the electricity price, which, however, depends on many circumstances (in particular charging rate and time) (Pehnt et al., 2011).

## Electricity generation

A key aspect is the integration of EVs and the energy system. A considerable number of EVs, interacting with smart grids, can introduce significant energy-storage capacity to electric grids and help overcome the load levelling problem (Mitchell, 2010). On the other hand, without adequate charging strategies, a strong increase in electricity demand for EVs[23] will have important implications for the electric grid, in terms of load balancing (Kaschub et al., 2010; Jochem et al., 2011).
The $CO_2$ mitigation potential of EVs is dependent on the way the used electricity is produced. Figure 5 shows the primary sources of electricity generation in various countries. As can be seen, the use of coal represented 79% of the electricity generation in China and 69% in India in 2008. Thus China and India are very carbon intensive economies. Indeed, the carbon intensity of electricity was almost 1,000g$CO_2$/kWh in India and 800g$CO_2$/kWh in China in 2008 (IEA, 2011b).

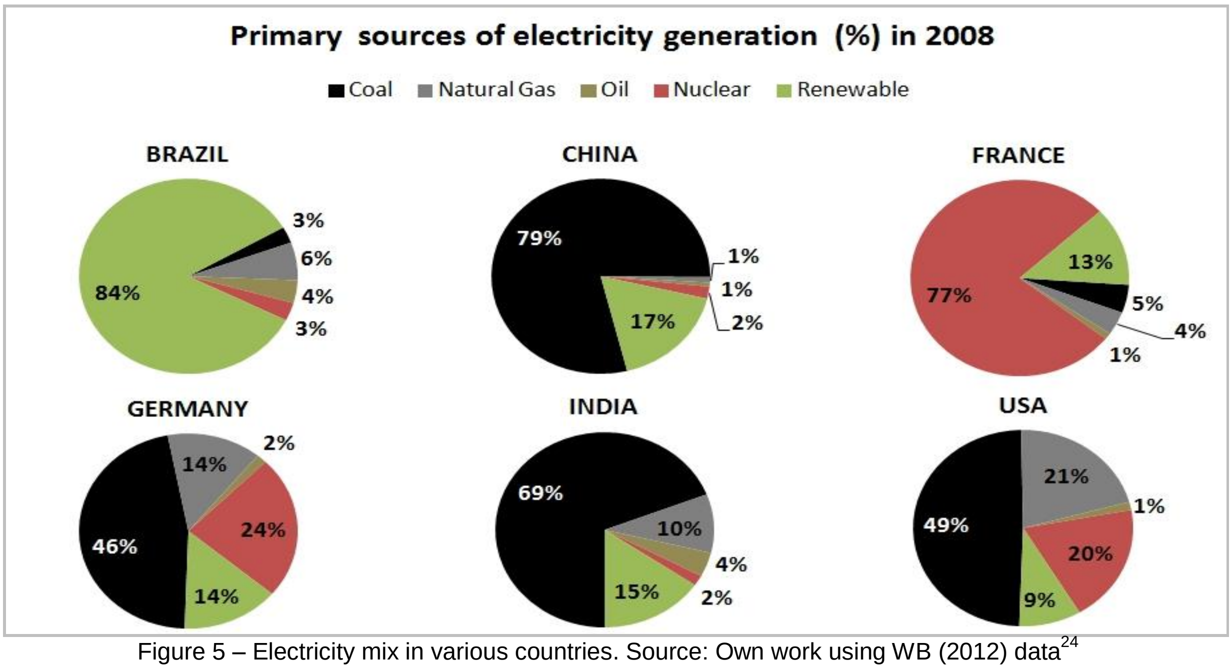


Figure 5 – Electricity mix in various countries. Source: Own work using WB (2012) data[24]

As can be seen, electricity generation is dominated by coal (hard coal and some lignite power plants), with the exception of France and Brazil, where nuclear and renewable (mainly hydro) represent the largest share, respectively. In all other countries considered here, the

[23] Under Greenpeace's (2012) Energy [R]evolution scenario, electricity provides 12% of transport total energy demand in 2030 and 44% in 2050.
[24] The share of coal in Germany includes lignite.

use of renewable sources for electricity generation still remained low in 2008, ranging from 9% in the US to 17% in China.
Therefore, the mitigation potential of electricity use over fuel use differs strongly: whereas substantial emission benefits could be obtained in Brazil; China and India are expected to increase their $CO_2$ emissions by introducing EVs, unless cleaner sources are deployed, thus decreasing the share of coal. Furthermore, the time of charging is relevant for some countries. E.g. in Germany in times of low electricity demand in windy nights the specific $CO_2$ emissions per kWh electricity is very low due to the high share on wind energy, which could locally reach a 100% share.
From this perspective, the future objectives of energy mix in the countries considered by their policy makers are highly relevant. Those targets differ strongly: For example, EU Member States will pursue to meet the target of 20% share of energy from renewable sources by 2020. In Germany, the share of renewables for electricity generation reached 25% in 2012 (BDEW, 2012). France aims at achieving a target of 27% share of renewables in the electricity sector by 2020 (NREAP, 2009). According to IEA's New Policies Scenario, the US could achieve a 15% renewable share by 2035. They remain less optimistic with China and India, where they indicate similar shares to those achieved in 2008 (WEO, 2011c).

## WTW carbon emissions

EVs produce zero tank-to-wheel (TTW) carbon emissions. However as earlier described, the way electricity is generated will have a significant effect on the well-to-tank (WTT) (and thus overall well-to-wheel (WTW)) carbon emissions these vehicles will produce. Figure 6 shows how various types of vehicle perform, in terms of WTW carbon emissions[25]. In this study, PHEV30[26] and HEVs provide the highest level of performance, which the lowest carbon emissions over the well-to-wheel cycle, followed by FCEVs and BEVs. However, there is a high uncertainty in these values as other studies show other results (see e.g. Thiel et al., 2010; Öko-Institut, 2011; Elgowainy, 2010; ICCT, 2012a).

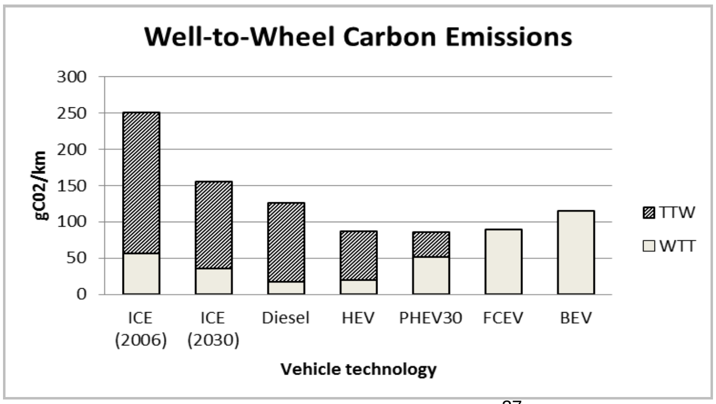


Figure 6 Well-to-wheel carbon emissions for different types of vehicles[27]. Note: ICE for various years (indicated in brackets). Data: US context. Source: Based on Kromer and Heywood (2007)

[25] See ICCT (2012a) for a method to calculate GHG emissions from EVs.
[26] PHEV30 refers to a Plug-in Hybrid Electric Vehicle with a 30-mile (ca. 50km) electric range.
[27] WTT refers to "Well-to-Tank". TTW means "Tank-to-Wheel". The values depend strongly on the underlying assumptions.

Since nuclear energy is extensively used for electricity generation in France, the WTT values for EVs are expected to be lower in this country. Conversely, Chinese and Indian values are expected to be higher. In the case of Brazil, Wyszynski (2010) calculates also the following carbon emission values: ethanol generates 210 $gCO_2$/km (83% TTW) and flex-fuel produces 217 $gCO_2$/km (84% TTW).

# 4. IMPACTS OF ELECTRIC VEHICLES ON GLOBAL OIL DEMAND AND $CO_2$ EMISSIONS

Various projections indicate that transport demand will continue to grow in the next decades. The way the transport sector, particularly road transport, reacts to transport needs will have a crucial impact on transport energy demand and related $CO_2$ emissions.

## Resulting oil consumption and $CO_2$ emissions from BAU development[28]

Suppose that under a business-as-usual (BAU) scenario – an extension of current trends –, the global passenger LDV stock more than doubles, thus reaching 2.13 billion vehicles in 2050. This represents a passenger LDV ownership rate of around 222 vehicles per 1,000 people. Such a vehicle stock will consume, despite ICEVs efficiency improvements, around 3,038 Mtoe in 2050 (IEA, 2012a). Since the global vehicle fleet would continue to rely almost entirely on fossil fuels, these energy needs would have to be met by oil fuels. This has enormous implications for the resulting crude oil tradings, i.e. extraction, refinement, transport etc., and therefore most probably also prices, which are expected to be discouraging. The oil production will have to increase by 79% between 2010 and 2050 to meet road transport demand. This has a significant effect on the reserves-to-production ratio. With transport heavily relying on oil fuels and rising demand for road motor fuels, there will be greater competition for scarce oil resources, which will be reflected in oil prices and import bills. The risks of geopolitical instability could increase the problem.

Therefore, under the current development pathway, not only would transport substantially increase oil demand (and costs) but also its corresponding $CO_2$ emissions. The climate implications of this development would be disappointing: $CO_2$ emissions from road transport would amount to 10.8 Gt $CO_2$eq. This growth will lead to a situation where $CO_2$ emissions from road transport do not decrease by 30%, as required to fulfil climate goals. Instead, if current patterns persist, $CO_2$ emissions from road transport will increase by 87% over the period 2010-2050 (IEA, 2012a).

In order to revert this trend, a “do-something” development should be pursued, in an attempt to deviate from BAU conditions. Within a wider set of transport policies aiming to promote sustainable development, actions to improve vehicle technologies should be implemented. Thus the energy and environmental impacts of successful EVs market penetration are now in turn explored.

[28] The analysis in this section is based on IEA 2012 data, following ETP 2012.

## Impacts of EVs on transport oil demand

Let us assume that the five national targets[29] indicated in Section 2 are met in 2020. This means that EVs represent the following shares of LDV vehicle stock in 2020: China (2%), France (5%), Germany (2%), India (15%) and the USA (<1%). Thus EVs will contribute to reducing oil consumption but, given the small shares of LDVs electric vehicles would hold in 2020, the oil savings are expected not to be substantial. Figure 7 shows how oil consumption is affected by the presence of EVs, both for the selected countries in 2020 and worldwide in 2050.

Transport oil demand will increase dramatically in China between 2010 and 2020. High increases will also take place in India and Brazil. In the OECD countries under consideration, given slow vehicle stock growth and fuel economy improvements, road oil consumption will remain relatively constant or, as in the USA, decrease. Achieving the national EV targets will have the greatest impact on oil savings in India and China, where 10.4 and 6.6 Mtoe could respectively be saved in 2020[30]. Worldwide, the amount of oil (Mtoe/year) that could be saved in 2050[31] depends greatly on the degree of EV market penetration, as shown below.

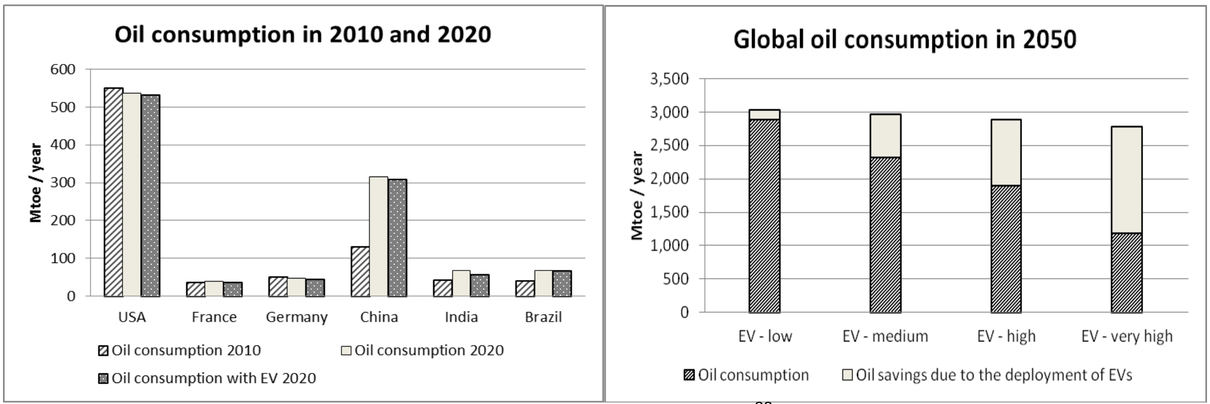


Figure 7 - Estimated total oil consumption (Mtoe): in selected countries[32] in 2010 and 2020 (left) and worldwide in 2050 under various scenarios[33] (right). Source: Own work, partially based on IEA data.

## Impacts of EVs on $CO_2$ emissions

As stated in Section 3, the carbon impacts of EVs depend on how electricity is generated, thus affecting WTT emissions. Based on data from Figure 6 and assuming annual mileage of 13,000km, it has been estimated that BEVs represent an annual saving of 1.77t $CO_2$ with respect to the average ICEV from 2006[34]. By 2030, it is estimated that the difference between both types of vehicles will only be 0.53t (due to ICEV efficiency gains and unless the electric grid becomes much cleaner). HEVs and PHEV30s seem to perform environmentally better, as they promise annual savings of 2.15t $CO_2$ and almost 1t $CO_2$ in

[29] Assuming these targets are applicable to LDVs, which seems particularly unrealistic in the case of India.
[30] Based on annual road oil consumption per vehicle in 2010, some vehicle efficiency improvements in 2020, estimated vehicle stock in 2020 under IEA's BAU and accomplishment of EV national targets stated in Section 2.
[31] Potential energy savings due to possible efficiency improvements in conventional vehicles between 2010 and 2050 are excluded. The authors acknowledge that minor improvements could however take place in the future.
[32] Rapid EV market penetration in Brazil currently seems very unrealistic. For illustrative purposes only, it is assumed that there will be 450,000 EVs in Brazil in 2020.
[33] "EV – low" means 100 million EV worldwide in 2050. "EV – medium" means 500 million EV worldwide in 2050. "EV – high" means 800 million EV worldwide in 2050. "EV – very high" means 1,300 million EV worldwide in 2050.
[34] We neglect higher $CO_2$ emissions for the vehicle (in particular battery) construction.

comparison with ICEVs from 2006 and 2030, respectively. According to the IEA (2011b), EVs can provide annual carbon savings of around 2t $CO_2$ over ICEVs.

Figure 8 shows the estimated carbon impacts of EVs worldwide in 2020 and 2050 under various scenarios. The estimated resulting $CO_2$ emissions vary significantly, depending on the number of EVs that will be on the world's roads by 2050. With modest efforts, the decrease in carbon emissions will be rather low. More ambitious targets could yield significantly greater environmental benefits. The mitigation potential of 1,300 million EVs could be around 2.5Gt$CO_{2eq}$. The reduction in $CO_2$ emissions will positively contribute towards reducing GHG emissions from road transport[35]. In addition, successful deployment of EVs will also reduce noise and air pollution, especially in urban areas.

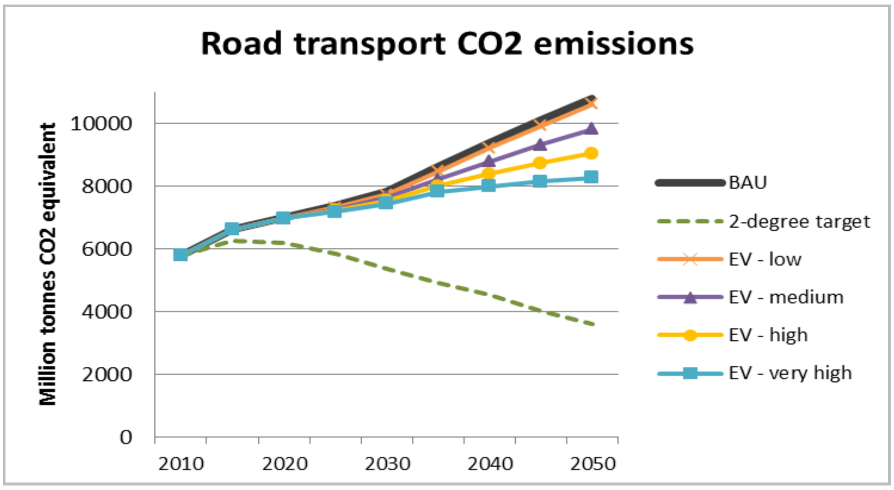


Figure 8 - Estimated global $CO_2$ emissions (Mt $CO_2$eq) under various scenarios. Source: Own work[36], partially based on IEA data.

## 5. CONCLUSIONS

Given the expected increase in global population and urbanisation, economic growth and travel demand, the road transport sector faces severe energy and environmental challenges.

The global vehicle stock will likely double by 2050, reaching two billion vehicles. Unless alternative technology vehicles gain a rapid market penetration, vehicle stock will continue to be almost entirely dominated by ICEVs in 2050. Particularly remarkable is motorisation growth in China and India. Road transport oil consumption is expected to grow dramatically in China. In addition to current OECD transport oil demand, rapid motorisation in non-OECD countries will increase the demand for oil substantially. This will probably lead to unexpected oil prices and energy insecurity, affecting public economic burden and political stability. Furthermore, the implementation of fuel economy standards and the development of more efficient ICEVs will not avoid the generation of excessive $CO_2$ and GHG emissions in the

[35] This reduction could be complemented by improvements in vehicle fuel economy. It is estimated that a further 2Gt$CO_{2eq}$ reduction in 2050 could be achieved by cutting global average car fuel consumption by 50% (FIA, 2009).

[36] Based on the assumption of 20 million EVs by 2020. See footnote 35 for the definition of "EV – low / medium / high / very high", which are indeed based on very optimistic values, but they include PHEVs and could also be applicable to HEVs (since they display similar well-to-wheel emission values). The well-to-wheel value of 1.96t $CO_2$ savings when EVs are deployed instead of ICEVs has been used.

transport sector, thus preventing the attainment of climate objectives. This situation might entail very negative consequences for future societies.
Of particular importance in this paper are the possible penetration rates of EVs, which have the potential to reduce dependency on oil fuels and to mitigate $CO_2$ and GHG emissions (especially if it comes along with an increase of electricity generation by renewable resources). In order to achieve emission targets, it is estimated that around 20 million EVs are needed on the world's roads by 2020. This requires that EVs overcome key barriers to enable successful and rapid market uptake. If substantial emission reductions are actually to be achieved, the effective integration of EVs and cleaner, smart electric grids is also a necessary step. The outlook of EVs beyond 2020 is even more uncertain and largely depends on the success EVs will have entering vehicle markets during the current decade. Consumer confidence in EVs as well as awareness of current transport, energy and environmental trends and understanding of the consequences of possible future high oil prices will be crucial to the market success of EVs.
It was initially expected that even a small share of alternative vehicles could have a significant impact on energy demand and emissions. Our analysis of the impacts of EVs shows however that a small number of these vehicles by 2020 and beyond will not deliver the potential energy and environmental benefits EVs promise today. Thus a slow market penetration of EVs will not suffice to curb current trends. Very high crude oil prices, reflecting current trends, would however contribute to acceleration of EV uptake.

## General policy recommendations

Concluding, the challenges in the transport sector consist mainly of reducing its oil dependency and its emissions. If road transport is to follow a sustainable pathway, a structural interruption is needed. This requires drastic and urgent action on the way we use personal transport. Even if major improvements in land planning and the implementation of effective measures to encourage a modal shift to more energy-efficient and environmentally-friendly modes of transport are realised, individual road motorised travel will continue to play a key role for personal mobility in the future. From this perspective, the improvement and deployment of clean vehicle technology is a promising pathway to achieve key energy and environmental goals. However, other complementary approaches will also be needed to make transport sustainable. From the current perspective, the current penetration rates of EVs are far below to contribute significantly to reduce oil dependency and GHG emissions. Nevertheless it is a necessary step to a sustainable mobility system. Key externalities, such as road accidents and traffic congestion could, however, only be solved by a holistic approach of policy measures, which provide an innovative environment with foresight to introduce new mobility concepts.
It is highly desirable that the road transport sector becomes more heterogeneous in terms of the type of energy sources it consumes. Though the presence of alternative fuel vehicles (e.g. vehicles using biofuels, LPG, CNG) are a positive step in this direction, it is electric drive vehicles that have the potential to achieve the most positive transformations. Today, EVs represent a real and cleaner alternative to conventional ICEVs for car travel. Nevertheless, it is necessary to integrate the energy system into these considerations and to foster EV penetration rates; e.g. by building consumer confidence and implementing other

supportive measures, such as provision of adequate and sufficient charging infrastructure. The target of 20 million EV worldwide by 2020 target is an ambitious but necessary goal. It remains to be seen whether this and other national targets will be eventually achieved, but it is a clear and necessary indication of the recognition of the role road transport plays, the challenges it faces as well as it signals the commitment to put forward effective solutions.

With regards to carbon emissions, EVs and electric grids go hand in hand. If the environmental benefits of EVs are to be maximised, the objective of electricity generation from clean sources is a key. Therefore, the promotion of electricity generation from renewable energy sources must be further promoted. Furthermore, the suitability of the grid for providing electricity for EVs should be analysed. The risk of increasing the likelihood of electric blackouts, especially in “sensitive” grids, cannot be neglected. During the next decades, EVs will generate air pollution during the WTT process. However, the relocation of emissions from mobile tailpipes in crowded cities (where the majority of the world population lives and will live) to power stations on the countryside represents an opportunity and leads to a strong decrease in external effects, since the number of affected humans is reduced significantly. This concentration facilitates target-oriented mitigation policies.

Since most of the projected vehicle growth will take place in non-OECD countries, it is these countries that can benefit most from more efficient vehicle technology. Effective policies, programmes and projects are needed to ensure that the world will benefit from superior and less environmentally-harming vehicle technology. Developed countries should lead the way in electric mobility, acting as first movers in EV adoption, and should support (e.g. through technology transfer) less developed countries so that they can leapfrog to cleaner vehicle technology.

Unless the road transport sector experiences a transformation, reflected in the electrification of road motor vehicles at large scale, no substantial oil and emission savings will be achieved in the BAU scenario. Governments should continue steering the electric mobility process with other key stakeholders to ensure that such transformation comes true.

Behavioural changes in response to e.g. high oil prices, better education, popularisation of car sharing and other policy measures aimed at encouraging modal shifts to more environmentally-friendly modes have not been explicitly considered in this study. These measures could lead to lower levels of car ownership, also in OECD countries. Further research on these evolving issues is needed.

# REFERENCES

ACEA (2012). The Automobile Industry Pocket Guide. European Automobile Manufacturers Association.

ACEA (2010). Overview of tax incentives for electric vehicles in the EU. European Automobile Manufacturers Association.

BDEW (2012). Erneuerbare Energie liefern mehr als ein Viertel des Stroms. Bundesverband der Energie- und Wasserwirtschaft (BDEW), Berlin.

BMU (2011). Das Energiekonzept der Bundesregierung 2010 und die Energiewende 2011. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU).

BP (2012). BP Energy Outlook 2030. London, January 2012.

CARS21 (2012). EV market projections: Part II – Government announcements. Available at: http://www.cars21.com/news/view/4922 [Accessed on 08/10/2012].

Dargay, J., D. Gately and M. Sommer (2007). Vehicle Ownership and Income Growth, Worldwide: 1960-2030. Energy Journal, 2007, Vol. 28, No. 4.

Deloitte (2011). Unplugged: Electric vehicles realities versus consumer expectations. Available at: http://www.deloitte.com/assets/Dcom-Global/Local%20Assets/Documents/Manufacturing/dttl_Unplugged_Global%20EV_09_21_11.pdf [Accessed on 08/10/2012].

DIW (2011). German Electricity Prices: only modest increase due to renewable energy expected. Weekly Report. German Institute for Economic Research. DIW Berlin.

EC (2012). Eurostat. European Commission. Available at: http://www.ec.europa.eu/eurostat.

EC (2010). EU Energy and Transport in Figures – Statistical Pocketbook 2010. European Commission.

EIA (2011). International Energy Outlook 2011. U.S. Energy Information Administration (EIA).

Electrification Coalition (2009). Electrification Roadmap – Revolutionizing Transportation and Achieving Energy Security. Available at: http://www.electrificationcoalition.org/policy [Accessed on 08/10/2012].

ElementEnergy (2012). Cost and performance of EV batteries. Final report for the Committee on Climate Change.

Elgowainy, A., J. Han, L. Poch, M. Wang, A. Vyas, M. Mahalik and A. Rousseau (2010). Well-to-Wheels Analysis of Energy Use and Greenhouse Gas Emissions of Plug-In Hybrid Electric Vehicles. Energy Systems Division, Argonne National Laboratory.

E-Mobil (2011). Baden-Württemberg on the way to electromobility. Structure study BW$^e$ mobile 2011. State Agency for Electric Mobility and Fuel Cell Technology Baden-Wuerttemberg.

Ensslen, A., S. Babrowski, P. Jochem and W. Fichtner (2012). Existe-il des différences d'acceptation des véhicules électriques entre la France et l'Allemagne? – Premiers résultats de l'analyse scientifique du test de flotte Cross Border Mobility for Electric Vehicles (CROME).

ERA (2011). Electric Road Transport policies in Europe till 2015: opportunities, experiences and recommendations. Final report study 1 and 2. ERA-NET Transport (ENT). ENT19: Electric Mobility. European Research Area (ERA).

EVI (2013). Global EV Outlook – Understanding the electric vehicle landscape to 2020. Electric Vehicles Initiative (EVI).

EVI (2012). EV City Casebook – A look at the global electric vehicle movement. Electric Vehicles Initiative (EVI).

ExxonMobil (2012). The Outlook for Energy: A View to 2040. ExxonMobil Energy Outlook.

FIA (2009). 50by50 Report – Making Cars 50% More Fuel Efficient by 2050 Worldwide. FIA Foundation for the Automobile and Society.

Fernandes Serra, J. V. (2012). Electric Vehicles – Technology, Policy and Commercial Development. Earthscan from Routledge.

Greenpeace (2012). Energy [R]evolution 2012 – A Sustainable World Energy Outlook. 4th Ed.

Gott, P. (2008). Is mobility as we know it sustainable? Global Insight. Available at: http://www.ihsglobalinsight.com/gcpath/AutoSustainabilityWhitePaper.pdf [Accessed on 08/10/2012].

ICCT (2012a). Calculating electric drive vehicle greenhouse gas emissions. The International Council on Clean Transportation.

ICCT (2012b). Top vehicle markets, 2011. International Council on Clean Transportation.

ICCT (2011). Vehicle Electrification Policy Study. Task 4 Report: Complementary Policies. International Council on Clean Transportation.

IEA (2012a). International Energy Agency, Energy Technology Perspectives 2012 – www.iea.org/etp [Accessed on 08/10/2012].

IEA (2012b). The Role of EVs in a Clean Energy Future. Presentation at Fully Charged 2012 – International Electric Vehicle Summit Dublin, 11 July 2012. International Energy Agency. Available at: www.iea.org/etp [Accessed on 08/10/2012].

IEA (2011a). Key World Energy Statistics 2011. International Energy Agency.

IEA (2011b). Technology Road Map – Electric and plug-in hybrid electric vehicles. International Energy Agency.

IEA (2011c). World Energy Outlook 2011. International Energy Agency.

IEA (2011d). $CO_2$ Emissions from Fuel Combustion: Highlights. International Energy Agency.

IEA/OECD (2009). Transport, Energy and $CO_2$. Moving toward sustainability. International Energy Agency.

IEA (2008). World Energy Outlook 2008. International Energy Agency.

IMF (2012a). World Economic Outlook – Growth Resuming, Dangers Remain. April 2012. World Economic and Financial Surveys. International Monetary Fund.

IMF (2012b). The Future of Oil: Geology versus Technology. Working Paper. International Monetary Fund.

IPCC (2007). Fourth Assessment Report: Climate Change 2007. Intergovernmental Panel on Climate Change.

IPCC (2000). Emissions Scenarios. Special Report. Nakicenovic, N. and R. Swart (Eds.), Intergovernmental Panel on Climate Change.

ITF (2012). Long-run Trends in Travel Demand. JTRC Roundtable, Paris 29-30 November 2012. Organisation for Economic Co-operation and Development / International Transport Forum. Available at: http://internationaltransportforum.org/jtrc/RoundTables/2012-Long-run-Trends/ [Accessed on 08/04/2013].

Jochem, P., T. Kaschub and W. Fichtner (2012). How to integrate electric vehicles in the future energy system?, in: Hülsmann, M; Fornahl, D. (Eds.): Evolutionary Paths Towards the Mobility Patterns of the Future, Springer, Heidelberg, Germany (forthcoming).

Johansson, O. and L. Schipper (1997). Measuring the Long-Run Fuel Demand of Cars. *Journal of Transport Economics and Policy*, 277-292.

Kahn, M. and Kockelman, K. M. (2012). Predicting the market potential of plug-in electric vehicles using multiday GPS data. University of Texas at Austin.

Kaschub, T., M. Mültin, W. Fichtner, H. Schmeck and A. Kessler (2010). Intelligentes Laden von batterieelektrischen Fahrzeugen im Kontext eines Stadviertels, in: Tagungsbandbeitrag VDE Kongress, Leipzig.

Kay, D., N. Hill, and D. Newman (2013). Powering Ahead – The future of low-carbon cars and fuels. Ricardo-AEA.

Keles D., D. Möst and W. Fichtner (2009). Die Entwicklung der Energiemärkte bis 2050 - Ein Überblick über ausgewählte Szenarien, in: Möst, D., Fichtner, W. und Grunwald, A. (Hrsg.): Energiesystemanalyse, Universitätsverlag Karlsruhe.

King (2007). The King Review of low-carbon cars - Part I: the potential for $CO_2$ reduction. Crown, UK.

Klopfert, F. and W. Hecq (2010). Clean Vehicles External Costs Comparison in the Brussels-Capital Region. An Attempt with Transfer Techniques. CEB Working Paper 10/037.

Kromer, M. A. and J. B. Heywood (2007). Electric Powertrains: Opportunities and Challenges in the U.S. Light-Duty Vehicle Fleet. Massachusetts Institute of Technology (MIT).

McKinsey (2012). Battery Technology Charges Ahead. Sustainability and Resource Productivity Practice. McKinsey Quarterly.

Meyer, I., M. Leimbach and C.C. Jaeger (2007). International passenger transport and climate change: A sector analysis in car demand and associated CO2 emissions from 2000 to 2050. Energy Policy, 35, pp. 6332-6345.

Mitchell, W. J., C. E. Borroni-Bird and L. D. Burns (2010). Reinventing the Automobile – Personal Urban Mobility for the 21st Century. MIT, Cambridge.

NPE (2012). Fortschrittsbericht (Dritter Bericht) der Nationalen Plattform Elektromobilität.

NPE (2011). Zweiter Bericht der Nationalen Plattform Elektromobilität.

NREAP (2009). National Action Plan for the Promotion of Renewable Energies, 2009 – 2020. Ministere de l'Ecologie, de l'Energie, du Developpement durable et de la Mer.

Öko-Institut (2011). OPTUM: Optimierung der Umweltentlastungspotenziale von Elektrofahrzeugen – Integrierte Betrachtung von Fahrzeugnutzung und Energiewirtschaft. Final Report. Öko-Institut e.V. - Institut für angewandte Ökologie.

OPEC (2011). OPEC Annual Statistical Bulletin 2010/2011 edition. Organization of the Petroleum Exporting Countries.

Pehnt, M., H. Helms, U. Lambrecht, D. Dallinger, M.Wietschel, H. Heinrichs, R. Kohrs, J. Link, S. Trommer, T. Pollok and P. Behrens (2011). Elektroautos in einer von erneuerbaren Energien geprägten Energiewirtschaft , Zeitschrift für Energiewirtschaft, Online First 6. Mai 2011.

PRTM (2011). The China New Energy Vehicles Program – Challenges and Opportunities. World Bank and PRTM Management Consultants, Inc.

Sperling, D. and D. Gordon (2008). Two billion cars. Transforming a culture. Available at: http://onlinepubs.trb.org/onlinepubs/trnews/trnews259billioncars.pdf [Accessed on 08/10/2012].

The Economist (2012). All the parities in China. Available at: http://www.economist.com/content/all_parities_china [Accessed on 08/10/2012].

Thiel, C., Perujo, A. and A. Mercier (2010). Cost and CO2 aspects of future vehicle options in Europe under new energy policy scenarios. *Energy Policy*, Vol. 38, Issue 11, November 2010, pp. 7142-7151.

Umweltbundesamt (2011). Nationale Trendtabellen für die deutsche Berichterstattung atmosphärischer Emissionen 1990-2009. Available at: http://www.umweltbundesamt.de/emissionen/publikationen.htm [Accessed on 08/10/2012].

UN (2004). World population to 2300. United Nations.

US (2012). Fuel Economy. Electric Vehicles. U.S. Department of Energy, U.S. Environmental Protection Agency. Available at: http://www.fueleconomy.gov/feg/evtech.shtml [Accessed on 08/10/2012].

van Haaren, R. (2011). Assessment of Electric Cars' Range Requirements and Usage Patterns based on Driving Behavior recorded in the National Household Travel Survey of 2009.

van Essen, H. and B. Kampman (2011). Impacts of Electric Vehicles – Summary report. Delft, CE Delft, April 2011.

Wards (2011). World vehicle population tops 1 billion units. WardsAuto. Available at: http://wardsauto.com/ar/world_vehicle_population_110815 [Accessed on 08/10/2012].

WB (2012). The World Bank Data. Available at: http://data.worldbank.org/.

WBCSD (2004). Mobility 2030: Meeting the challenges to sustainability. The Sustainable Mobility Project. Full Report. World Business Council for Sustainable Development.

Wyszynski, T. (2010). Battery electric vehicles in Brazil - The impact of a battery electric vehicle fleet on the electricity grid and the mitigation of $CO_2$ emissions. December 2010