Green Power for Electric Cars

Development of policy recommendations to harvest the potential of electric vehicles

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Author(s):
Bettina Kampman
Cor Leguijt
Dorien Bennink
Lonneke Wielders
Xander Rijkee
Ab de Buck
Willem Braat

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Further information on this study can be obtained from the contact person, Bettina Kampman.

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Summary

Introduction

Contrary to the trends in most other sectors, greenhouse gas emissions of the transport sector are still increasing, and are predicted to grow further in the coming years, at current policies. As there is no simple solution to the challenge of achieving significant CO_2 reductions in transport, it has become clear that a large range of efficient and effective CO_2 reduction measures will have to be taken.

In the coming decades, electric and plug-in hybrid vehicles could play a significant role in this move towards sustainable transport. If these vehicles run on renewable electricity, they could substantially cut CO_2 emissions and improve local air quality.

Electric vehicles might even help to make the electricity sector more sustainable, if the batteries in the vehicles could be used to manage the variable output of an increasing share of wind and solar-based power generation. However, the extent to which these advantages can be harvested under current policies is open to question.

T&E, Friends of the Earth Europe and Greenpeace European Unit have therefore jointly commissioned this study to look into how the full potential of electric cars can be realised. The study aims to analyse the potential impact of the electrification of road transport on EU power production and to develop policy recommendations to ensure that this development will lead to the growth of renewable electricity in Europe.

Electrification of road transport

Electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) provide very promising opportunities for the future development of a sustainable transport sector. However, many questions regarding their potential share in the car fleet, their energy efficiency, charging patterns, annual mileage, cost and cost structure have not yet been answered.

Compared to internal combustion engine technology (ICE), battery electric drive trains have a number of benefits for the transport sector, such as:

- The potential to use a large range of energy sources, including all types of renewable energy, in combination with high energy efficiency.
- The potential for sustainable and carbon neutral (CO_2-free) mobility if powered by renewable energy sources.
- Less or no air pollution (depending on the type of power production) and lower noise levels.

The well-to-wheel environmental impact of EVs and PHEVs is largely determined by the type of electricity production used to charge the batteries. If electricity is produced from lignite or coal, well-to-wheel CO_2 emissions are typically higher than or equal to the emissions of a comparable ICE car. When the electricity comes from gas-fired power plants, emissions are significantly lower. Electricity from renewable sources, such as wind, solar or hydro energy, would result in zero CO_2 emissions per kilometre.

In order to assess the potential impact of these vehicles on the electricity sector, three scenarios were developed for 2020. Even though some of these scenarios were clearly quite ambitious (with up to 31 million EVs and PHEVs in the EU-27), the additional energy demand from these vehicles will remain limited in the coming decade compared to the current electricity demand: less than 0.3% of current consumption in the moderate scenario, and 2.9% and 2.6% in the fast and ultra-fast uptake scenarios. Demand may, of course, increase further after 2020, depending on the success of this technology.

Effects on the EU power supply sector

The effects of these scenarios have been analysed on a general level for the EU power sector, and more specifically for three case studies: France, Germany, and the UK. It was concluded that the extra power demand in these scenarios would be met by existing power plants. The exact kind of electricity produced to meet this demand would depend on the availability, flexibility and marginal cost of the power production sources at any given moment in time.

When vehicle batteries are charged in base load hours, i.e., at night, coal/lignite and nuclear will be in a strong position to meet this additional demand. For extra demand in peak hours, an increase in gas-fired power production is most likely in the countries that were analysed. CO_2 emissions from this additional electricity production in the EU fall under the EU ETS cap, which will ensure, in principle, that any increase in emissions is balanced out by reductions elsewhere[1].

In the coming decades, an increasing share of renewable 'must-run' electricity production from wind or solar energy will require more flexibility in demand and in power production from the other sources. Gas-fired production, pump-storage hydro and interconnection could be used for this, as could EV and PHEV batteries if used for energy storage in times of excess renewable energy supply. This requires smart metering/smart storage technology, combined with demand side management, which is currently under development.

Policy instruments: how can the green opportunities be harvested?

Policies could be implemented to ensure that the additional electricity production for these vehicles is 100% green. If that is the aim, the best policy option is national regulation to ensure that renewable electricity targets are increased by the additional amount of electricity consumption from EVs and PHEVs.

Policies aimed at promoting the voluntary purchase of green electricity by electric car owners will also be useful and will help clear the way for more ambitious policies. For example, governments or car dealers can promote the voluntary purchase of green electricity by electric car owners while electricity suppliers, local governments and companies that own and operate charging points can ensure that renewable electricity is used for the charging points for these cars. National governments could support these developments, for example through fiscal policies.

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[1] Increasing electricity demand from transport will have an upward effect on the CO_2 price in the ETS. This effect has not been studied further in this report, but is expected to remain small in the coming decade as the additional electricity demand will be limited.

Under the current EU regulation on CO_2 from cars, an increase in electric vehicle sales will effectively result in less stringent standards for conventional cars. This cancels out the potentially positive impact of electric cars on CO_2 emissions and oil consumption in transport. The regulation should be improved by eliminating super credits and the practice of zero counting for electric vehicles.

In addition, the Renewable Energy Directive (RED) could be further improved so that actual data is reported on renewable electricity used for vehicle charging. In the FQD and regulation on CO_2 and cars, more realistic methodologies should be implemented to take into account the actual energy use and the CO_2 emissions of electricity used in these vehicles. This requires accurate metering, which is also an important aspect to ensure any future regulation of electricity and to provide an opportunity for demand side management.

An important issue for further research and development at both the EU and national level is the potential, feasibility and cost of using EV and PHEV batteries renewable energy storage in the longer term. The appropriate technology, infrastructure and standards need to be developed in the coming years to ensure that they are implemented and fully operational as the share of variable renewable energy supply increases. This would, among other things, allow active management on the demand side, which is set to become an important ingredient in a future electricity system.

1 Introduction

1.1 Background

Electrification of road transport will be the solution to many problems related to both the transport and the power sector. This is the claim being made by many car manufacturers and power companies, scientists and government agencies. They argue that electrification can:

- Greatly increase the efficiency of vehicles and thus reduce their fuel (energy) use.
- Reduce CO_2 emissions, depending on the carbon intensity of the charged electricity.
- Facilitate and enable the growth of renewable energy through the use of vehicle batteries as power storage devices, supplying variable energy from renewable energy sources, such as wind and solar, and feeding this back to the grid when supply is low.
- Offer greater diversification of energy sources and hence increase energy security.
- Allow the road transport sector to access the full range of renewable energy sources, beyond liquid and gaseous fuels derived from biomass.
- Thereby circumvent problems linked to unsustainable biofuels, which can create environmental and socio-economic problems.
- Help enhance local air quality and reduce noise problems.

Electric and plug-in vehicles are more energy efficient, less polluting and enable the use of many forms of different primary energy sources, including renewables. As such, they may provide a very significant contribution to sustainable transport in the medium term and long term. However, some of the claims are rather unrealistic under current conditions in the transport and electricity market. Furthermore, electric cars can only at best represent part of a solution to climate emissions of transport, the need to implement a large range of other effective greenhouse gas reduction measures in this sector remains.

In this report, we focus in particular on an assessment of one of the claims listed above, namely that electrification will facilitate the growth of renewable energy. Increasing the electricity demand, especially overnight when car owners will tend to plug in their vehicles to recharge them, may in fact increase the overall (base-load) electricity demand which, at the moment, consists mainly of coal and nuclear-based energy. However, governments have the opportunity to put policies in place to prevent this from happening.

T&E, Friends of the Earth Europe and Greenpeace European Unit have jointly commissioned this study. Its main aim is to look into the means to realise the full potential of electric cars on the growth of renewable energy in Europe. The study aims to analyse the potential impact of electrification of road transport on EU power production and to develop policy recommendations to ensure that this development will lead to growth of renewable energy in Europe.

1.2 Aim and scope of this study

The objective of this study is to establish regulatory options for the EU to ensure that climate policies in road transport result in a push for electricity from renewable sources rather than coal and nuclear or unsustainable biofuels. In other words, these options should aim to ensure that electric vehicles and plug-in hybrids can make a maximum contribution to overall greenhouse gas reductions and sustainable transport.

The geographical scope of this study is the EU and its member states and its main focus is on the period from now until 2020. However, we will provide electric vehicle scenarios until 2030 to illustrate the potential future growth of the electricity demand for these vehicles.

It should be noted that the study focuses on greenhouse gas emissions only. While air quality and noise are subjects not included in this study, they might still be important in the overall assessment of environmental effects[2].

1.3 This report

In the next chapter, we will first provide some background information on the EU policies relevant to this study. Chapter 3 describes the possible impact of the introduction of electric vehicles on the transport sector and explores a number of scenarios for the market introduction and resulting electricity demand of these vehicles. Chapter 4 then assesses the effects of these cars on the European power supply sector under current policies. Three case studies (France, Germany and the UK) are used for this analysis. Chapter 5 identifies the potential policy instruments with which the EU and member states can ensure that the electricity needed for these vehicles is produced with renewable energy sources. Both macro and micro policies are addressed and compared. The final chapter then provides conclusions and recommendations.

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[2] While direct emissions from electric cars are zero, there are still CO_2 emissions from the electricity production.

2 Relevant policy background

2.1 Introduction

Both the EU transport and vehicle market and the power sector are regulated by EU policies to some extent: EU policies exist for CO_2 emissions of passenger cars; targets have been set for the renewable energy share in both the transport sector and for overall energy use; and the power sector is included in the EU Emission Trading System that puts a cap on the total CO_2 emissions of the sectors involved. In addition, more overarching CO_2 policies are in place such as the 20% GHG emissions reduction target for 2020 (compared to 1990 emission levels) and the EU effort-sharing agreement that sets national targets for GHG reductions in non-ETS sectors. These policies all have a role in stimulating and creating the conditions for road transport electrification. They may also provide the means to ensure that these developments will be sustainable and lead to maximum GHG reductions in the future.

Below is a brief overview of the EU policies directly relevant to the topics addressed in this report. As electrification impacts on two sectors that used to be treated quite separately, namely the transport and the electricity sector, policies for both sectors are included.

2.1.1 Relevant transport policies

As the development of electric cars has only very recently boomed (again, as there have been various attempt to further develop them over the past century, but with very limited success), they are only briefly mentioned in the recent transport-related directives.

In brief, the relevant parts of the directives aimed at transport are the following (from CE, 2009).

Renewable Energy Directive (RED) (EC, 2009c)

This directive defines a target for the renewable energy share in the EU member states by 2020, and a separate target for use of renewable energy in the transport sector. The key issues for this study are the following:

- A target of 10% renewable energy in transport by 2020[3].
- Sustainability criteria for biofuels are provided, including a minimum GHG reduction requirement (and a methodology to calculate the reduction), currently excluding indirect land use change effects.
- Double counting of biofuels from waste and residues for the 10% transport target.
- The contribution of renewable electricity as calculated from:
  - a The total electricity use in transport. And
  - b The average renewable electricity share in either the member state or in the EU.

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[3] The directive defines the target as 10% of the fuel used in the *road* transport sector. However, renewable energy use in other modes may also be counted towards this target.

However, the Directive also states (in Art. 3(4)) that by 31 December 2011 the Commission will present a proposal permitting all the electricity originating from renewable sources used to power all types of electric vehicles to be counted toward the target, subject to certain conditions.

- Renewable electricity in road transport is multiplied by 2.5 for the 10% transport target (this applies only to renewables used in road transport, not in rail transport).
  NB: This double and 2.5x counting applies only to the 10% transport target; there is no double counting for the overall 20% renewable energy target (see below).
- Member states now have to implement this legislation in national policies and define action plans by 30 June 2010 to meet the targets.

Revised Fuel Quality Directive (FQD) (EC, 2009b)

- A reduction of 6% from well-to-wheel greenhouse gas emissions of transport fuels between 2010 and 2020, compared to the EU-average level of life-cycle GHG emissions per unit of energy from fossil fuels in 2010. According to the directive, these reductions should be obtained through the use of biofuels, alternative fuels and reductions in flaring and venting at production sites. However, the methodology for accounting for them is yet to be determined.
- An additional 4% GHG emissions reduction is voluntary, where 2% is foreseen to be obtained through the use of environmentally-friendly carbon capture and storage technologies and electric vehicles, while the additional 2% reduction can be obtained through the purchase of credits under the Clean Development Mechanism of the Kyoto Protocol. These additional reductions are not currently binding, but this may change after the reviews in 2012 and 2014.
- The methodology to determine the GHG emissions of biofuels and electric transport should be in line with that of the RED (see above), with the exception that the FQD does not allow double counting of biofuels from waste or residues. The detailed methodology to determine GHG emissions of fossil fuels and their alternatives will have to be further developed in the coming years.

Regulation on CO_2 from cars (EC, 2009a):

- Sets an emissions target for car manufacturers: by 2015 the average CO_2 emissions of new passenger cars should be no more than 130 g CO_2/km. After 2015 the emissions target will be lowered further to 95 g CO_2/km by 2020.
- Electric cars count as zero emissions.
- Electric cars (and any other cars with less than 50 g CO_2/km according to the type approval tests) get super-credits in the period between 2012 and 2016: they may be counted as 3.5 cars in 2012 and 2013, 2.5 cars in 2014, 1.5 cars in 2015 and 1 car from 2016 onwards[4].

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[4] This means that without super-credits, car manufacturers will receive 130 g/km credit for every electric car sold, which they may use to compensate for cars with emissions higher than the 130 g/km target. From 2012 until 2015, this credit will be much higher, as the 130 g/km is multiplied by the super-credit factor.

2.1.2 Relevant policies in the electricity sector

EU Emission Trading System:

- Sets a cap on the CO_2 emissions of the EU power sector and industry for the period until 2020. In the transport sector, electric rail transport is already included in this system; aviation will also be included in the near future. Emission allowances for the electricity production sector are auctioned (this is not the case for all companies involved in the ETS; part of the allowances are allocated for free to industries that operate in an international competitive market). Trading of allowances is permitted.
- This cap has been set until 2020. In principle, any increase in electric power production will thus have to be carbon-free, either through additional emissions reductions elsewhere in the ETS (e.g., efficiency improvements in the industry or power sector) or through more carbon-free electricity production. Part of the emissions reductions can also be achieved through the CDM (Clean Development Mechanism), which involves investments in projects that aim to reduce emissions in developing countries.

Renewable Energy Directive (RED) (EC, 2009c)

- This directive sets a 20% target for the renewable energy share in the overall energy use in the whole EU by 2020. Separate targets are given for each member state.
- The RED provides a renewable energy target for both the overall energy use (20%) and the transport sector (10%), not for the electricity sector. However, it can be concluded from these two targets that the renewable energy share in electricity production needs to be about 30-40% in most countries if the 20% target is to be met (assuming that the renewable energy share in transport will not be higher than the 10% target and that there is relatively limited scope for renewable heat production).

3 Electrification of road transport

3.1 Introduction

The focus of this study is on the impact of road transport electrification on the electricity sector, which will be the topic of the next chapters. Nevertheless, we will start here with sketching the impact on the transport sector, as this is the sector from which the demand for electric cars will coming.

Electric vehicles seem to have some very clear advantages over conventional, combustion vehicles: their efficiency can be higher (in terms of energy use per kilometre), they may improve local air quality and their traffic noise is limited compared to ICE vehicles. When looking at options for significant GHG reductions in transport and at the development of sustainable transport in general, electric vehicles could play an essential role in the future transport systems provided the electricity sources are low carbon.

However, at the moment their costs are still high, their driving range is limited (note that this is only true for EVs; PHEVs will have conventional driving ranges), the charging infrastructure that would allow car owners to charge at convenient locations is yet to be built and, in view of these shortcomings, consumer confidence still has to be gained. So far, the internal combustion engine is the dominant technology, which has benefited from economies of scale and many decades of development. Therefore, large-scale market introduction of electric vehicles necessitates an appropriate policy framework.

We start with a brief outline of the current status of the developments and an estimate of the well-to-wheel CO_2 emissions of electric vehicles, taking into account various forms of electricity production. We then describe the potential benefits and disadvantages to the transport sector, especially related to their potential role in GHG reductions and sustainable transport. The last section in this chapter is devoted to the development of three concrete scenarios for the introduction of electric and plug-in hybrid passenger cars in the EU. These scenarios will be used in the assessment of the potential effects on electricity production in the next chapter.

3.2 Technical status and expectations

Clearly, the market share of electric vehicles is still very small at the moment, and only a limited number of vehicle types are currently for sale. These are mainly relatively small vehicles typically intended for urban transport, or niche-market vehicles such as sports cars (e.g., the Lotus Elise) or delivery vans. A number of car manufacturers have announced that they will be introducing family-type electric cars in the next couple of years. However at the moment, these types of passenger cars are only for sale in very limited numbers, and are typically conventional ICE passenger cars in which the customary engine and drive trains are replaced with electric motors, drive trains and batteries. Purchase costs of current EVs are therefore still relatively high compared to ICE vehicles of similar size. The same is true for plug-in hybrids, where so far experience has only been gained with converted versions, as the first commercially available plug-in hybrids are only expected to be introduced in the coming years.

In both EV and PHEV developments, there are still two significant barriers to overcome: cost and life of the battery, and the driving range that can be achieved with a battery pack of reasonable cost and weight. These are the same barriers that hampered earlier attempts to introduce EVs in the 1990s. Despite significant R&D efforts, government policies (for example the ZEV regulation in California) and pilot tests, EVs have never been able to achieve a breakthrough and gain significant customer interest and market share. High costs and limited performance, in combination with the strong market position of ICEs, have so far been impenetrable barriers to EVs.

However, the development of new, improved batteries for mobile applications and the increasing pressure on car manufacturers to reduce CO_2 emissions have recently caused greater effort from the car industry and associated industries to develop affordable, high performing EVs and PHEVs. Within the car and battery industry, those with high expectations have claimed that the technology required to make EVs a viable commercial prospect is already mature (electric motors, drive trains, high-performance Lithium-Ion batteries) and only a few years of further development are needed to meet car requirements, increase production volumes and reduce the cost. However, those who are more sceptical refer to the technical limitations of these batteries and to the equally high expectations in the 1990s, which were never fulfilled.

In this report, we will not go into a detailed discussion of the technical status, barriers and developments. We will basically assume that the development of EVs and PHEVs will be successful in the next decade and sales will increase from 2015 onwards. Because of the current uncertainties in developments and market uptake, we will look at three different market introduction scenarios, which will be described in section 3.5. Clearly, if the technological and cost breakthrough is not achieved, and EVs and PHEVs do not enter the market on any significant scale, the report will be irrelevant, as the impact on the power production will then be negligible.

3.3 CO_2 emissions of electric vehicles

One of the main objectives for wanting to replace the ICEs with EVs or PHEVs is the CO_2 reductions that the new technology can achieve. There are two reasons for this expectation: first, electric motors have much higher efficiency than internal combustion engines, leading to less energy use per kilometre. Second, the CO_2 emissions of these cars will decrease further in the future as the share of renewable energy increases in EU power production. Furthermore, it is expected that it will be easier to significantly increase the share of renewable electricity than the share of renewable transport fuels.

To quantify the well-to-wheel (i.e., life cycle) CO_2 emissions of EVs, two parameters are especially important:
- The energy use per kilometre (in terms of kWh/km). And
- The CO_2 emissions of electricity production (in g CO_2/kWh).

Energy use per kilometre

The first parameter, energy use/km is currently quite difficult to estimate, as there are few EVs in use and there is a lack of reliable and comparable energy use data. Also, current EVs are often relatively small cars, which cannot simply be compared to the average ICE vehicle but should instead be compared to equally small ICE cars. Energy use/km depends on parameters such as the efficiency of the engine and drive train, the vehicle weight and size, tyres, aerodynamics, etc. An important factor in energy efficiency of vehicles is the weight of the batteries on board, which can typically add 200 kg or more in the current situation, compared to conventional vehicles of similar size and comfort. This weight may decrease in the future due to battery developments though this is still uncertain.

Looking at recent literature, energy use estimates for EVs are found to vary between 0.11 and 0.20 kWh/km (EEA, 2009). It was concluded (CE, 2008) that a car similar to a Volkswagen Golf would use about 0.20 kWh/km. Another study (BERR, 2008) assumed a value of 0.16 kWh/km in their calculations for 2010, 0.13 kWh/km for 2020 and 0.11 kWh/km for 2030. A range of 0.15-0.20 kWh/km might therefore seem to be a reasonable estimate for an average all-electric passenger car in the coming years, although technological developments may reduce these values in the longer term.

CO_2 emissions per kWh electricity[5]

CO_2 emissions of power production can vary significantly between countries, depending on the fuel mix that is used. For example, CO_2 emissions per kWh are highest if lignite or coal is used (due to their high carbon content), lower for gas-fired power plants and close to zero for most types of renewable energy[6]. CO_2 emissions also depend on the type of power production, with newer power plants achieving a higher efficiency than older ones. Data for CO_2 emissions of different power production systems are shown in Figure 1 and Figure 2. Note that the first graph estimates emissions in 2000 from a life-cycle approach (i.e., also including emissions of coal mining and transport, wind-turbine production, etc.), whereas the second provides estimates of the power production stage only but also incorporates future emissions estimates.

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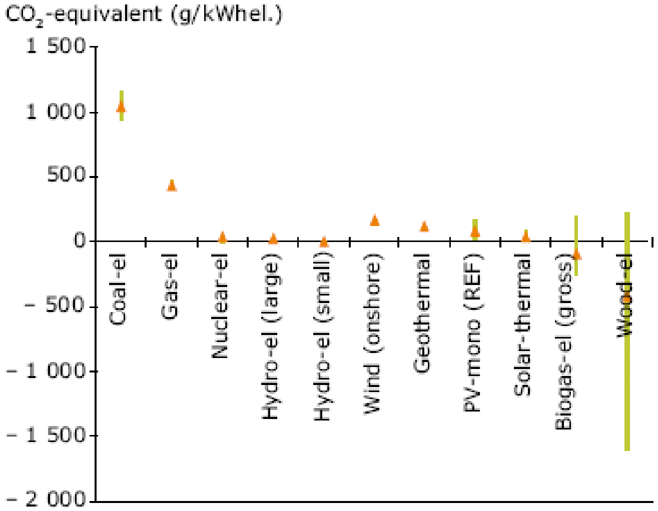
[5] One may argue that these emissions are zero because of the ETS cap. However, as the emissions are still released (the ETS only requires that an equal amount of emissions have to be reduced elsewhere), this is ignored here. This will be further discussed later in the report.

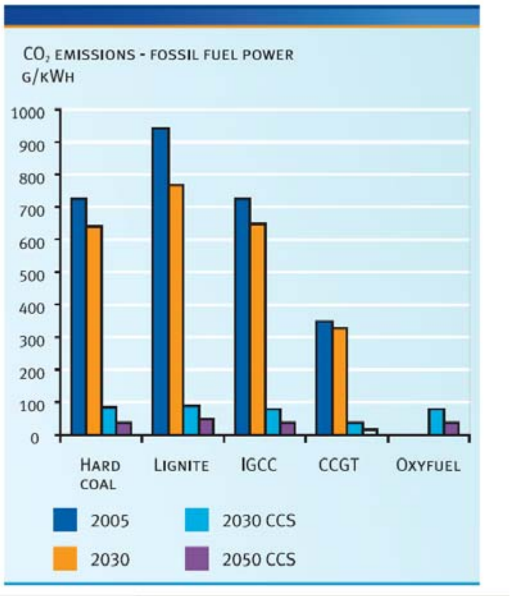
[6] Note that also emissions that have adverse health effects such as NO_x and PM_{10} are highest for lignite and coal, lower for gas and lowest for many types of renewable energy (with the possible exception of biomass that is co-fired in coal power stations).

Figure 1 Life cycle GHG emissions of various energy systems (2000)



Source: EEA, 2008; based on the GEMIS model, Oeko Institut. The life cycle emissions for nuclear exclude the 'back end' of the nuclear fuel cycle - as no valid data are available on the conditions of future final repositories for spent nuclear fuel. Also, the 'recycling' of PU-239 from spent fuel is not included, as no adequate data is available. More details to be found in EEA, 2008.

Figure 2 Emissions of fossil fuel power production



Source: Eurelectric, 2007; The Role of Electricity, A New Path to Secure, Competitive Energy in a Carbon-Constrained World.
CCS = Carbon Capture and Storage, IGCC = Integrated Gasification Combined Cycle, CCGT = Combined Cycle Gas Turbine.

Quite a large range of estimates exist for the average CO_2 emissions per kWh electricity in the EU and depend on various factors, for example, how heat generation is incorporated in the calculations. IEA (2006) estimates average EU-25 emissions to be about 380 g CO_2/kWh; EEA (2009) provides estimates between 410 and 443 gCO_2/kWh (based on EURE, 2008 and EABEV, 2009). As the fuel mix varies between EU countries, average CO_2 emissions of the power sector may also differ significantly between countries: they are higher in countries with a large share of coal and/or lignite, and lower in countries with high shares of gas, nuclear power generation or hydro energy.

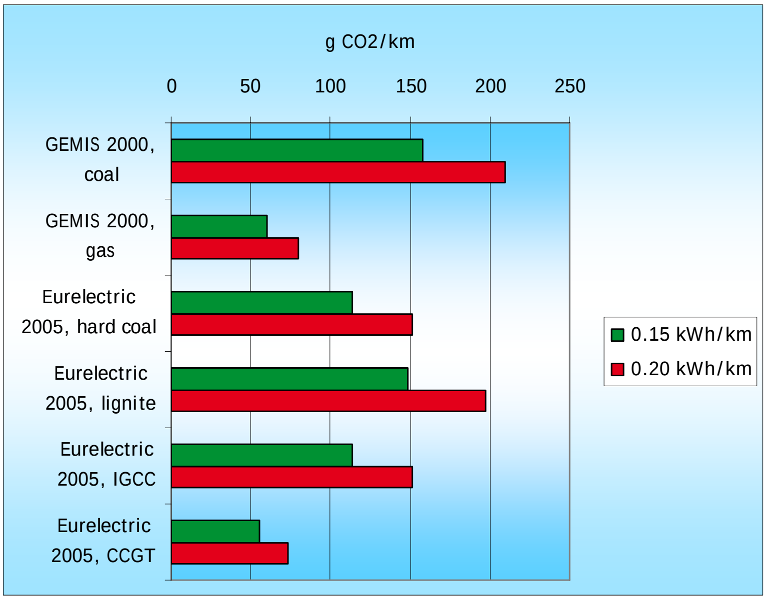
It is expected that CO_2 emissions from the power sector will decrease quite significantly in the coming decades as the share of renewable energy increases in line with the RED directive and the ETS cap is tightened. Estimates for 2030 result in about 130 g CO_2/kWh on average (EEA, 2009, based on EURE, 2008).

CO_2 emissions of EVs per kilometre

Combining these two data sets results in estimates of CO_2 emissions per vehicle kilometre. Results for individual power production routes using current emissions data and two different assumptions regarding energy use per EV kilometre are shown in Figure 3. Clearly, EV CO_2 emissions depend strongly on the power production route, with emissions of coal power more than twice as high as those from gas power. The impact of energy efficiency of the EVs themselves is also clearly discernible.

When these results are compared to the CO_2 emissions of conventional ICE vehicles, it becomes clear that the CO_2 emissions of EVs are not always lower than those of ICEs. The average EU passenger car currently emits about 184 g CO_2/km from well-to-wheel (160 g/km direct emissions and about 15% indirect emissions due to oil production and refining). Direct car emissions will have to be reduced to 130 g/km by 2015 and to 95 g/km by 2020. The emissions from EVs charged from lignite-fired power production are more than or equal to the emissions from the current average ICE (depending on the energy efficiency of the EV). The data on coal power production are somewhat inconclusive. Gas-fired power production seems to score better, as will, of course, renewable energy (not included in Figure 3).

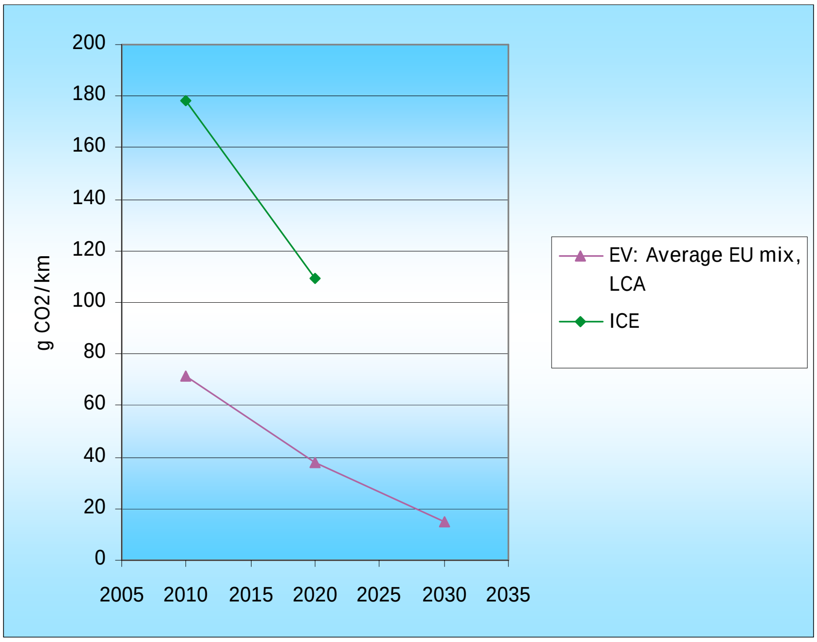
Figure 3 **CO_2 emissions per km (well-to-wheel) for various fossil fuel energy sources, with two values for EV average energy use**



Source: Electricity emissions data from Eurelectric (2008) and EEA (2008), EV energy consumption data own estimates. NB: Data include indirect emissions; an estimate of 5% is assumed for the Eurelectric data.

Results for CO_2 emissions of EVs powered by the *average* EU electricity mix are shown in Figure 4. Both EV energy efficiency and CO_2 emissions of power production are assumed to improve over time, in line with the BERR (2008) and Eurelectric (2008) studies. For comparison, the average CO_2 emissions of ICEs are indicated as well, assuming that these follow the emissions targets for the regulation on CO_2 from cars until 2020 (no targets are defined yet for the period after 2020). With these assumptions on energy efficiency per kilometre and CO_2 emissions per kWh, EVs would clearly emit much less CO_2 than current new passenger cars.

Figure 4 **Comparison of average well-to-wheel CO_2 emissions of ICEs with those of EVs powered by the average EU electricity mix**



NB: Data include indirect emissions; an estimate of 5% was assumed for electricity and 15% for ICE fuels.

See chapter 4 for further discussion on the type of power production that will actually be used to charge the EV batteries in various EU countries.

3.3.1 Well-to-wheel energy efficiency comparison of EVs with ICEs

As EVs can contribute to the policy goals for CO_2 emissions, CO_2 should be one of the primary indicators for EV assessment. However, as low-carbon energy production can be expected to be scarce for at least several decades, truly green electric cars should also have a high energy efficiency, i.e., they should use the primary energy efficiently. This will be beneficial in terms of both energy cost and environmental impact.

For an honest comparison of EV efficiency compared to that of conventional vehicles, one should consider the efficiency factors from a ‘well-to-wheel’ perspective rather than ‘tank-to-wheel’, beginning with the recovery of natural resources and ending with the transformation of electricity into kinetic energy by the electric drive train. This analysis should also include emissions from production and the scrapping phase of the vehicle and batteries. Each node in the line has its own efficiency rate, with some characterised by a high variance. The literature review shows that studies have used different rates

and calculation models; for that reason underlying calculations are only indicative and based on assumptions from other reports.
In the well-to-tank analysis of EV use, the following nodes can be identified:

- Recovery of natural resources (for fossil fuels or nuclear energy).
- Electricity production.
- Grid transportation.

Recovery of natural resources and grid transportation can vary, depending on the origin of the energy. On average, they have a steady efficiency rate of about 92% (WWF, 2008; SenterNovem, 2006).

Efficiency of electricity production also varies. Looking at the Dutch fossil fuel electricity production case, rates vary from 39% for coal-powered plants to 43% for natural gas powered plants, with an average of 42% for the period 1998-2004 (ECN, 2005). Potential future higher efficiency rates can be found in the different modes of electricity production, for example, in NGCC (Natural Gas Combined Cycle) powered plants that can reach an efficiency rate of more than 58% (ECN, 2005). Coal-fired power plants have an efficiency rate of between 36 and 44%, where the newer plants are in the higher range of the efficiency scores.

Average rates are less affected by extremes and, thus, are not expected to rise by more than a few percent in the future (SenterNovem, 2006). An indicative figure for the well-to-tank efficiency is thus 0.92 x 0.42 = 38%.

Battery charging, battery storage, transmission, electric resistance and the electric motor all have their impact on the total tank-to-wheel efficiency. The electromotor reaches an efficiency of 90% and together the tank-to-wheel efficiency is about 65–80% (WWF, 2008; Deutsche Bank, 2008; EC, 2008). Therefore, the well-to-wheel efficiency varies from 25 to 30%.

The well-to-tank efficiency of conventional ICE vehicles is high at about 83% (WWF, 2008; EC, 2008). However, in the combustion process most energy is turned into heat; only 15–20% is transformed into motive power (WWF, 2008; Deutsche Bank, 2008; personal communication with TNO). An additional small amount of energy is turned into heat due to the friction of moving parts between the engine and the wheels. The well-to-wheel efficiency for the ICE is therefore 12 to 17%.

Table 1 **Current fuel chain efficiency rates for ICEVs and EVs**

	ICEV	EV
Well-to-tank	83%	38%
Tank-to-wheel	15–20%	65-80%
Well-to-wheel	12–17%	25-30%

Clearly, the overall results show that EVs are currently almost twice as efficient as ICEVs, from a well-to-wheel perspective.

However, these data are likely to change in the future. The tank-to-wheel efficiency of ICEs is expected to increase in the coming years as the car manufacturers will reduce fuel consumption to meet future CO_2 standards. At the same time, electric vehicles will also become more energy efficient. Electricity production based on fossil sources is also expected to become more energy efficient, as we see ongoing improvements in power production technology. Furthermore, the renewable energy share will increase, which will boost the overall environmental performance of EVs.

3.4 Potential effects on the transport sector

As stated earlier, electric vehicles have significant potential for achieving significant GHG reductions in the transport sector and, in general, for making transport more sustainable (King, 2007).

Compared to current engine technology, battery electric drive trains have the following benefits:

1. They have the potential for higher efficiency than combustion engines, i.e., an electric engine requires less energy input for the same energy output, even when electricity production is included. This results in less primary energy use per km, as shown in the previous paragraph[7].
2. These vehicles provide the opportunity to use any renewable energy source for transport whereas conventional engines need liquid or gaseous fuels. In practice, this means that to be able to drive on renewable sources, conventional engines require biofuels or biogas[8]. The renewable energy share can therefore be increased much faster in EVs than in ICEs. In view of the current debate on GHG reductions from the use of biofuels, and especially the changes being effected in land use, other renewable fuel options are necessary to decarbonise transport in the future as evidence is increasing that biofuels will always remain a scarce resource. Note that the biomass-electricity-vehicle route is typically more efficient than the biomass-biofuel-vehicle route in terms of GHG savings and km per hectare of land use (Scope, 2009).
3. If the electricity is produced from renewable energy or relatively low-carbon energy sources such as gas, the well-to-wheel GHG emissions of EVs and PHEVs are (much) lower than those of comparable vehicles with combustion engines running on fossil fuels. The literature suggests that GHG emissions of electric vehicles are lower than those of comparable combustion engine vehicles, if the GHG emissions of the average EU electricity mix is assumed (see section 3.3 or, e.g., BERR, 2008; CE, 2008).
4. The electricity produced for these vehicles is automatically covered by EU ETS, which ensures that any CO_2 emissions caused by this means of electricity production are compensated with reduced CO_2 emissions elsewhere in the ETS. This assumes that the ETS emissions cap is not extended as a reaction to the additional electricity demand. This scenario is unlikely to happen in the next ten years, as the ETS caps have been set until 2020, and this additional demand would be low.
5. Electrification will lead to reduced oil demand and diversification of energy sources, thereby improving security of energy supply.
6. EVs and PHEVs driving on batteries have no direct vehicle emissions and produce much less noise than conventional vehicles. This can clearly benefit local air quality and reduce noise pollution, potentially resulting in significant health benefits. Note that the net air quality benefits will be smaller as the emissions of electricity production may well go up, depending on the type of production. In addition, air quality benefits at

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[7] The efficiency of EVs is also expected to increase (see insertion above). This may reduce the benefits, but it is unlikely that ICEVs will ever be able to catch up.

[8] Hydrogen might also be an option in the future and is being demonstrated and tested in various demonstration projects worldwide. However, the costs are still a large obstacle to further deployment, especially for the hydrogen infrastructure.

vehicle level are likely to diminish in the coming decade, as the regulation for vehicle emissions (the Euro-classes) is expected to be further tightened in the future. This will lead to considerable reductions in emissions for conventional engines.

Clearly, the type of electricity production used to power the vehicles has a strong impact on the environmental impact of EVs and PHEVs. Another important factor is the potential effect of EVs and PHEVs on the total transport volume, i.e., on the kilometres driven.

Compared to conventional cars, the current cost structure of these vehicles results in higher purchase costs, due to the high cost of batteries, and lower driving costs, due to the lower tax on electricity and higher energy efficiency. This may lead to an increase in mileage, especially if driving ranges are improved in the future. This would then result in an increase in energy use and thus greenhouse gas emissions.

In the future, other business models might lead to other cost structures, focusing more on the cost of car ownership than on the car purchase cost (BERR, 2008). For example, car purchase costs will go down and driving costs will go up if batteries are leased and paid per kilometre or if batteries are paid per charging cycle, for example when exchanged at a battery swapping station (as in the Better Place project).

Depending on the cost structure and government policies, there might also be a risk that electric cars will be additional to, rather than a replacement for, conventional cars. This may happen, for example, if their range remains limited but they get financial or other benefits, such as free parking in city centres, reduced congestion charges, access to urban restriction zones, etc. This may then lead to a potential increase in total demand for cars and car transport.

To summarise, electrification of road transport using EVs and PHEVs could be a very significant step towards future sustainable transport, mainly because of the much higher efficiency of these vehicles and the potential to use a large variety of renewable energy sources. However, the actual benefits achieved with this technology depend strongly on the type of electricity production used as well as on consumer behaviour. This last point relates to the cost structure of these vehicles and the question whether they may lead to an increase in car kilometres compared to conventional vehicles[9].

3.5 Scenarios for electrification of road transport

As concluded in section 3.2, the market potential and future development of electric cars is currently uncertain. To address this uncertainty in our analysis of the impact on the electricity sector, three different scenarios were created based on the literature and expert opinions.

- The **moderate/medium uptake scenario** – this assumes a relatively modest development of EVs and PHEVs.
- The **fast uptake scenario** – assuming that electrification is successful in the coming decade, and especially that plug-in hybrid vehicles (PHEVs) achieve a significant market share in new vehicle sales in the period up to 2020.

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[9] As this effect is still highly uncertain, it is not taken into account in the scenarios developed in the following paragraph.

- The **ultra-fast EV scenario** – a scenario that assumes a very high uptake of electric vehicles in the coming decade.

Note that these scenarios are purely hypothetical and are intended only as a basis for the analysis of the potential impact on the power sector. More detailed scenarios might be developed if the drivers and industry developments were analysed in more detail.

The **moderate/medium uptake scenario** is based on the 'business as usual' scenario in BERR (2008) describing the potential uptake of EVs in Britain, which has been extrapolated to the rest of the EU. As the number of EVs in Europe is currently very low, the number of EVs in 2010 has been reduced to zero. This scenario then assumes that EVs have a 0.4% share of total passenger car vehicles sales in 2020, resulting in about 0.5 million EVs on the road in the EU in that year. PHEVs are assumed to be somewhat more successful, reaching a 1.3% share in sales by 2020, amounting to about 1.5 million vehicles in the EU in 2020.

The **fast uptake scenario** is similar in ambition to the high-range scenario from BERR (2008), extrapolated to the EU but with a relatively large market share for the plug-in hybrids. The reason for this assumption is that these vehicles might be more attractive to consumers as they are less limited in range.

This scenario assumes that EVs have an 11% share of total passenger cars vehicles sales by 2020, resulting in almost 5 million EVs on the road in the EU in that year. PHEVs are assumed to be even more successful, reaching a 24% share in sales by 2020, amounting to about 15 million vehicles in the EU in 2020. Clearly, as there are only a few EVs and no PHEVs on the market at the moment, this scenario assumes a very fast uptake (and thus an increase in production/availability) of these new technologies.

Finally, the **ultra-fast EV uptake scenario** is based on the ambitious vision of EVs in SN&M (2009), extrapolated to the EU. In this scenario the development of EVs takes off from the year 2010 and by 2020 production is almost at par with the production of fossil fuel vehicles. In addition, PHEVs have gained a share of the car market.
This scenario assumes that EVs have a very impressive 40% share of total passenger car vehicles sales in 2020, resulting in almost 25 million EVs on the road in the EU in that year. PHEVs are assumed to be somewhat less successful, reaching a 7% share in sales by 2020, amounting to about 5.5 million vehicles in the EU in 2020.

Figure 5 provides an overview of the uptake of EVs and PHEVs in the EU car fleet for these scenarios up to 2020. Extending these scenarios beyond 2020 to 2030 results in the numbers shown in Figure 6. Clearly, these are only shown for indicative purposes, as there is no basis yet to make a reliable or well-founded future projection, considering the current penetration of these new technologies in the fleet.

Figure 5 Total number of EVs and PHEVs in the EU car fleet by 2020 in the three scenarios (million vehicles)

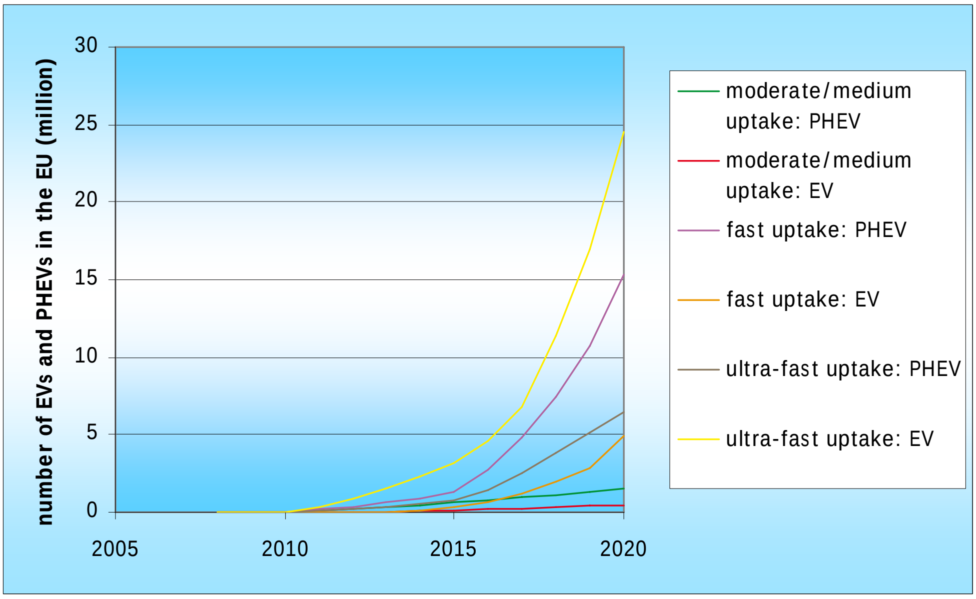
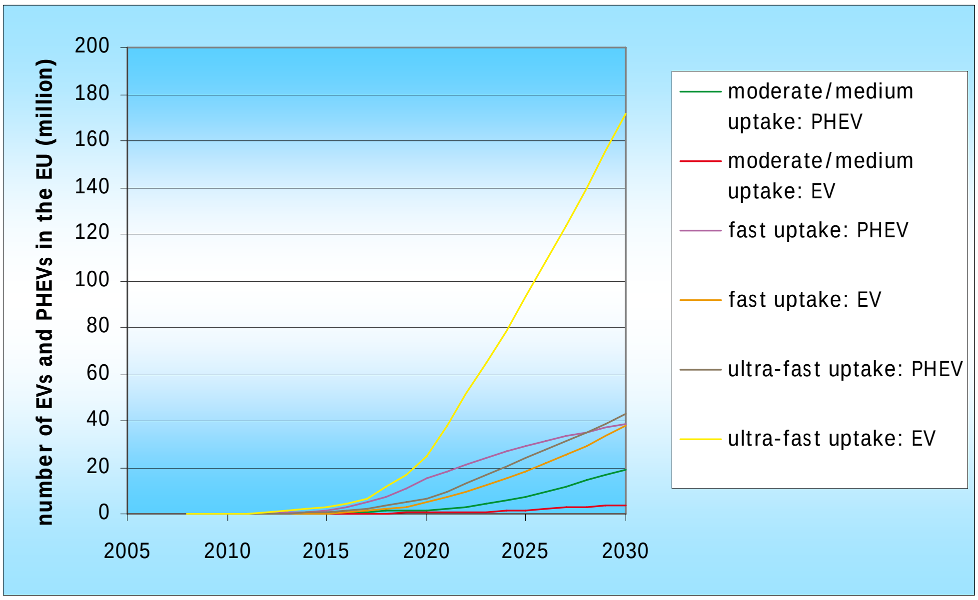


Figure 6 Total number of EVs and PHEVs in the EU car fleet in the three scenarios for the period up to 2030 (million vehicles)



It should be noted that both the fast uptake and the ultra-fast uptake scenario would require a great deal of effort on the part of governments and the car industry, as well as breakthroughs in the technology and cost of batteries.

For these three scenarios the total energy used by electrified vehicles was calculated[10]. To facilitate a more detailed calculation the following assumptions were made:

- Both electric cars (EV) and plug-in hybrid vehicles (PHEV) will be developed and obtain a share of the transport market.
- EVs are assumed to have an annual mileage of 8,640 km (about 80% of that of petrol cars), while petrol and diesel PHEVs have mileages of about 10,800 and 15,200 km/year respectively.
- Both PHEVs using petrol and diesel will be developed. PHEVs using petrol will run on electricity for 80% of their total mileage while PHEVs using diesel will be used mainly for long-distance travel and will only use electricity for 50% of their mileage. These assumptions are based on own estimates, as no reliable data have been found in the literature (and PHEVs are not yet in use on a significant scale).
- PHEVs on petrol will be more common than PHEVs on diesel[11].
- Electric cars are assumed to consume 0.72 MJ/km (0.2 kWh/km, based on data in CE, 2008). This value seems to be quite a conservative estimate.
- The PHEVs are assumed to be 20% more efficient than their conventional counter parts.
- PHEVs will be less efficient than EVs due to design constraints and the double drive train.
- The total kilometres driven by car in the EU will not be affected by the introduction of EVs and PHEVs.
- The impact of electric light goods vehicles will be very small. While this may not be realistic, scenarios with electric vans would not lead to very different results than the ones used here.
- The overall prognosis on the number of vehicles and vehicle kilometres are taken from TREMOVE v. 2.7b. This is used in conjunction with annual sales data and a vehicle introduction model to calculate the number of EVs and PHEVs and their annual mileage.

The total electricity demand of these vehicles in the various scenarios is shown in Table 2. For comparison, the total final electricity consumption of the EU-27 in 2006 was 2,813,437 GWh. Clearly, compared to the current overall consumption, the additional energy demand of these vehicles remains quite limited in 2020, even in the ambitious scenarios: about 2.9 and 2.6% in the fast uptake and ultra-fast EV scenarios respectively. In the medium/moderate uptake scenario, the additional demand is less than 0.3% of current consumption. The two fast uptake scenarios illustrate that not only the number of vehicles is relevant, but also the mileage and energy efficiency: the total number of electric and plug-in hybrid vehicles is lower in the fast uptake scenario than in the ultra-fast uptake scenario (20 million versus 31 million vehicles), but the electricity use is higher in the first case. This is due to the assumptions that annual mileage for EVs is relatively low in the ultra-fast scenario, and that the PHEVs drive on electric power for a relatively large share of their mileage.

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[10] Note that energy use in the production phase of the vehicles and batteries is not included. The data given here are only for vehicle use.

[11] This assumption is based on the expectation that the advantages of PHEVs compared to conventional cars (in terms of cost and environmental impact) are expected to be highest in cars with limited mileage - the higher the share of electric driving in the overall car use, the higher the efficiency gains and energy cost reductions.

Table 2 **Electricity needed for electric passenger car transport in the EU-27 in 2020**

	Energy needed		Number of vehicles (millions)	
	PJ	GWh	EV	PHEV
Medium/moderate uptake scenario	30	8,333	0.5	1.5
Fast uptake scenario	296	82,167	5	15
Ultra-fast EV scenario	263	72,972	25	6

As stated earlier, these are ‘worst case’ scenarios; we aim to assess the potential impact of these developments, covering the whole potential playing field.

This share will increase (much) further in the period after 2020, if the electrification of transport continues and the energy consumption of these vehicles is not drastically reduced. Using the same assumptions as listed above (i.e., not assuming efficiency improvements or changes in mileage) and using the vehicle uptake data shown in Figure 6, these scenarios would lead to an electricity demand in 2030 of about 350 PJ, 900 PJ and 1,800 PJ respectively – clearly a much more substantial demand (3–18% of the 2006 production).

3.6 Potential indirect effects in the sector

In these scenarios, we have assumed that the total vehicle kilometres driven in the EU in 2020 are not affected by the market introduction of EV and PHEV and that the fuel efficiency and annual mileage of conventional vehicles do not change either. However, under current policies these assumptions may be somewhat optimistic for a number of reasons: the impact of a different cost structure on car use, potential increases of car ownership, and the potential impact on the fuel efficiency of conventional cars due to the current regulation on CO_2 from cars.

First, electrification may impact on the cost structure of driving cars. Depending on the business model used for these cars, fixed vehicle costs such as purchase cost may become (much) higher, while variable costs would be (much) lower - at current taxation levels. According to standard economic theory (backed up by empirical evidence), lower variable costs would result in an increase in total kilometres driven[12]. This effect may be reduced if business models are implemented that spread out at least part of the battery cost over its lifetime. For example, car buyers might choose to lease or rent the batteries, paying for them per kilometre, per kWh or per charging cycle. An alternative business model is one that is planned for use in the Better Place project (www.betterplace.com), where car drivers generally charge their own batteries, but where a lease and subscription system is set up where they can also exchange their depleted batteries for full ones at dedicated stations. The business model is based on a leasing scheme for the batteries, in combination with a subscription model where the costs depend on travel distances.

Second, there is some concern that electric vehicles would be additional to the existing car fleet, rather than replacing conventional cars. This concern is mainly due to various government incentives provided by an increasing number

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[12] Despite their potentially limited range, EVs may then be used for short trips that are now made on foot or by bicycle, for example.

of countries, such as cheap or free parking, reduced road charges, access to environmental zones, etc.

Third, electric cars have a special status under the current regulation on CO_2 from cars, as was shown in section 2.1.1. Electric vehicles count here as zero-emissions vehicles, thereby allowing the auto manufacturers to sell cars that are less fuel-efficient if they are also selling EVs, compared to the situation without EVs. The penetration of EVs and PHEVs in the EU fleet could then actually increase total WTW emissions, since the CO_2 emissions of EVs are not zero in reality, as shown earlier. These effects would be exacerbated if the super-credits, which currently run out after 2015, were to be continued to 2020.

In the longer term, on the other hand, one can envisage that the regulation will be modified to take account of new technologies. In that case, sales of EVs and PHEVs will help manufacturers achieve their targets without reducing the effectiveness of the CO_2 regulation.

3.7 Effects of electric vehicles on oil and biofuel consumption

One would expect that, in principle, if electric vehicles replace conventional ICE vehicles, their introduction would reduce the consumption of liquid (and gaseous) transport fuels, i.e., petrol, diesel and biofuels. However, as the current regulation on CO_2 from cars (EC, 2009a) includes EVs as zero-emissions cars, oil consumption may in fact not be reduced - as explained in section 2.1.1 - fuel consumption of conventional cars may then increase. If super-credits apply, which is the case between 2012 and 2015, oil consumption is even likely to increase, compared to a scenario without any electric vehicles. However, as part of the electricity used will be counted towards the RED target (at a rate of 2.5-times) *biofuel* consumption would decrease due to EVs.

The impact of this policy on oil consumption and CO_2 emissions of passenger cars is illustrated in Figure 7. Here, the share of EVs in EU passenger car sales is varied, and the impact of EV sales on the emissions of these new EV cars is shown. In addition, results are shown for different levels of super-credits. These results assume that car manufacturers use the credits they receive from electric cars to the full, i.e., that if there is a 130 g/km target, it would be met in all electric vehicle scenarios. This is thus a worst-case scenario.

In reality, we would not expect that the emissions of ICEs would increase compared to those of current cars, as more fuel efficient ICE technology is clearly being developed and implemented because of the fuel efficiency target which is now in place. However, it does seem reasonable to conclude that the ICE fuel efficiency improvements may be slower with EVs than without them.

Furthermore, it is assumed here that the number of cars and annual mileage are independent of the share of electric vehicles and that there is no difference in the annual mileage for ICEs and EVs[13].

As can be seen in the graph, with high super-credits, ICE fuel use for new cars may increase significantly if the market share of EVs is increased. Without super-credits, ICE fuel use will remain constant. Note that these results imply

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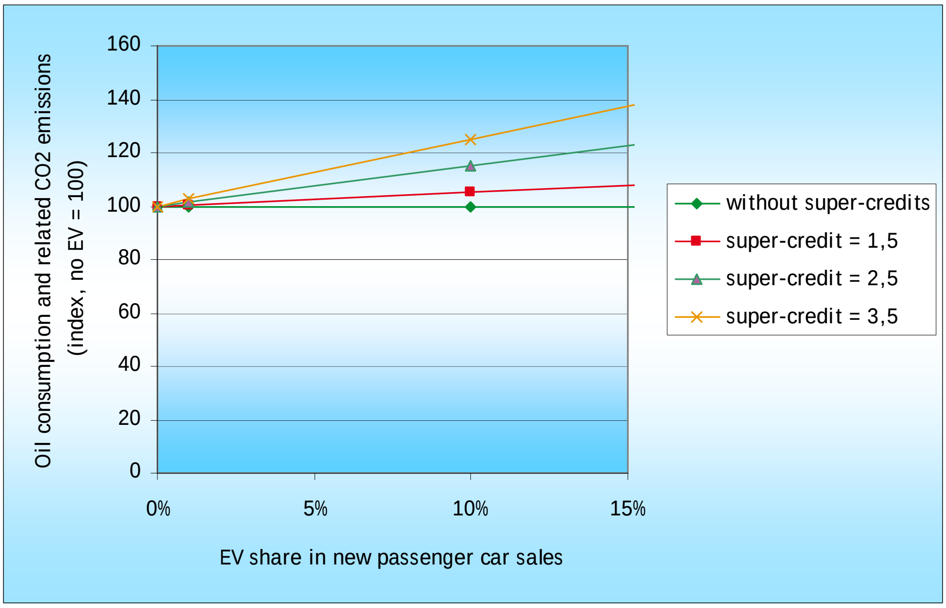
[13] If these ICEs have more annual mileage than EVs (which is likely due to the limited range of EVs), the oil consumption would actually increase as a result.

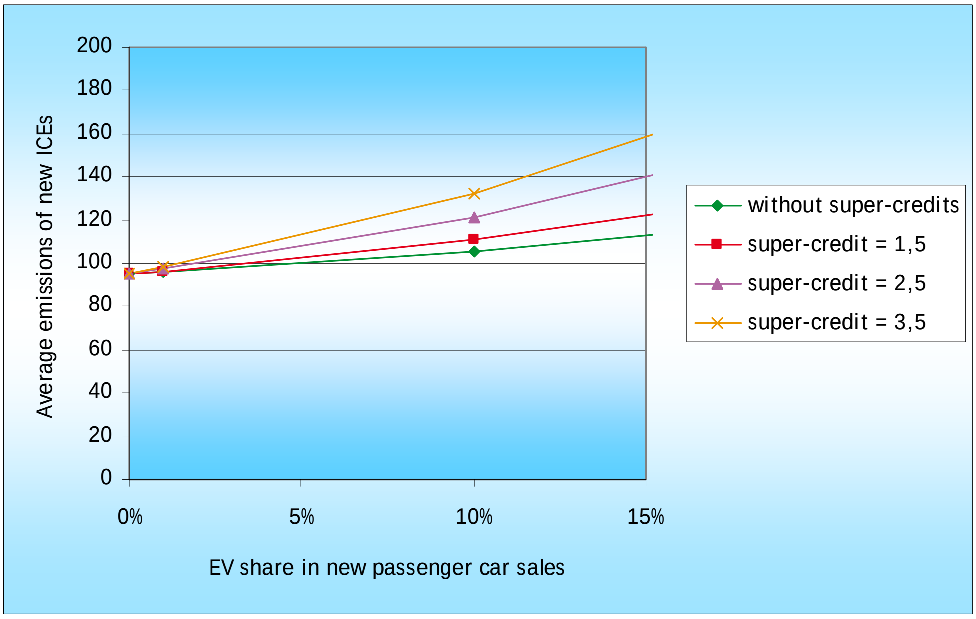
that total energy use in transport will increase in all cases, as this graph does not include the electricity used for EVs.

Figure 7 **The effect of an increasing share of EVs in passenger car sales on oil consumption of passenger cars sold (worst-case scenario under the current regulation on CO_2 from cars)**



The reason for this result is that the sales of EVs allow car manufacturers to increase the CO_2 emissions of ICEs that are sold, whilst still meeting the emissions targets. This is illustrated in Figure 8, where the 2020 emissions target of 95 g/km is assumed.

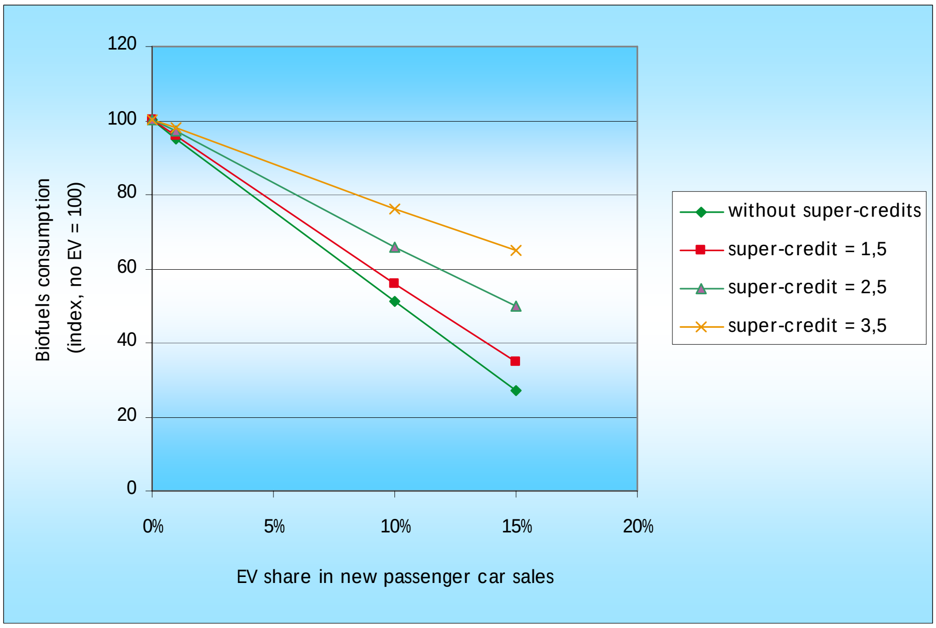
Figure 8 **Average emissions of new ICE passenger cars at a target of 95 g/km, with different shares of EVs in passenger car sales (worst-case scenario under the current regulation on CO_2 from cars)**



Despite expectations that oil consumption will remain constant or increase with growth in EV market share, biofuels consumption is likely to decrease as EV market shares increase if the share of renewable electricity is sufficiently high. Renewable electricity in road transport also counts towards the 10% RE target in 2020, reducing the need for biofuels.

This effect is illustrated in Figure 9, where a renewable electricity share of 35% is assumed (the expected EU average in 2020), again using the assumptions mentioned above. Higher renewable energy share and higher EV share will lead to lower demand for biofuels.

Figure 9 **The effect of an increasing share of EVs in passenger car sales on biofuels demand at 35% renewable electricity (under the current regulation on CO_2 from cars)**



3.8 When will the batteries be charged?

As is evident in the next chapter, it is very relevant for the electricity sector whether the batteries in the EVs and PHEVs are charged at night, when electricity demand is low, or during the day, when it is high. The impact also depends on whether charging takes place on weekdays or over the weekend. It also varies according to the season and from region to region (even locally).

Unfortunately, it is too early to predict exactly how battery charging will be distributed during the day or over the week. This will depend on, for example, the location and availability of public charging points, type of fleet (individually-owned or shared vehicles, company cars, etc.), whether companies will provide charging points, how long charging will take, and whether electricity companies provide incentives for charging at specific times. These questions have not been answered yet.

In the next chapter we look at two scenarios: one where the cars are charged during the peak hours of the day (08.00-20.00 hrs) and one where they are charged at night (24.00-08.00 hrs).

Smart metering or dedicated battery-charging stations (in combination with battery-swapping stations) may allow battery charging at hours where there is, for example, a wind power surplus or a relatively low carbon-power source. However, this option has not been included in the analysis here as it is not yet common practice.

3.9 Conclusions: Electrification of road transport

- There is still a high level of uncertainty regarding the future market introduction of electric cars and plug-in hybrids as the battery technology is not yet fully developed for transport applications, and these vehicles are not yet deployed on a large scale. Questions regarding potential share in the car fleet, energy efficiency, charging patterns, annual mileage, cost and cost structure have not yet been answered.
- We have therefore developed three different scenarios for 2020, using assumptions for these variables: a medium/moderate uptake scenario, a fast uptake scenario and an ultra-fast EV scenario. These scenarios result in an uptake of EVs between 0.5–25 million and 1.5–15 million PHEVs by 2020. The high estimates may seem unrealistic in view of the current sales of these vehicle types, but are included as extreme cases for the sake of the analysis in the following chapters.
- EVs and, to a lesser extent, PHEVs, have a number of advantages compared to current car technology based on ICEs.
  - They are more energy efficient.
  - They allow the use of a much larger range of energy sources, including all types of renewable energy.
  - They enable sustainable and carbon neutral (CO_2-free) mobility if they are powered by renewable energy sources such as wind, solar and hydro.
  - They can contribute to urban air quality improvements[14] and reduce noise from the transport sector.

  Some of these advantages may decrease over time, as ICEs will become cleaner and more fuel efficient in the future. However, the flexibility of renewable energy sources can prove an important feature that can contribute to sustainable mobility and CO_2 reductions in the transport sector in the future.
- Depending on the source of electricity generation and on the energy efficiency of the vehicles, power production for electric vehicles could, in fact, result in substantial CO_2 emissions. For instance, in the case of electricity produced by low-efficient lignite-fired power plants, CO_2 emissions from EVs would be higher than those of comparable ICE vehicles. However, this figure represents a maximum level, which is mostly relevant for countries where lignite power production has a large share (e.g., Germany, Poland and Hungary). Assuming the average EU electricity mix, CO_2 emissions would be about half of that of current conventional cars – again depending on the energy efficiency of the vehicles.
- As the power sector is part of the European Emission Trading System (ETS), any additional CO_2 emissions resulting from this additional electricity demand would, in principle, have to be compensated by CO_2 reductions elsewhere in the ETS. The impact on the power sector and on the ETS will be discussed further in the next chapters.

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[14] Note that they may, however, increase emissions of the electricity production.

- Compared to current overall consumption, the additional energy demand of these vehicles would remain quite limited in 2020, even in the ambitious scenarios: about 2.9 and 2.6% in the fast uptake and ultra-fast EV scenarios respectively. In the medium/moderate uptake scenario, the additional demand would be less than 0.3% of current consumption. Demand may increase further after 2020, depending on the success of this technology and the efficiency of the EVs.

4 Effects of electric cars on the European power supply sector

4.1 Introduction

In this chapter we investigate the possible effects of the growth of electricity consumption due to a growing number of electric and plug-in electric cars in Europe[15] based on current electric vehicle and power sector policies.

The focus is on the short term, 2020, taking into consideration the existing installed production capacity for electricity production and developments foreseen for the forthcoming years. Based on the analysis we also try to forecast whether, in the long run (after 2020), additional power capacity will need to be built to satisfy additional demand from electric vehicles, and discuss what type of power capacity that will be.

The analysis includes cases studies of three EU countries: Germany, the United Kingdom and France. These are selected because of their large contribution to electricity consumption on a European level (almost 50%, see Table 3) and also because of the significant differences in the composition of their installed electricity generation capacity and electricity supply.

Table 3 **Share of Germany, United Kingdom and France in total EU-27 gross electricity production (2007)**

Country	Electricity production
Total EU-27	3.362 TWh/yr (100%)
Germany	637 TWh/yr (19%)
UK	396 TWh/yr (12%)
France	570 TWh/yr (17%)
Total Germany, UK, France	**1.603 TWh/yr (48%)**

Source: Eurostat, 2009.

The detailed case study analyses can be found in Annex A (Germany), Annex B (France) and Annex C (United Kingdom). This chapter only contains the main results.

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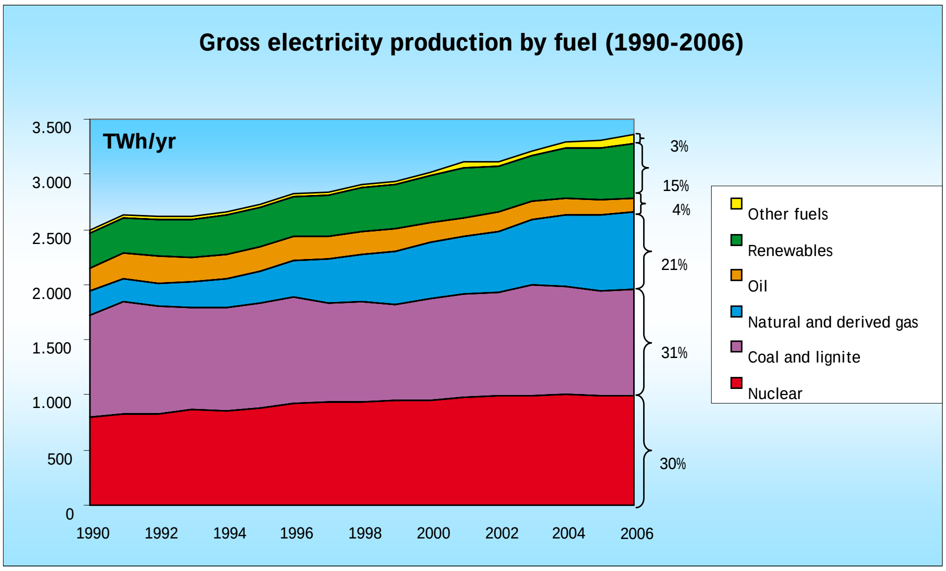
[15] Besides electric cars other effects play a role in the development of future electricity demand like a growing number of electric appliances, heat pumps, eco design measures, etc. In this study, however, we will limit the analysis to the expected growth in future electricity demand attributable to electric vehicles.

4.2 Developments in the EU electricity production sector

Figure 10 shows the current composition of electricity supply in the EU-27, and developments in the past 15 years. Specific developments for Germany, France and the UK are shown in the Annexes.

Figure 10 **Gross electricity production (in TWh/yr) by fuel 1990-2006, EU-27**



Source: Capros et al., 2008.

As can be seen, electricity production grew across the EU-27 at an average annual rate of +1.7% between 1990 and 2006. The largest contributions come from coal, gas, nuclear and renewables. The contribution of (natural) gas increased from approximately 8% in 1990 till 21% in 2006. The share of renewables consists mainly of hydro power and, to a lesser extent, biomass. The contribution of wind and solar remains limited thus far.

Developments until 2020 and 2030

It is difficult to forecast developments for the amount of electricity consumption as well as the composition of electricity supply for 2020. Major factors influencing these developments are given in Table 4.

Table 4 **Factors influencing future electricity production and composition of electricity supply**

Sector	Factor
Economy	*Economic development/growth* Economic recession results in a drop in electricity demand or a drop in capital available from banks/investors to invest in new power generation capacity. Economic growth is the main driving force for the growth of electricity consumption shown in Figure 10. *Prices of electricity/fuels* Electricity prices have shown large fluctuations in recent years, due to changes in prices of fuels. *CO_2 prices* According to the EU-ETS directive CO_2 credits for electricity producers will be auctioned. The CO_2 emissions of the electrical power industry are capped already (EU ETS).
Policy	*Renewable energy directive* Legal targets for contribution of renewable energy to total energy consumption per member state. *EU ETS directive* Caps on total CO_2 emissions of large industries, including power plants (-20% in 2020 vs. 1990); auctioning of CO_2 credits *EU policy on energy efficiency* Targets for increasing energy efficiency. Minimum standards for and labelling of electrical equipment. *National policies (like feed in tariffs, taxes, subsidies, fiscal stimulation)* Geopolitical factors affecting the future availability of fossil fuels for the EU member states. Geopolitical climate negotiations regarding the post-Kyoto period.
Technical developments	Technical and economic development of conventional and renewable energy sources. Development of CO_2 capture and storage (CCS). Construction of interconnection capacity. Storage of electricity in general and of renewable electricity in particular, and smart metering.

In the study European Energy and Transport; Trends to 2030 - update 2007 (European Commission, 2008) prognoses are estimated for the fuel mix of future electricity production. The results from this study were derived using the PRIMES model[16]. In 2008 the PRIMES model was used to analyse the policy package on climate change and renewables. In this additional study different scenarios - with or without RES (Renewable Energy Sources) trading, with or without CDM/JI - were used. In Figure 11 the results of the different scenarios are depicted. Note that all scenarios in that study show a growth in electricity demand.

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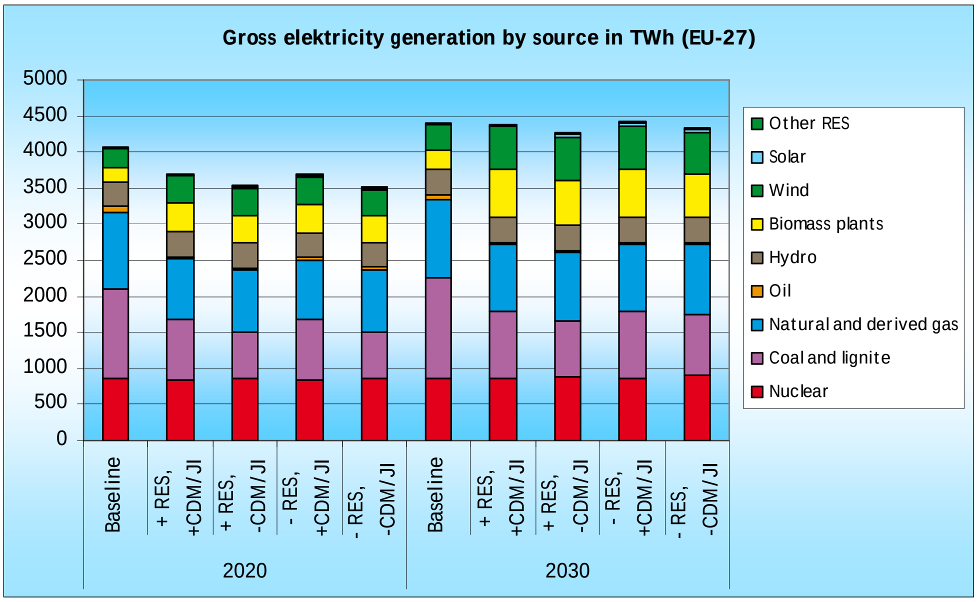
[16] The PRIMES model is run by the E3MLab of National Technical University of Athens (NTUA) and has been used to quantify the Baseline scenario for all the EU-27 member states up to the year 2030. PRIMES is a partial equilibrium model of the EU energy system providing projections for the medium and long term starting from 2010 and running up to 2030 with results for every fifth year. The PRIMES model was complemented by a series of specialised models and databases, including the POLES world energy model and the GEM-E3 macro-economic model.

Figure 11 Prognoses for the fuel mix of future gross electricity production (EU-27, in TWh/yr)



Source: Capros et al., 2008.

Baseline:	**Baseline scenario**: the business-as-usual scenario of DG-TREN at end November 2007.
+ RES, +CDM/JI:	**EC Proposal with CDM and with RES trading**: same as +RES, but with possibility to take emission credits from CDM lowering the carbon value to a uniform price of € 30/tCO_2.
+ RES, -CDM/JI:	**EC Proposal with RES trading:** same as scenario –RES, -CDM/JI, but exchange of GOs among the member states is allowed, resulting in RES developing differently from member state RES obligations but overall RES developing on a cost-effective basis.
-RES, +CDM/JI:	**EC Proposal with CDM without RES trading (RSAT-CDM)**: same as scenario +RES, -CDM/JI, but part of emission reduction can be justified by emission reduction credits taken from the CDM mechanism lowering the carbon value to a uniform price of € 30/tCO_2.
-RES, -CDM/JI:	**EC Proposal without RES trading :** scenario corresponding to the effort-sharing scheme proposed by the European Commission which meets the target separately in the EU (for the EU ETS, 27 Non ETS and 27 RES targets) and does not allow exchange of GOs among the member states.

The member states are allowed to meet their targets by buying '*guarantees of origin*' (GOs) for renewable electricity produced in other member states. This entails the respective member states reaching a bilateral agreement that the importing member state is allowed to count the GOs as part of its target while the exporting member state is not[17].

Using the CDM flexibility mechanism implies lower emission reduction efforts in the EU and lower carbon prices for the ETS as well as the non-ETS sectors at a national level. This will further imply that, in the EU, a lower level of RES is necessary to meet CO_2 reduction targets. As the CDM projects do not count towards the RED renewable energy targets, additional/specific efforts are then necessary to meet these targets. Generally, there will be weaker incentives for structural changes in the EU energy system, in both the demand and the supply sectors (Capros et al., 2008).

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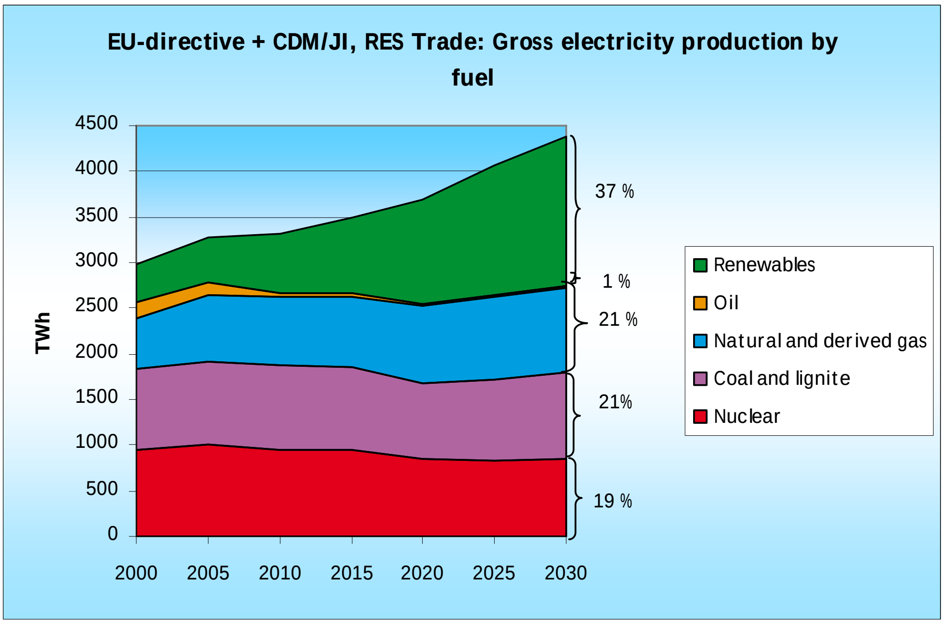
[17] At the moment such bilateral agreements are not yet in place.

Since the opportunities of RES trading and CDM/JI are operative, the RES trading and CDM/JI scenario has been chosen here to estimate the growth in renewables. The estimated gross electricity production in this scenario is given in Figure 12.

Figure 12 **Gross electricity production (in TWh/yr) by fuel**



Source: Capros et al., 2008.

As can be seen from the scenario in Figure 12, the share of renewable electricity is expected to increase to 31% by 2020 and 37% by 2030. To meet the *renewable energy* target of 20% by 2020 the share of *renewable electricity* will have to increase to about 35% till 40% by 2020.

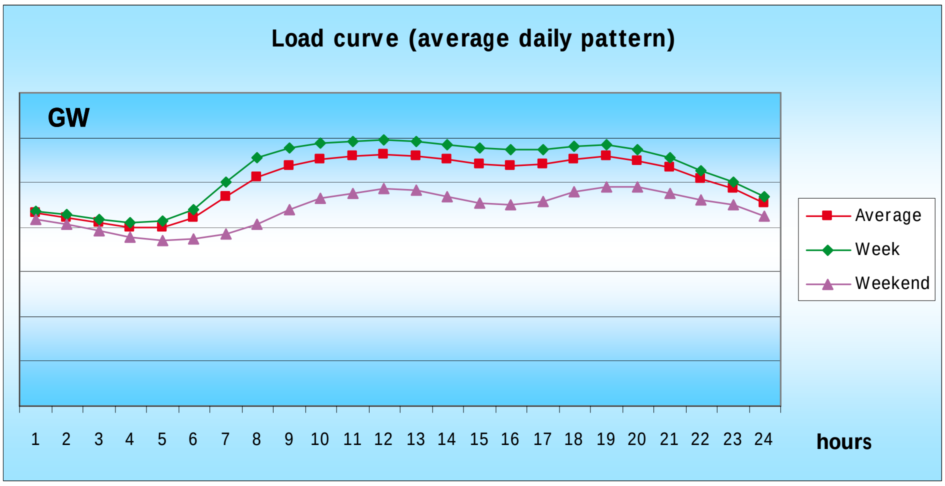
4.3 Flexibility of power supply, peak load and base load capacity

Important aspects to consider in relation to the potential of renewable energy supply sources in meeting electricity demand at any given point in time are flexibility and fluctuations in power supply.

Flexibility

Electricity consumption fluctuates from second to second, from hour to hour and from day to day. Figure 13 shows a typical electricity demand pattern (load curve); for details, we refer to the original publication.

Figure 13 **Typical pattern load curve (average day)**



Source: Entsoe, 2009.

As Figure 13 shows, during an average day hourly electricity consumption (capacity demand) at night is substantially lower than during the day.

If there is wind energy available this will be the first source to meet (partially) electricity demand since wind energy is supply driven (if it is there, it is there), has zero marginal costs and has priority access to the grid. The remaining electricity demand has to be met by demand-driven electricity generation capacity. The lowest level of this remaining demand is the level for which base load will provide the necessary production capacity, that is, the minimum level of demand which will always occur. During peak hours, additional electricity production capacity is needed that can respond quickly to a sometimes unexpected increase in electricity demand. In general, gas turbine power plants (single cycle) can rapidly respond to demand fluctuations and can even be turned on and off fairly easily, making them very flexible electricity production installations. In contrast, coal and nuclear power plants, most frequently used for providing base load capacity, are less flexible[18].

Besides flexibility, so-called merit order is another factor on which the demand-driven electricity production source depends. The merit order in a well functioning electricity market is defined according to an ascending order of marginal operating costs of power plants at any point in time. An example of a merit order is shown in Figure 14.

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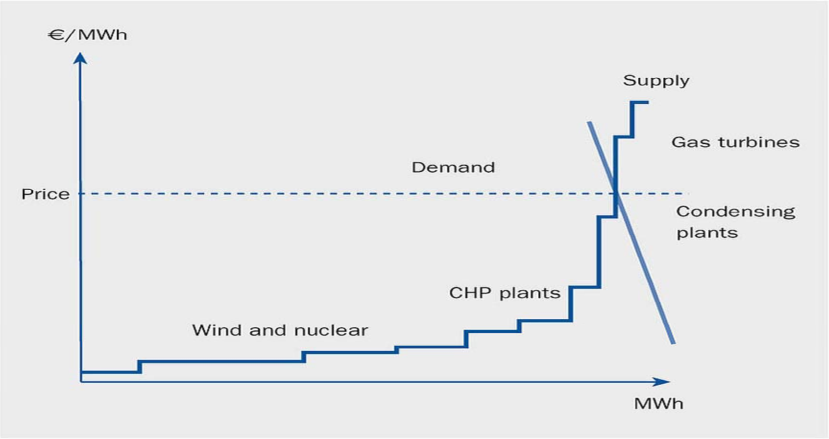
[18] Modern types of coal and nuclear power plants are somewhat more flexible than older ones, so when they are already running they can respond more quickly to a change in demand.

Figure 14 **Example of a merit order (Denmark), illustrating which plants produce power at a given market price**



Source: Risø DTU

The number of hours per year a demand-driven power plant operates depends on fuel prices, plant efficiency, CO_2 prices, size and the speed with which production can be increased or decreased (flexibility). In the case of Combined Heat and Power plants (CHP), the heat production is also a factor affecting the number of load hours. In the merit order, plants with a must-run status (like e.g. wind farms, must-run CHP plants, waste burners combined with electricity generation) rank first[19] while plants with low marginal costs, such as nuclear, hydro run-of-river and lignite plants, rank second, followed by other sources of electricity generation. As for coal and gas-fired power plants, their exact ranking in the merit order will partly depend on the energy efficiency (and therefore the age) of the specific plant concerned. Older plants are less efficient than new ones of the same type, so they their ranking in the merit order falls as capacity expansion progresses over time (European Commission, 2008). During hours of low electricity demand, such night time, coal and nuclear facilities along with must-run operated plants are the main suppliers of electricity at the moment.

Integral and marginal demand

When analysing which power plants provide the necessary electricity to meet additional electricity demand from electric cars, it is important to distinguish between integral and marginal additional demand. In terms of the way in which *integral additional demand* is being met by different sources of electricity generation, this extra demand will be met by the electricity mix at that specific moment in time. This means that wind energy will contribute to meeting this additional demand whenever available while base load capacity will meet this demand at night and gas-fired power plants during the day. *Marginal additional demand* can only be met by demand-driven capacity, based on the merit order. This means that wind energy, which is supply driven, will never be the marginal source, unless future situations occur in which the amount of wind energy becomes so substantial that it is switched off if production exceeds demand.

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[19] In fact, they lead to a downward shift of the load curve and therefore lower the net electricity demand, which has to be met by demand-driven generation capacity. Must-run production capacity can only be the marginal power plant when the amount of electricity generated by these plants exceeds the minimum base load demand.

From an integral perspective, wind energy is expected to increase its contribution due to its rising share in the European electricity supply, its low marginal costs (no fuel costs), its must-run character and priority access to the grid. Gas-fired power stations mainly supply electricity during middle load and peak load hours. Table 5 shows the average load factor per power plant type and the prognoses for 2010-2030 based on simulations of the PRIMES model. The load factor indicates the amount of time a plant operates at its maximum capacity (1 = 100%). The table concurs with the statements made above and shows that nuclear and coal have the highest load factor, i.e., they are almost always operating at their maximum capacity (base load). Wind energy has a must-run status, but only has a load factor of about 0.20 to 0.25 because the wind is not always blowing (at full speed). For offshore wind, the load factor is higher, up to 0.4.

Table 5 **Average electricity load factor**

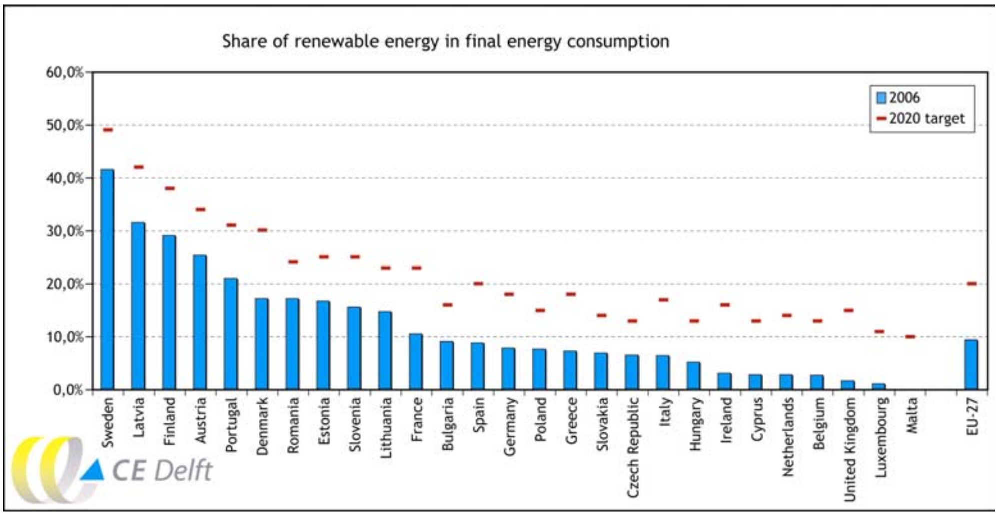
		2000	2005	2010	2015	2020	2025	2030
1.	Nuclear	0.75	0.80	0.83	0.84	0.84	0.92	0.93
2.	Solid fuels plants	0.51	0.53	0.59	0.65	0.71	0.73	0.77
3.	Hydro	0.46	-	0.48	0.48	0.55	0.52	0.54
4.	Large gas plants	0.40	0.47	0.42	0.45	0.45	0.44	0.40
5.	Biomass plants	0.37	0.32	0.34	0.33	0.33	0.34	0.34
6.	Small gas & oil	0.28	0.26	0.24	0.26	0.30	0.32	0.33
7.	Wind (on shore)	0.20	0.20	0.23	0.25	0.26	0.26	0.27

Source: European Commission, 2008.

4.4 Renewable energy and fluctuations

The EU has adopted targets for renewable energy production for the different member states by 2020, see Figure 15. These targets have a legally binding status (EC, 2009c).

Figure 15 **Targets for renewable energy for the EU**



Implementing substantial amounts of renewable energy, especially wind energy, requires a flexible energy supply due to the fluctuating character of the most important renewable sources such as wind energy that is only available when the wind is blowing[20]. For the North Sea region the annual electricity production of wind turbines would produce at their maximum production capacity approximately for 40% of the time (3,500 equivalent full load hours/year)[21].

Problems will arise if wind energy production plus the production from inflexible base load plants exceed the electricity demand, typically at night and weekends, when demand is low. At this moment these situations happen only occasionally, but they will occur more and more as the share of wind energy continues to rise. Flexibility in power supply, energy storage, interconnection and demand-side management are ways to deal with these situations. As such, in the present situation, large-scale wind energy and flexible gas power stations can be seen as a natural combination. Smart metering could also provide a possible solution when used to match the moment at which electric cars are being charged to periods when there is a lot of wind energy available or by controlling other electrical appliances in a flexible way whenever possible (demand response). Real problems are not predicted until about 2020, and such problems are country-specific and depend on the existing plants providing base load, new plants that are planned to provide base load and interconnections with other countries with different power supply characteristics, such as Norway. Since a power plant operating lifetime can be 40 years or longer, flexibility in the electrical power supply is already a factor of concern now.

4.5 Demand-side management: Potential use of electric vehicles to store energy

From 2015 onwards, as the amount wind energy and other fluctuating energy sources increase, load balancing will become more complicated[22]. Also situations might occur more and more, especially at night, when wind-generated electricity and inflexible 'conventional' sources exceed electricity demand. The question is not *if* this will happen, but *when*.

In such cases, in order to prevent renewable energy being wasted (e.g., wind capacity taken out of production), excess energy has to be exported via interconnection or stored, e.g. by using pump storage hydro[23]. In the future, batteries from electric and plug-in hybrid vehicles might also provide an attractive option for electricity storage, demand-side management and load balancing. EVs and PHEVs may thus help solve these issues of the future power sector.

Batteries from electric vehicles could act as a storage device (Grid-to-Vehicle, G2V), allowing demand-side management by the power companies. Daytime charging can then occur whenever necessary or optimal, whenever the vehicle is plugged in. Benefits can be highest if battery technology offers the possibility for relatively quick charging. For practical reasons, users must then

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[20] To a certain extent this variability is predictable based on historical wind patterns.

[21] Other renewable sources, such as (renewable) biomass and hydro power, fluctuate less. Also, in some countries or areas, wind power production is more 'balanced' because of existing different and independent wind regimes in the area.

[22] See, for example *De ruggengraat van de energievoorziening* (AER, 2009), and http://www.tennet.org/english/tennet/publications/annual_report/annual_report_2004.aspx

[23] See also: Power System Operation with Large-Scale Wind Power in Liberalised Environments (Ummels, 2009).

always be able to choose if they want to allow this option, and then indicate when the batteries should be fully charged.

Consumers are likely to require some kind of financial incentive for this. In the Netherlands it is estimated that car batteries could provide storage capacity of about 125 GWh (20 GW)[24]. For the EU this would mean roughly up to 3,125 GWh of storage capacity, depending on the uptake scenario for EVs and types of battery used.

Additionally, there is a G2V concept in which the battery of the electric vehicle is not only used as a storage device but is also able to feed back electricity into the grid to meet peak demand when the supply of renewables is limited (Vehicle-to-Grid, V2G). However, this requires significant improvements to battery costs and lifetime – the latter is typically expressed in number of charging cycles. Using them for this type of concept thus reduces the number of kilometres that can be driven with them. This option may therefore be costly and potentially unattractive for car owners, but concerns may be overcome in the longer term if battery development is successful, and the benefits outweigh the cost.

The options described above need a lot of innovation. They depend crucially on smart grids and the possibilities for smart metering – the infrastructure, metering systems and standards need to be developed. Also, batteries will need further development to make them suitable for this task. In view of the strongly increasing renewable energy share in the coming decades, it may well be useful to develop the technologies necessary for smart charging (active demand management) in the coming years to make sure that the systems are mature and implemented in EU electric car fleet once there is a need for it.

4.6 Conclusions: expected impact on the EU electricity sector

- In the coming decade, electricity demand for electric cars will result in extra electricity production from existing power plants. The magnitude of the extra electricity demand due to electric cars depends on their uptake. In the scenarios analysed here, the extra demand in 2020 varies between +0.3% and +2.9% of the current (2006) electricity production. As the high uptake scenarios are (much) higher than typically expected, in reality demand is most likely to be nearer the lower than the upper end of this range.
- Given existing market conditions the kind of electricity produced to meet extra demand will be determined mainly by the availability, flexibility and marginal costs of the electricity production sources at that given moment in time.
- The impact of the market introduction of EVs and PHEVs on electricity generation depends significantly on the actual moment the vehicle batteries are being charged: during peak hours (especially between 18:00 and 22:00) or during base load hours.
- Grid restrictions may also play an important role, limiting the amount of expected electricity demand that the grid can accommodate at a given point in time, e.g. because the grid capacity might eventually limit the amount of cars that can be charged at the same time.

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[24] This is under the assumption that 40% of the Dutch car fleet is being replaced by electric vehicles. *Elektrische concepten voor woningen* (CE, 2009).

- For extra demand in peak hours, (single cycle) gas-fired power production will be strongly positioned given the flexibility of power production[25]. However, this requires gas-fired power production to be available in substantial amounts.
- Gas fired production could well be combined with input of renewable energy, since single cycle gas-fired electricity production can easily be switched on and off. Pump storage hydro might also help to provide the necessary flexibility in production. Smart metering combined with demand-side management (smart charging) could provide flexibility on the demand side. Since (current) wind energy capacity has a must-run character (supply-driven instead of demand-driven), wind energy will not be the marginal power plant that supplies the electricity attributed to peak load demand from electric vehicles (marginal demand). However, the share of wind energy in the integral electricity mix for total electricity demand is expected to increase. In the future (after 2020), smart metering or electricity storage in the batteries of electric cars, for example, will enable wind energy and other renewable sources to become a more important source of supply for peak load demand from electric cars.
- For substantial extra demand in base load hours, coal and nuclear power will be strongly placed in the long term since these marginal power plants meet additional base load demand. As the installed wind capacity increases, whenever wind energy is available, its share of supply for extra demand will increase (as the percentage of net demand, after deducting must-run wind energy, which has to be met by demand-driven power plant decreases).
- The exact position of different plants in the merit order will depend on the specific circumstances under which the extra demand of electricity takes place and the question of which capacity is available at that specific moment in time to ramp up when necessary; power companies will try to predict and incorporate the extra demand in their availability schemes, in order to maximise profit.
- Table 6 provides an overview of which type of power is likely to be produced in order to meet the extra demand of electric vehicles in the three countries analysed in this study (see Annexes A, B and C). However, there are large uncertainties associated with these estimates, as developments in the sector in the coming years are currently difficult to predict. A distinction is made between the marginal sources, which are always demand-driven, and the integral electricity mix (integral level; supply and demand-driven sources) for meeting additional electricity demand at any given moment in time.
- Without clear extra incentives, the additional electricity demand generated by EVs and PHEVs will not automatically be met by renewable energy sources and most of the electricity will come from conventional plants. When EVs and PHEVs are charged during base load hours, the share of renewable electricity in the integral electricity mix to meet this additional base load demand will depend on factors like the available must-run wind capacity. The share of renewables will depend on the political targets that are set, on the energy markets in general and the electricity markets in particular, which vary from member state to member state.

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[25] Combined Cycle Gas Turbines (CCGT) are less flexible than single cycle turbines, because the steam-side of the CCGT-turbine limits the speed with which the installation can be ramped up and down in power capacity.

Table 6 A first indication of extra power supply for electric vehicles in Germany, France and the UK[26]

	Peak load	**Base load**	
	Short term (< 2020)	**Short term (< 2020)**	**Long term (> 2020)**
Germany	*Marginal:* Coal/lignite Gas *Integral:* Coal/lignite Gas	*Marginal:* Coal/lignite Nuclear *Integral:* Coal/lignite Wind energy (must run)	*Marginal:* Coal/lignite Nuclear (?) Wind energy (+ gas/storage) *Integral:* Coal/lignite Wind energy (+ gas/storage)
France	*Marginal:* Nuclear (if not available then gas, coal, oil) Pump storage hydro *Integral:* Nuclear (if not available then gas, coal, oil) Pump storage hydro	*Marginal:* Nuclear *Integral:* Nuclear Wind energy (must run)	*Marginal:* Nuclear *Integral:* Wind energy (+ storage)
United Kingdom	*Marginal:* Gas *Integral:* Gas	*Marginal:* Coal Nuclear Gas *Integral:* Gas Wind energy (must run)	*Marginal:* Coal (?) Nuclear Wind energy (+ gas/storage) *Integral:* Coal (?) Nuclear Wind energy (+ gas/storage)

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[26] For all the cases/situations it is also possible and likely that interconnection is a factor in providing short and long-term future base load and peak load capacity.

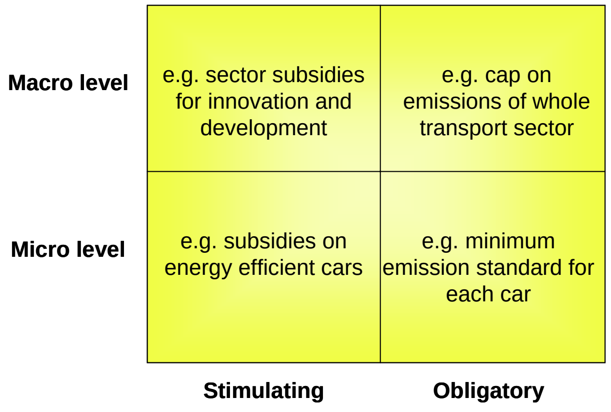
5 How can green opportunities be harvested?

5.1 Introduction

The aim of this chapter is to explore options for the EU to ensure that electrification of road transport results in a push for electricity from renewable sources rather than from coal and nuclear sources.

First, we will focus on what will happen in the event of a shift towards electric road transport, under the present macro-economic policies on carbon emissions, renewable energy and transport. We will also look at risks that a growing electricity demand from electric vehicles might pose to present policy instruments, such as the ETS system caps. We will then investigate new options, regarding both macro-scale and micro-scale instruments, as well as stimulating and obligatory instruments. This categorisation is illustrated in the following Figure 16.

Figure 16 **General classification of policy instruments in macro and micro level, and in stimulating and obligatory instruments**



	Stimulating	Obligatory
Macro level	e.g. sector subsidies for innovation and development	e.g. cap on emissions of whole transport sector
Micro level	e.g. subsidies on energy efficient cars	e.g. minimum emission standard for each car

Recommendations for the different actors, such as the EU and national governments, in chapter 6 are derived from this analysis.

We would like to add that it is currently very difficult to predict whether significant electrification is indeed likely to happen in the timeframe considered in this report, or if electric vehicles and plug-in electric vehicles will remain a small (niche) market in the future. There are still technological and cost barriers to overcome, and it will take at least several years before this can be predicted with more certainty. The following is therefore hypothetical and is based on the assumption that EVs and/or PHEVs will gain significant market share because of current policies.

5.2 Effects of road transport electrification on present policy goals and instruments

A shift from conventional drive trains towards electric vehicles will have several effects on the current climate policy goals and instruments such as the agreed EU targets for CO_2 emissions, the targets for renewable energy and the ETS. Of course, there are many other factors that have an influence. *Note that we use a marginal analysis here, focusing only on the effect of a shift to EVs.*

The following assumptions are made:
- Power production will increase.
- As EVs are potentially more energy-efficient than ICEs, total energy use can be reduced if EV fuel efficiency is optimised.
- If EVs are charged with power from fossil fuel sources, the pressure within the ETS will increase since the CO_2 emission cap of the ETS is fixed until 2020. For the longer term (after 2020), the cap has not yet been fixed.
- There will be a shift in renewable energy deployment, as the RED defines renewable energy targets for both the overall energy use and the transport sector. If EVs are charged with at least some power from renewable sources, this will lower the demand for biofuels (see section 3.7), and increase the demand for renewable electricity and heat. The overall renewable energy demand will fall somewhat as the total energy demand is reduced and the targets are set as a percentage of total *energy* demand.
- Oil consumption and associated CO_2 emissions will decrease but not to the extent foreseen as the CO_2 regulation for passenger cars currently assumes that electric vehicles have zero emissions. If so-called *super-credits* apply (as is currently the case in the period between 2012 and 2015, see section 2.1.1), this effect will be exacerbated.

This report analyses the replacement of a (relatively limited) part of the current combustion engine car fleet by electric and plug-in hybrid vehicles, and assumes that there are no changes to the amount of kilometres driven. In the event that electric vehicles lead to *extra* transport (km), total energy use will decrease less (or might even increase) and the renewable energy targets will be more difficult to achieve.

The effects are not the same for CO_2 and renewables since the policy instruments that are implemented to reach these goals are different. Both are discussed in more detail below.

5.2.1 CO_2 emissions

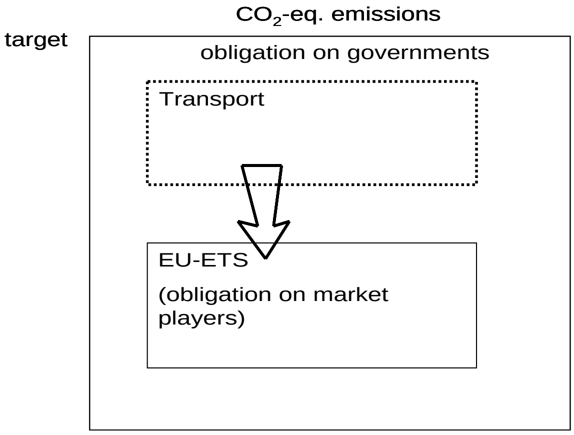
The EU has agreed to lower its CO_2 emissions by 2020 by 20% with respect to the emissions in 1990. That aim will rise to 30% if other nations join in the effort, and all the policies are likely to be revised in case of an ambitious global climate agreement. For the transport sector, the contribution should come partly from more efficient cars, partly from the use of renewable energy and partly from reduced demand for energy-intensive modes. However, there is no CO_2 emission cap imposed on the emissions from the transport sector as such.

On the other hand, a cap *has* been imposed on the emissions from the large industries and the electric power supply sector. The cap is accompanied by the EU Emissions Trading Scheme (EU ETS) so that industries can trade their emission rights and investments made by those industries that have the most cost-effective opportunities to meet the targets.

A shift towards electric vehicles run on power from fossil sources would mean bringing emissions from outside the ETS cap under the ETS cap, both under the EU target of minus 20% emissions. See also Figure 17 for this effect.

As described above, because of the current regulation on CO_2 from cars, CO_2 emissions from cars might not actually decrease to the extent intended under the legislation, which would increase the effort needed to meet the overall 20% target.

Figure 17 Schematic effects of a shift towards electric vehicles on the CO_2 emission targets



In the period until 2020, the ETS cap will ensure that CO_2 emissions of the EVs will have to be compensated by CO_2 reductions elsewhere, resulting in a direct CO_2 reduction: emissions of transport fuels will decrease and the extra electricity production will not lead to extra emissions. This is, of course, only valid if the cap is not increased as a result of these developments. However, overall CO_2 reductions in the EU will not be affected since these have been determined by the 2020 goals.

Because electric vehicles tend to be more energy efficient than ICE vehicles and generally cause lower CO_2 emissions[27], a shift towards electric vehicles helps to realise the overall emission targets but puts extra pressure on the EU ETS cap since it increases electricity demand. This will lead to a higher CO_2 price in the EU ETS than without this shift. This effect will be modest until 2020, since even the fast and ultra fast uptake scenarios of EVs accounts for only +2% to +3% of electricity demand in 2020 (with respect to the 2006 electricity production) whereas energy efficiency programmes exist that reduce electricity demand.

However, *with* the zero emissions rating and super-credits for EVs in the current CO_2 and cars policy, fuel consumption in transport may stay the same or increase, as will the CO_2 emissions, and the pressure on both the non-ETS and the ETS sectors will increase. This effect depends on the share of EVs, the use of super-credits and the average annual mileage of EVs and ICEs (section 3.7).

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[27] Depending on the specific type of power production.

Risks
A large shift towards electric vehicles will, in general, generate an upward pressure on the CO_2 price under the ETS cap. Since even the ultra fast uptake scenario for EVs will only result in a 2-3% growth in electricity production in 2020 (compared to 2006), this can be regarded as a very minor issue.

5.2.2 Renewable energy

The EU also agreed to implement 20% renewable energy by the year 2020. Each EU member state has been allocated its own specific target, based on factors such as the percentage of renewable energy a state has achieved already. Most member states have no market obligation in respect of renewable energy[28] and work with financial incentives and subsidies, making the obligation a government one.

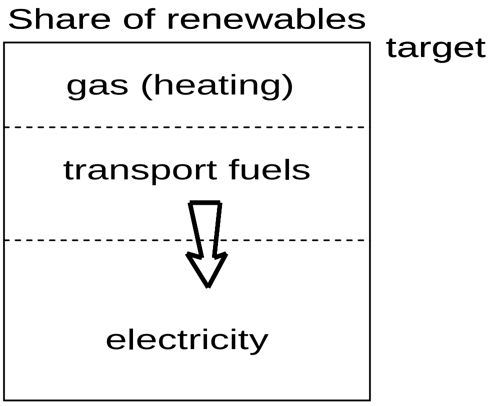
Under these renewable energy policies, a shift towards electric vehicles means that the 10% transport target (and therefore also the overall 20% target) will be met by less biofuel and more renewable electricity – again depending on the share of EVs and their power source, the use of super-credits and the average annual mileage of EVs and ICEs. Some indicative figures on this effect were provided in section 3.7.

Furthermore, it can be concluded that that electrification of road transport makes it easier to reach these RED targets because:

- Electric vehicles are expected to be more energy efficient. Marginal analysis shows that the shift will result in lower primary energy consumption in the EU and, therefore, a lower absolute target for renewables since the targets are defined as a percentage of overall consumption.
- There are more methods available for large-scale renewable electricity production than for renewable and sustainable liquid or gaseous fuel production, especially in view of the apparently limited potential of sustainable biofuels.

The shift itself has no impact on the level of the targets or their climate benefits.

Figure 18 **Schematic effects of a shift towards electric vehicles on the renewable energy targets. The total share of renewables is fixed; countries are free to chose a mix consisting of renewable heat, renewable transport fuels and renewable electricity**



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[28] Exceptions are: Poland, the UK, Belgium and Sweden, which have an obligation for a specific percentage of renewable *electricity* supply.

Risks
A shift towards electric vehicles contains no specific risk concerning the renewable *energy* targets. Only in those countries where an obligation exists for market parties for a specific percentage of renewable *electricity* in their portfolio will those parties be expected to want the pressure put on them relieved. The extent of such resistance will depend on the extra demand for electricity from road transport.

Another risk is that member states have difficulties in meeting their renewable energy targets. In the case of a pure shift from ICE to EV, these difficulties will be relieved somewhat due to the better energy efficiency of EVs over the energy chain. In the case that the current regulation on CO_2 from cars results in both more EVs and selling of ICEs with lower energy efficiency, meeting the renewable energy targets will be even more difficult. This risk may be reduced if policies are implemented that ensure that fuel efficiency of ICEs is not affected by EV sales (e.g., through fiscal measures and other suggestions that can be found in section 5.3.2).

5.3 Potential policy measures for green electric transport

As shown in chapter 4, the electricity demand of EVs and PHEVs will not automatically be met by additional renewable electricity production but, in the time frames considered in this report, mainly lead to more coal, nuclear or gas powered production[29] by the current production plants – depending on the time of battery charging and on future developments in the electricity sector. However, the additional CO_2 emissions of the power sector will, in principle, be compensated elsewhere under the ETS. Additional investments in renewable energy production are just one of the options to meet the cap. Other options include investments in energy efficiency, CDM and fuel shifts.

Below we consider the question of how the EU, national and local governments can ensure that this extra electricity demand is met by increased renewable electricity production, resulting in truly 'green' cars. Looking at the various options to achieve this, we see two different approaches: a **macro and a micro route.** The macro route implies that the policy instruments deployed target all electricity use. The micro route implies instruments that target specifically electricity used in electric vehicles. This second route includes looking at how current **transport policies** could be modified to meet this aim.

5.3.1 Macro route

We have identified a number of green electricity options for transport via general policy instruments that target electricity production.

Most member states do not have a specific target for renewable *electricity*, but mainly an assigned target for renewable *energy* (as a percentage of total energy use). The EU, or individual member states, could adopt a target for renewable electricity that could be implemented as a governmental target or as a mandatory percentage of renewable electricity production (or consumption), as Sweden, the UK, Poland and Belgium have already done. If this percentage is 'x', then every x% of additional electricity use due to EVs and PHEVs would be met by additional renewable electricity production.

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[29] Except for those member states that have adopted (and implemented policies for) specific targets for a certain percentage of renewable *electricity*.

Another approach would be to tax fossil energy, thus implementing a pricing scheme to promote renewables (as implemented in the UK and Sweden).
The current EU Renewable Energy directive already enables member states to set up a cooperation between countries so that one member state produces part of the renewable energy for another member state so long as the member state that wants to sell renewable energy to another is obliged to first meet its own renewable energy targets. The possibility of cooperation between countries under the RED is important for the obligatory scheme referred to above since an obligation for market parties to have a certain percentage of renewable electricity in their portfolio might require a sufficiently large and liquid market to ensure that no parties or groups can dominate that market. Markets that are too small tend to have more market imperfections.

In order to ensure that the growing transport electricity demand is *fully* met by additional renewable electricity, a target could be implemented obliging member states to guarantee that every kWh of electricity consumption above a certain maximum volume should be met in full by renewable electricity production. In fact, such an approach would set a cap on electricity production from fossil fuels.

One can imagine that such a scheme will not be implemented on all surplus electricity consumption but only on electricity consumption for the transport sector with targets based on sales volumes of electric vehicles multiplied by the average electricity used by an electric vehicle (or on actual monitoring of electricity use, see the next paragraph)[30].

It should be noted that these schemes will only work when minimum levels of renewable electricity production (i.e., not capacity but production) have already been implemented in the market. Otherwise, targets only for renewable electricity for electric vehicles are simply not likely to be met by *additional r*enewable electricity production but by existing production.

5.3.2 Micro routes using existing transport policies

Electric transport is currently included in the main EU climate policies for transport: the RED, the FQD and the regulation on CO_2 from cars (see section 2.1.1).

The **RED** may be used to promote the use of renewable energy for cars, if the current methodology for the renewable electricity calculation is improved. In the current definition, member states cannot report the actual share of renewable electricity but only the total electricity consumption of road transport, and use either their national or the EU average share of renewable electricity to determine the renewable energy use of their EVs and PHEVs.

These policies could provide a stronger drive for renewable electricity use, if member states are allowed to report their actual renewable electricity use. This would require setting up a reliable monitoring system of that renewable electricity consumption but this would enable countries to reduce their biofuels target if they succeed in promoting the use of EVs and PHEVs and in providing effective incentives to charge these vehicles with renewable electricity. The micro routes described in the following paragraph could be deployed for the latter. This could be combined with metering along with actual simultaneous production and use of renewables, as outlined below.

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[30] This scheme might be problematic for setting long-term targets for renewable electricity for transport, since this would be highly dependent on accurate forecasting of future sales of EVs and PHEVs.

The **FQD** would also benefit from a more realistic estimate of the CO_2 intensity of electric production chain. If it assumes that electricity production has the CO_2 emissions of the average EU or member state electricity production, it may not provide an accurate enough estimate of actual transport energy emissions, as these vary significantly between sources[31] and depend on the charging time.

Using the average CO_2 emissions of electricity production could provide a useful first order estimate, as an analysis of the actual, detailed impact on the power sector is difficult to make (see chapter 4). For this, either the national or EU average electricity production could be used. This is the approach taken in the Californian Low Carbon Fuel Standard, as described in the text box below.

A more accurate methodology that takes the marginal production into account might be enabled by accurate (smart) metering of the battery charging process in the future.

As mentioned before, the regulation on **CO_2 from cars** currently takes EVs as zero emission vehicles. This may help stimulate the introduction of EVs in the near future. However, once EV sales increase, alternatives should be considered to prevent a potential increase in energy use and CO_2 of transport emissions due to electrification.

- One option would be to tackle this as suggested above for the FQD, by using more accurate emission data for electricity production. A relatively simple way would be to mimic the Californian regulation on GHG emissions from cars, providing one emission factor for all EVs, based on average power production emissions – see the text box below.
- However, EVs could also be included in a more sophisticated way, for example, by combining actual energy use data (in kWh/km) with an average CO_2 emission factor of electricity production (in g CO_2/kWh). This would have the benefit of promoting the development and sales of more energy efficient EVs, an important factor in EV CO_2 emissions.
- Alternatively, the CO_2 target could be converted to a MJ/km target. In combination with the FQD policy that sets a reduction requirement on CO_2/MJ emission, this could effectively cover total specific emissions of vehicles.
- Another alternative might be to not count EVs towards the target. In that case, the target would only apply to ICEs. This could be complemented with a separate target for EVs. Both targets could then be reduced in the future in line with the specific technical potentials of these technologies.

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[31] We would argue this, despite the fact that ETS caps the emissions. ETS does not cap emissions of individual sectors or companies but only ensures that CO_2 is reduced elsewhere if necessary. The FQD rather looks at the specific emissions due to transport activity, where the emissions of electricity production should be included.

The Californian approach

The Californian Low Carbon Fuel Standard

In 2007, the US state of California established a Low Carbon Fuel Standard (LCFS) that would regulate the well-to-wheel greenhouse gas emission of transport fuels. Since then, it has been further developed and specified, and it will take effect in January 2011. The LCFS defines emission reduction targets for both gasoline and diesel, of -10% between 2010 and 2020, with yearly reduction targets in between. It is envisaged that this target will be met mainly by biofuels, and to some extend by electricity and hydrogen.

What is interesting for our study is that the LCFS regulation provides rules for reporting and monitoring of the electricity used for transport, and it provides a methodology and default data for the CO_2 emissions of various fuel pathways, including electricity.

The well-to-wheel carbon intensity of the various fuels that are envisaged to be used in transport are determined using the GREET model, adapted to the Californian situation. This methodology is quite similar to the one adopted in the RED.

The LCFS, however, also specifies CO_2 emissions of two electricity pathways: California average electricity mix (124.10 gCO2e/MJ) and California marginal electricity mix of natural gas and renewable energy sources (104.71 gCO2e/MJ). Other values of CO_2 emissions of electricity may be used, provided that information about the production process is given. In order to account for the higher efficiency of electric motors compared to combustion engines, these emissions/MJ are then divided by the Energy Economy Ratio (EER), which is defined to be 3.0 in case gasoline is replaced, and 2.7 in case of diesel replacement. These factors are used for both battery electric and plug in hybrid vehicles. Compared to current emissions of gasoline (95.86 gCO2e/MJ) and diesel (94.71 gCO2e/MJ), EVs can thus clearly contribute to meeting the lower LCFS standards in the coming decade.

Reporting requirements to include electricity used for transportation in the LCFS are also included in the regulation.

Specifics of the regulation can be found in the Final Regulation Order, at
http://www.arb.ca.gov/regact/2009/lcfs09/finalfro.pdf

The Californian regulation on GHG emissions from cars

In 2005, California set limits on the GHG emissions from new vehicles, similar to the recent EU's CO_2 regulations for passenger cars. Alternative fuels are included by defining upstream adjustment factors, a multiplier reflecting greater or lesser upstream greenhouse gas intensity.

Electric vehicles have a factor of 130 g CO_2/mile, meaning that every EV that is sold will count as 130 g/mile. Hydrogen ICEs have an upstream emissions factor of 290 g/mile, hydrogen EVs of 210 g/mile.

The regulation further states that 'The Executive Officer may approve use of a lower upstream emissions factor if a manufacturer demonstrates the appropriateness of the lower value by providing information that includes, but is not limited to, the percentage of hydrogen fuel or the percentage of electricity produced for sale in California using a 'renewable energy resource''

Source: The California Low-Emission Vehicle Regulations
(With Amendments Effective April 17, 2009).

5.3.3 New micro routes

The micro route implies that the EU or national governments promote or regulate that electric or plug-in vehicles are fully charged with renewable electricity. This can be done for the whole EU car fleet, but would also include national or local initiatives. The number of possibilities for policy instruments on the micro level is large but the following types can be distinguished:

- Regulation.
  - Governments may set obligations to market parties to meet the targets (i.e., 100% green electricity in cars).
- Subsidies and fiscal measures.
  - Governments may grant subsidies or tax reductions to parties who contribute to the target of 100% green electricity in cars.
- Voluntary agreements with e.g. car sellers.
  - Governments may make voluntary agreements (‘covenant’) with market parties to contribute to the target.
- Information campaigns.
  - Market players may be stimulated by information campaigns to contribute to the target.

Additional policy measures are needed to secure that the green consumption for electric cars will be accompanied by additional green production. For example, by raising the national targets by the same (measured or estimated) amount or by not counting the same amount of green ‘certificates of origin’ for the national target, which is in fact the same kind of measure but the other way round. Note that these accompanying measures are macro, not micro.

Since policy instruments like regulation and financial stimulations need reliable methods for verification, it is useful to distinguish between situations with dedicated, central, charging points, and situations where households charge their electric vehicle from an ordinary wall socket that is not separately metered.

Dedicated (central) and separately metered charging points

Where dedicated charging points are used, metering the quantity of electricity used for charging is relatively easy. This can be applied as a basis for regulation or for financial incentives aimed at green charging of the vehicle. Think of central charging points in parking garages or parking lots, charging points at petrol stations or stations where complete battery packages can be changed. Where local or national authorities own the charging points, they can simply buy green electricity for these points (by buying certificates); supplementation is a problem to be solved in such a scenario.
Having a smart grid, smart meters and charging points, cars in the future can be charged whenever renewable electricity is available

Home chargers, not separately metered

If the charging point can not be separately metered, as in the case of home chargers, there is currently no basis for regulation or financial incentives regarding the amount of electricity for electric vehicles. Policy measures may, in that case, be based on *estimates* of the percentage of electricity used for charging of electric cars. Alternatives may be the use of an additional intermediate meter for the charging wall socket for the car, smart meters combined with smart identification of charging electric cars, a special kWh meter *inside* the car, or 100% green electricity consumption (by buying certificates) for all households that own electric vehicles.

Metering in the vehicles

In addition to having dedicated metering technology at the charging points, metering could also be built into the vehicles itself. This could provide all the functions described above.

Alternative micro routes

Alternative micro routes that do not imply metering in some way or another may be that each electric car will be sold including a certain volume of 'green electricity' or with a discount for renewable energy contracts. Also a certain volume of green 'certificates of origin' for renewable electricity production could be included in the sale. To be sure that only additional production is stimulated, the latter should then be excluded from the national targets, or the national targets raised by the respective amount.

Additional information campaigns to encourage consumers to charge their vehicles with renewable energy may also help.

5.4 Achieving effective demand-side management with vehicle batteries

As explained in section 4.5, EVs and PHEVs could play an important role in a future electricity system in which renewable energy sources like wind and PV have major shares in power production. Since production from these types of sources depends on factors like wind speed and sunlight irradiation rather than on operator control, balancing the load in such a system becomes much more complicated. In addition, situations might occur more and more, especially at night, when renewable electricity and inflexible 'conventional' sources exceed electricity demand. The question is not *if* this will happen, but *when*.

To match the resulting variable production with demand, demand-side management that uses the potential flexibility in battery charging demand is an option that requires further attention and support. This could be achieved with policies and R&D programmes that encourage the further development and implementation of the technologies and standards required to harvest these opportunities.

5.5 Metering: a prerequisite for effective policies?

Many of the possible policy measures mentioned above imply metering of the electricity used for charging electric vehicles. This applies especially to micro-level regulatory and/or financial policies. For macro-level policy measures, specific metering might be necessary but a viable alternative is to count the number of electric vehicles and multiply that by a number for the estimated or measured average annual electricity consumption per electric car.

Specific metering is therefore not a prerequisite for more renewable electricity in transport but it might be a prerequisite for micro-level regulation and/or financial incentives, especially for 'home charging'.

Smart metering would take this one step further as it also enables concepts like smart charging of batteries whenever renewable electricity is available and charging when renewable electricity production exceeds demand. This can contribute to a future renewable energy system as discussed in the previous paragraph and (in more detail) in section 4.5.

An interesting question is whether electric cars can identify themselves in 'smart grids' in the near future in a way that their electricity consumption at charging points can be easily monitored on a national level. Though companies are working on such identification (and necessary standardisation) to be able to direct and invoice the specific charging hours of the electric car, this technology is not yet standard in electric cars. Once this has been developed further and implemented on a large scale, interesting opportunities may arise. Another route for this will be identification and metering of the volume of electricity for charging at smart meter level rather than the electric car itself. Also here, interesting innovations are in progress but will not yet be available for that purpose in the near future.

5.6 Pros and cons of different policy instruments

Incentive packages at the *micro level* have the advantage that they are relatively easy and fast to implement and also do not hinder the roll-out of electric cars. The disadvantages are that such packages are non-committal so whether the intended effect is achieved remains a question. A 100% effect will certainly not be obtained. If the aim is to ensure that all electricity consumption of electric cars will be green, regulation is needed. Depending on the way the charging points will be organised in the market, regulation might imply specific metering and specific registrations and monitoring. To ensure that this consumption of green electricity leads to *additional* renewable electricity production (and not just to a shift), this has to be accompanied by macro measures. Regulation targeted specifically at the electricity consumption of electric cars will obviously hinder the roll-out of electric vehicles.

At *macro level*, policy measures can be directed at a green percentage of a country's total electricity consumption or the green percentage of its total volume of additional electricity consumption of electric transport. The latter can be estimated when the number of electric cars is monitored. Such macro-policy measures have the advantage that they do not hinder the individual electric car buyer or driver and that they lead to secured results. The disadvantages are that they might require long legislation procedures and difficult political negotiations.

5.7 Policy instruments: conclusions

The present implemented policy measures (EU ETS, the renewable energy targets and the greenhouse gas emission targets for each member state) ensure that electric vehicles will not lead to increases in GHG emissions and that a certain percentage of the electricity will be from renewable sources. Since electric cars generally show better energy efficiencies and lower CO_2 emissions (over the supply chain) than internal combustion engines, they can help to achieve overall governmental emission targets in the long term. However, in the current situation, the CO_2 regulation of cars creates a loophole in the policies, as it allows conventional vehicles to emit more if EVs are sold. CO_2 emissions and oil use in the transport sector will thus not decrease to the extent envisaged if electrification is successful, as long as this policy is not amended.

In the longer term, there might be pressure from the ETS sectors to weaken the ETS targets. However, the impact of EVs and PHEVs on the ETS is expected to be relatively small, given the minor contribution they are expected to make in terms of total electricity consumption by 2020. However, transport electricity demand can be expected to play a role in ETS negotiations after 2020.

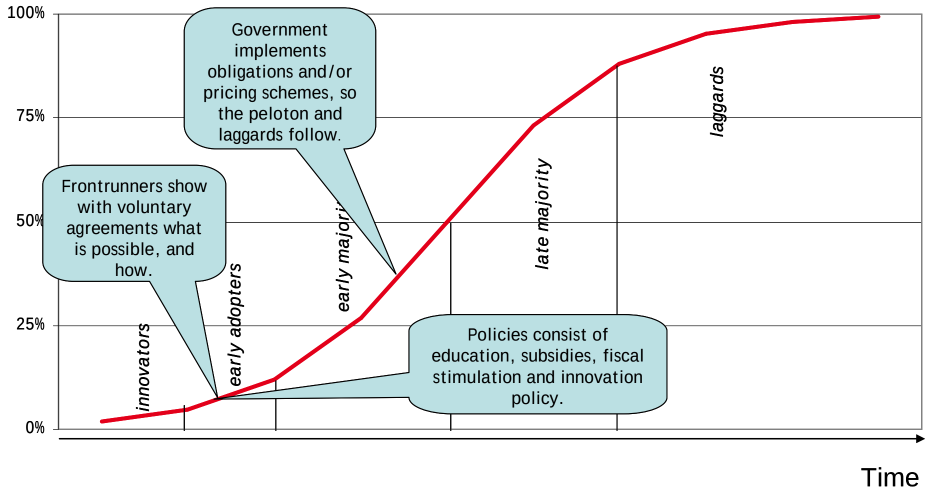
If policy aims are to both stimulate electric vehicles and ensure that the additional electricity consumption is 100% green, we conclude that the best policy options are macro-policy regulations targeted at 100% additional green electricity production for all electricity that is consumed by electric vehicles.

To this end, the electricity consumption of road transport needs to be determined. We see two options for this. Firstly, accurate metering to secure time-equivalent renewables production. This seems to be technically possible but requires significant investment in metering equipment, reporting and verification. Alternatively, to avoid bureaucratic metering and monitoring procedures, the volume of electricity may also be determined on the basis of the number of electric cars (which should be monitored) multiplied by an estimated or measured volume of electricity that an average electric car uses annually.

If such policies require long legislation procedures and political negotiations before implementation, for the short term a policy package aimed at voluntary purchases of green electricity by electric car owners (frontrunner programme) might be useful to help clear the way.

The ‘truly green car’ has been used as the objective thus far in this analysis. As shown above, policies can be defined to achieve that objective. However, a different strategy involving a broader scope may also be followed. Instead of aiming at the ‘truly green car’, a long-term goal could be set for a ‘truly green electricity sector’, with a clearly marked time path and milestones. Smart metering technology and standards then need to be developed and implemented as well as micro-level policies and initiatives to clear the way for future developments. This can be accompanied by a macro-level regulation on energy companies to have an increasing percentage of renewable energy in their portfolio. A trading scheme and a large and liquid market are considered necessary to ensure that all parties have the same market opportunities. Figure 19 illustrates how these policy instruments may develop over time.

Figure 19 **Illustration of different policy instruments needed in different phases of the energy transition in general, starting with stimulating instruments aimed at frontrunners, followed by more regulatory instruments aimed at ‘the chasing group’ and laggards**



6 Conclusions and recommendations

6.1 General conclusions

Electric vehicles (EVs) and plug-in electric vehicles (PHEVs) provide very promising opportunities for the future development of a sustainable transport sector. If they successfully enter the market in the coming decades under the right conditions, they will not only reduce local emissions and increase the overall energy efficiency of cars, but they may also move a step further to achieving zero emissions from well-to-wheel. In the future, they could also provide an effective means to store energy from renewable sources such as wind and photovoltaic solar energy (PV), in times when supply exceeds demand, and therefore contribute to the significant uptake of renewables in the electricity sector.

However, these potential benefits will not be achieved automatically. Policies will have to change to make it happen.

Under current policies, an increase of EVs and PHEVs is likely to lead to more electricity production from coal, gas and nuclear power plants, without necessarily reducing oil demand for conventional cars (see the next section). The existing EU ETS cap will then have to ensure that the CO_2 emissions of the extra electricity production are compensated with mitigation measures elsewhere. Furthermore, there is not yet a means to ensure that the potential benefit of these vehicles to the deployment of high shares of renewable energy will be harvested.

The main aim of this study was to identify the policy options which the EU and national governments can take to ensure that a successful market uptake of EVs and PHEVs will provide an incentive to increase the share of electricity from renewable sources. We therefore first assessed the expected developments under current policies, deriving the opportunities for policy improvements and modifications, resulting in an overview of potential policy options and recommendations.

6.2 Effects under current policies

Effects on the transport sector

The impact of EVs and PHEVs on the sustainability of transport and on the CO_2 emissions of the sector depends significantly on the source of electricity generation.

- In the case of coal as the energy source, CO_2 emissions over the whole energy chain (i.e., from ‘well-to-wheel’) are roughly comparable to those of conventional cars, with higher emissions if lignite is used.
- If electricity from gas-fired power plants or from the average EU electricity mix is used, well-to-wheel emissions are significantly lower.
- CO_2 emissions per kilometre can be near zero if carbon-free renewable energy is used.

Furthermore, these vehicles provide the opportunity to use all types of renewable energy sources whereas conventional vehicles require liquid or gaseous type of (bio)fuels. Under current prospects this means that high shares of renewable energy can thus be achieved with less negative impact on, for example, land use, competition with food and greenhouse gas emissions. Electric cars also generally show better energy efficiencies than conventional cars from a well-to-wheel, supply-chain perspective. Replacing conventional (ICE) cars with EVs and PHEVs can thus help to achieve both overall CO_2 emission targets and ambitious CO_2 standards for cars and vans.

However, in the current situation, this potential is not yet harvested due to a stipulation in the regulation on CO_2 from cars that states that EVs are counted as zero emission cars. An increasing share of EVs in the passenger car sales may then lead to reduced efforts to improve the energy efficiency of conventional, ICE cars with the result that under the current regulation, sales of EVs will probably not reduce oil consumption and CO_2 emissions in the transport sector. So-called super-credits, implemented in the directive to temporarily promote the sales of EVs, further exacerbate this effect and may even increase overall CO_2 emissions of the car fleet if the share of EVs in the passenger car sales increases.

In addition to these impacts on CO_2 emissions and renewable energy use, EVs and PHEVs will have benefits for local air quality and noise pollution, as they don't pollute the atmosphere and have lower noise levels than conventional cars. The power production may, however, lead to emissions elsewhere – again depending on the type of electricity production.

Effects on the electricity sector

In the coming decade, the impact of EVs and PHEVs on the power sector is likely to be limited. The extra electricity demand for electric cars will grow to no more than 3% of the existing demand. This additional demand will be met by extra production of the existing power plants

However, this may change after 2020. In order to harvest the potential of these technologies in the future, it is important to set the right conditions already in the coming years, for two reasons:

1. To steer development in a sustainable direction. And
2. To make sure that the right smart metering and smart storage technology are available so these vehicles can play an important role in the technological integration of renewable energy sources in the existing power grid after 2020.

The case studies in this report show that the origin of electricity production for EVs and PHEVs depends on the time of day when the batteries are being charged and on existing production capacity in a country. Without clear extra incentives, the additional electricity demand generated by EVs and PHEVs will not tend to come from renewable energy sources. If batteries are being charged during base load hours (at night), base load production is increased. This is normally provided by coal/lignite or nuclear plants (in Germany and France respectively), in some cases by from gas-fired power plants (in the UK). Charging at peak load (daytime) leads to a more complex response, as the marginal power production may vary during the day. Results are shown in Table 7.

Table 7 A first indication of extra power supply for electric vehicles in Germany, France and the UK[32]

	Peak load	Base load	
	Short term (< 2020)	**Short term (< 2020)**	**Long term (> 2020)**
Germany	*Marginal:* Coal/lignite Gas *Integral:* Coal/lignite Gas	*Marginal:* Coal/lignite Nuclear *Integral:* Coal/lignite Wind energy (must run)	*Marginal:* Coal/lignite Nuclear (?) Wind energy (+ gas/storage) *Integral:* Coal/lignite Wind energy (+ gas/storage)
France	*Marginal:* Nuclear (if not available then gas, coal, oil) Pump storage hydro *Intergral:* Nuclear (if not available then gas, coal, oil) Pump storage hydro	*Marginal:* Nuclear *Integral:* Nuclear Wind energy (must run)	*Marginal:* Nuclear *Integral:* Wind energy (+ storage)
United Kingdom	*Marginal:* Gas *Integral:* Gas	*Marginal:* Coal Nuclear Gas *Integral:* Gas Wind energy (must run)	*Marginal:* Coal (?) Nuclear Wind energy (+ gas/storage) *Integral:* Coal (?) Nuclear Wind energy (+ gas/storage)

Note a distinction is made between the *marginal* power plant, where the extra unit of additional electricity might be coming from, and the integral level for which one can say that extra demand will be met by the electricity mix at that specific moment in time (see also section 4.3).

In the current situation, renewable energy is hardly ever the marginal power source, as these sources are normally not affected by demand but by supply (supply-driven, e.g., wind energy). In the coming decades, renewable energy shares will increase significantly and this may change. It may then become attractive to use car batteries to store any renewable energy overcapacity, rather than reduce supply (e.g., by turning wind turbines away from the wind). Overcapacity can be expected to occur first during base load hours, i.e., at night when most car owners have their cars at home and not in use. This opportunity may be best harvested with smart charging, i.e., charging vehicle batteries so that this sustainable overcapacity is used whenever possible.

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[32] For all the cases/situations it is also possible and likely that interconnection plays a role in providing short and long-term future base load and peak load capacity.

The CO_2 emissions of electricity production in the EU are part of the EU ETS. As the ETS cap has been set until 2020, this system will ensure that an increase in emissions from EU power production results either in CO_2 mitigation elsewhere in the ETS or in additional CDM projects to compensate the emissions[33]. A significant increase of electricity demand from the transport sector will thus impact the parties involved in the ETS and have an upward effect on the CO_2 price in the ETS.

In general, grid capacity seems to be sufficient to allow charging of the EVs and PHEVs entering the market in the next decade. However, there are indications that specific problems may arise in specific local situations, where the grid capacity may become insufficient. Over time, if this vehicle technology proves successful, larger market shares of electric vehicles may cause grid problems in more regions, requiring more large-scale adaptation of the grid. Smart charging may reduce this effect, and prevent temporary grid overload. This effect has not been studied further in this report, but may require more attention in the coming years.

6.3 Recommendations

We recommend further investigation of a number of policy options that can help to ensure that a future large-scale market introduction will promote and facilitate green electricity production, distinguishing between a macro and a micro-level approach and then providing specific recommendations for different levels: EU, national governments and other parties.

Macro level

If the aim is to both stimulate electric vehicles as well as to ensure that the additional electricity consumption is 100% renewable, we recommend implementing macro policy measures targeted at 100% additional green electricity production for electricity consumed by EVs and PHEVs. These can be implemented by member states as national governmental targets or as a market regulation (e.g. imposed on energy companies, car manufacturers or in shared obligations).

In addition, it is advisable to further assess the potential, feasibility and desirability of using batteries of EVs and PHEVs for renewable energy storage in the longer term. They should provide the possibility for active demand-side management, which will most probably become an important ingredient in an energy system with significant shares of fluctuating renewable energy supply.

Fully harvesting the green potential of EVs and PHEVs on a macro level also means that the methodology of the regulation on CO_2 from cars needs to be modified to ensure that a shift to EVs and PHEVs leads to a reduction of energy use (and oil consumption) in the transport sector. A number of options are provided in section 5.3.2

Micro level

In addition, a number of micro policy routes can be identified to help clear the way for more macro-type policies and renewable energy developments and to allow consumers, businesses and governments to help improve the sustainability of EV and PHEV battery charging. For example, government

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[33] There is debate about the effectiveness of CDM projects, which we will not go into here. The share of CDM is limited in the ETS, so part of the extra CO_2 emissions will have to be compensated within the ETS.

policies or car dealers may promote voluntary purchases of green electricity by electric car owners (frontrunner programme). Electricity suppliers, (local) governments and companies that own parking spaces may ensure that charging points for electric cars are charged with renewable electricity while individual car owners that charge their cars at home can opt for renewable electricity.

6.3.1 EU level

The EU has recently decided on a number of policies for the period until 2020: the ETS, RED and FQD directives and CO_2 from cars regulations. These are key conditions for the future market introduction of EVs and PHEVs. As long as the share of electricity used in road transport is low, these policies are expected to work properly. However, they do not seem well suited for higher shares of EVs and PHEVs.

We therefore recommend a number of methodological improvements for these directives.

- The RED and the FQD could be further improved by allowing member states (RED) or fuel suppliers (FQD) to include actual data on renewable electricity used for charging of EVs and PHEVs, rather than taking the average renewable power production mix in the case of RED or the average carbon intensity in the case of FQD.
- In the regulation on CO_2 from cars, more realistic methods should be used to ensure that they are based on the actual energy use and related CO_2 emissions. A number of potential options are provided in chapter 5, such as using the average (or actual) CO_2 emissions of electricity production, in combination with measurements of the energy use per kilometre, or setting specific efficiency targets for EVs.

Setting up a methodology (and technology) for accurate measuring of the electricity use of EVs and PHEVs, both at type approval and during actual use, seem to be a prerequisite for longer term improvements of these directives.

The EU can also actively contribute to harvesting the potential that the batteries in EVs and PHEVs offer for demand-side management in a future of much higher shares of fluctuating and ‘must-run’ renewable energy supply. The infrastructure that supports these possibilities needs to be developed, as well as standards for metering, smart grids and (perhaps in the longer term) Vehicle-to-Grid concepts. We also recommend the further assessment of these possibilities along with a comparison of costs and feasibility with alternatives such as increased interconnectivity and other types of energy storage. These issues are important regarding the future energy system and deserve EU-level incentives. Providing standards and regulations for metering and, in the near future, smart metering can also support these developments. Questions for further research could be: what does this mean for smart metering and power grid characteristic and standards, what are the requirements for the batteries, and what are the costs and implications, compared with the alternatives?

In addition, the EU may also set up information campaigns aimed at the various market players in order to raise awareness of the potential of greening transport with renewable electricity, and to encourage them to contribute to the target.

6.3.2 National level

If the policy target is to ensure that the additional electricity consumption of EVs and PHEVs is 100% from renewable sources, we recommend national governments to implement macro policy measures targeting 100% additional green electricity production for all electricity consumed by EVs and PHEVs.

These can be implemented as government targets or as market regulations (e.g., imposed on energy companies). The existing renewable energy targets would then have to be increased by the amount of electricity consumed by road transport.

The electricity consumption of EVs and PHEVs then needs to be monitored and estimated, by:

- Counting the number of EVs and PHEVs, and multiply this by an average annual electricity use of these vehicles. Or
- By separate metering and monitoring either in the EVs and PHEVs itself or at charging points.

The first option will be easier and cheaper, but metering and monitoring of individual cars and/or charging points fits in the two-way communication (smart grids and smart metering) described above. It can thus be an enabler for the transformation of the electric infrastructure to accommodate a large share of renewables.

In addition to these macro type policies, member states may also consider implementing a number of policy measures that may be somewhat less effective but are relatively easy to implement. For example, governments may grant subsidies or tax reductions to parties who contribute to the target of 100% renewable electricity for cars. These policies might target companies, cities or households with charging points. In addition, governments may aim to make voluntary agreements with market parties (e.g., car dealers) to contribute to the aim of driving on renewable electricity. Also, national governments may actively support research into and development of a strategy for a ‘truly green electricity sector’, as described above, promoting the integration of EVs and PHEVs with renewable electricity production.

6.3.3 Other parties

Car manufacturers may consider taking measures to encourage consumers to charge their EVs and PHEVs with renewable energy, for example by offering information about renewable energy to car buyers, or by working together with energy suppliers, making attractive offers to car buyers. They may also think of more innovative means, for example, by offering shares to EV buyers in a newly built wind farm.

Local governments and companies that offer dedicated charging points for EVs and PHEVs can ensure that the electricity at these points is from renewable sources by the purchase of guarantees of origin (GOs). They may also implement information campaigns regarding the potential of renewable electricity for EVs and PHEVs.

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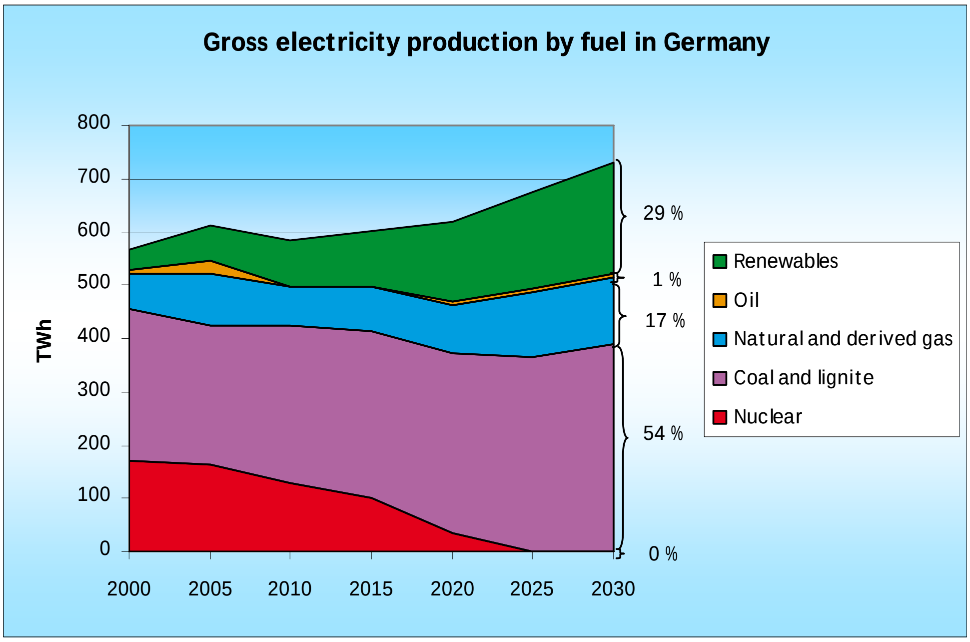
Annex A Case study 1: Germany

A.1 Current electricity generation and developments until 2020

Figure 20 gives an overview of expected electricity generation in Germany from 2000 until 2030, given the current EU legislation and with RES trading and CDM/JI. The main sources in 2005 were coal/lignite and nuclear power, amounting to approximately 75% of electricity production (IEA, 2006). The contribution of renewables is steadily growing, up to 29% in 2030.

Figure 20 **Gross electricity production (in TWh/yr) by fuel, Germany**



Source: Capros et al., 2008.

In Germany renewable electricity contributes to 15.1% of total electricity consumption (2007), 6.4% of which is wind energy. According to the renewables directive, the share of *renewable energy* in total energy consumption will have to increase to 18% by 2020 in order to meet the target. This means that the share of *renewable electricity* will have to grow to between 35 and 40%.

Developments through to 2030 are highly uncertain. Legislation will mean the closure of all nuclear power plants[34]. A steady ongoing growth of renewable sources can be expected (e.g., 25 GW offshore wind energy in 2030) but also

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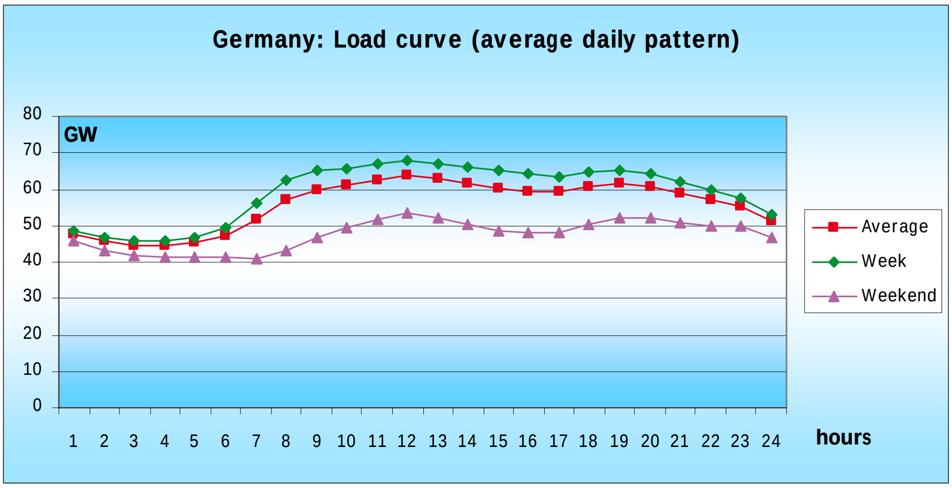
[34] Capros et al. takes into account this political agreement on phasing out nuclear energy. Discussion on this agreement was reopened again recently. If the outcome of this is different, this might influence the analysis.

plans are being launched for new coal-fired power plants[35]. At the same time it might be expected that some of the older inefficient lignite/coal-fired power plants will reach the end of their lifetime and be closed. Finally, interconnection capacity is expected to increase, for instance between the Netherlands and Norway[36].

In order to give some insight into the way the electricity demand in Germany is met by the various power plants, we first look at the average pattern of electricity demand during the week and in the weekend (see Figure 21). The highest demands are during the week between approximately 08:00 and 20:00. At night demands are about 30% lower.

Figure 21 **Load curve, Germany**[37]



Source: Entsoe, 2009.

If we combine the technically available generation capacity in Germany for 2006 with Figure 21, which depicts the average electricity demand during the day, we get Figure 22 with the following load curve.

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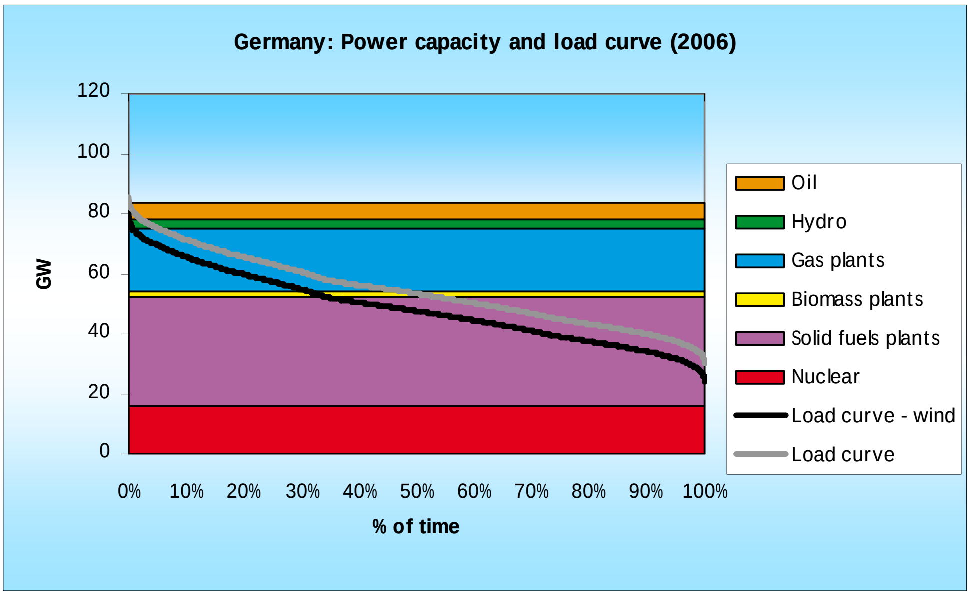
[35] It involves approximately 30 lignite or coal-fired plants totalling over 31,000 MW (source: http://www.bund.net/bundnet/themen_und_projekte/klima_energie/kohlekraftwerke_stoppen/geplante_standorte/).

[36] See for example: http://www.slideshare.net/Hakvoort/Investments-in-electricity-interconnections.

[37] The figure depicts the average daily load curve. In reality the load curve in winter e.g. will have a higher peak and base load demand.

Figure 22 **Power capacity available for meeting demand and load curve 2006, Germany**



Source: Power capacity based on Capros et al. (2008) and IEA (2009); load curves based on Entsoe (2009).

The load curve indicates the percentage of time in a year that minimum capacity demand occurs. Figure 22 reveals that the minimum capacity demand, which occurs all year round (100% of the time), is approximately 30 GW, the so-called ‘base load’ demand. A second load curve is shown which is corrected for the annually available supply-driven (must-run) wind capacity[38]. This second load curve therefore gives insight into the net electricity demand that has to be met by demand-driven generation capacity. Figure 22 also gives insight into the production capacity which is available to meet demand whereby it is assumed that that the installed power plants run with a load factor of about 90% (this means that the plants run 90% of the time during a year). For example, nuclear energy, and partly capacity from solid fuel plants (coal/lignite), provides capacity to meet demand that has to be provided by demand-driven sources 100% of the time (‘base load’). Hereby we assume that the 90% of installed capacity is available throughout the year and the only time a plant is shut down is because of maintenance. Distribution losses, electricity uses of the energy sector and exports are taken into account.

The merit order (ranking order) of the power plants, which will meet the demand, is based on the degree of flexibility and marginal cost for providing the marginal unit(s) of extra electricity demand at a specific moment in time. In general, the must-run and cheapest alternative options provide base load and if capacity demand increases, other installed capacity will be switched on, or power plant capacity will be increased[39].

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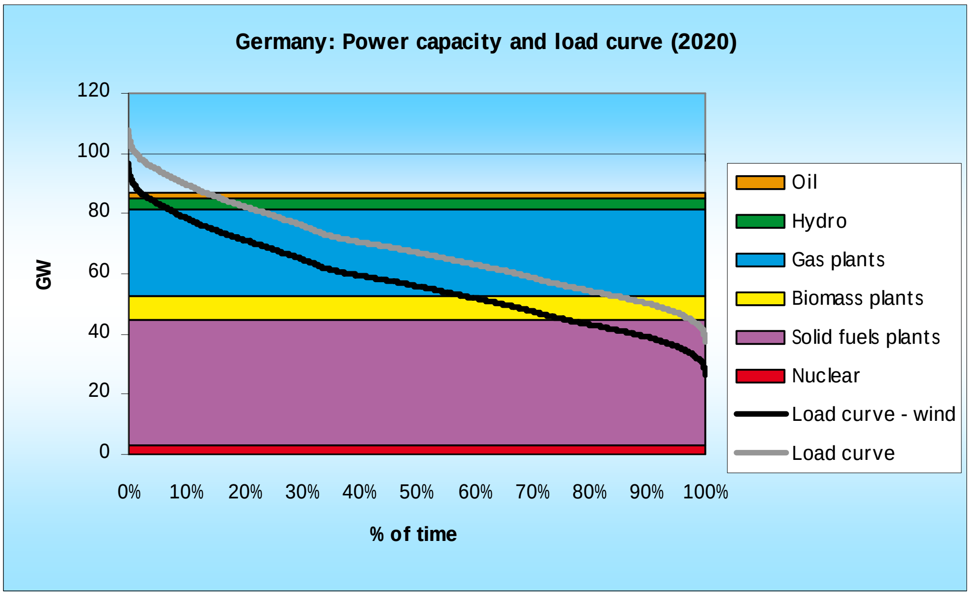
[38] In Germany the ‘must-run’ character also has a legal status in the sense that wind electricity gets priority access to the grid.

[39] The reason lignite/coal-fired power plants provide base load is also related to the fact that switching them on and off is relatively inefficient, expensive and time-consuming.

Gas turbine power plants are often more flexible in meeting short-term fluctuations than, for example, lignite/coal-fired power plants[40]. Also the 'must-run' character of different sources can make production capacity inflexible[41]. In Germany nuclear plants are being ramped down as (predicted) production from renewable sources rises since this production capacity has priority access to the grid and the increasing share of wind energy has a must-run character.

In Figure 23 below the expected load curves and production capacities for the year 2020 are given.

Figure 23 **Power capacity available for consumption and load curve 2020, Germany**



Source: Power capacity based on Capros et al. (2008) and IEA (2009), load curves based on Entsoe (2009) with the assumption that the electricity consumption will increase by 2%/yr until 2010 and by 1.5%/yr from 2010-2020.

Clearly, the amount of time that biomass production capacity contributes to meeting the electricity demand, for instance, is much greater than in Figure 22 due to the growing share of renewable energy.

A.2 Effects of electric vehicles on power supply

Given the composition of the production park in Germany, it seems reasonable to assume that during base load hours coal, lignite and nuclear energy will be the main sources to meet the extra (marginal) electricity demand of electric vehicles. From an integral perspective, part of the electricity mix being produced and fed into the electric vehicles might come from wind energy,

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[40] This is not the case for every gas-fired power plant though. CCGT plants need some time to start up (one or two hours). When running, they can be quite responsive in ramping up and down between full load and partial load but their efficiency deteriorates more quickly at part loads than that of most coal plants, and most CCGT plants become operationally unstable once they fall to between 50% and 70% of full load.

[41] If, for example, a CCGT (combined gas fired power plant) is producing heat it will also be producing 'must-run' electricity.

whenever available (see section 4.3). As long as the electricity generated by wind farms does not exceed the electricity demand at any given point in time, wind energy will not provide the electricity necessary for extra electricity demand from electric cars.

Given the dominant position of coal and lignite, these might also play an important role as a marginal source in peak hours[42]. In addition, gas might deliver the electricity required during peak hours. As indicated before, some types of gas-fired power plants (single cycle gas turbine plants) have the advantage of being flexibly available, making them suitable for peak hours as well as for compensating electricity production from renewable sources when these are not available.

As explained in the previous chapter, we distinguish three scenarios for the growth of the amount of electric cars:

1. Moderate/medium uptake scenario.
2. Fast uptake scenario.
3. Ultra-fast EV scenario.

Table 8 **Effect of the three scenarios for the growth of the amount of electric cars in Germany, for 2020**

	Moderate/medium uptake		Fast uptake		Ultra-fast EV	
	EV	PHEV	EV	PHEV	EV	PHEV
Number of cars (million)[43]	0.1	0.3	1	3,1	5	1,3
Electr. needed (GWh)	1.972		19.472		17.222	
% El. production (2007)	+0.3%		+3.0%		+2.7%	
Power needed (GW)	0.2		2.2		2.0	

As shown in Table 8 the additional electricity consumption for electric cars in Germany in 2020 will be in the range of 0.3% to 3% of the German electricity production in 2007[44]. The additional electric power needed, as given in Table 8, is the capacity needed if charging cars is spread evenly over the entire day. So every hour of the day 1/24 of the electric car fleet is being charged. In practice, this will not be a realistic assumption since car charging will probably be concentrated at certain time intervals: when everybody gets home at 18:00, during the working day, or at night. To get better insight into the effects of different charging scenarios we distinguish two scenarios for extra electricity demand of electric cars:

1. An increasing electricity demand as depicted in Table 8 during peak hours (08:00–20:00).
2. An increasing electricity demand as depicted in Table 8 at night (24:00–08:00).

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[42] This capacity comes from old lignite plants that are relatively energy inefficient (< 30%). In the merit order they compete with gas-fired power plants, (see also: WWF, 2008).

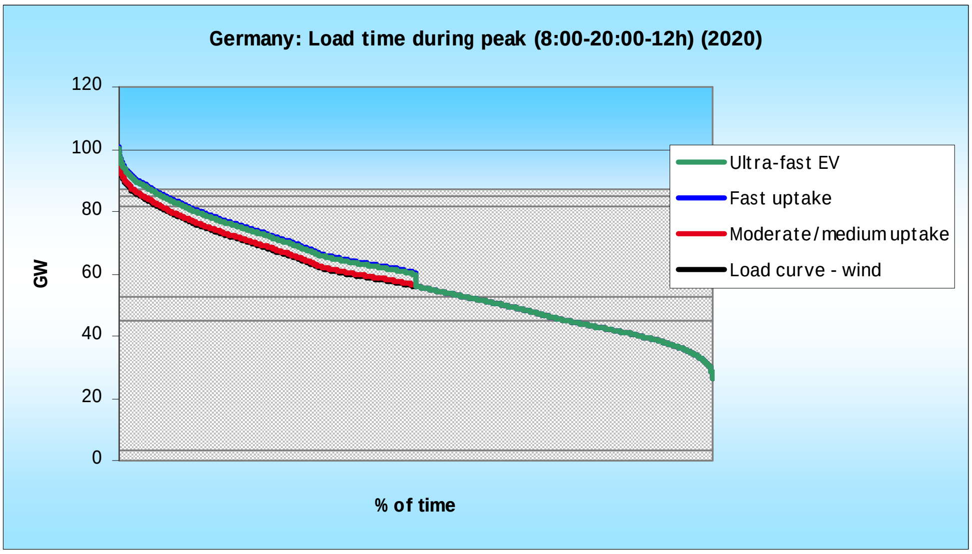
[43] Total number of cars (total car fleet) assumed in the different scenarios in 2020.

[44] The reason that the PHEV scenario leads to more electricity needed than the Fast EV scenario has to do with the assumption that EVs are substantially more efficient in electricity use than the PHEV (source: Athlon: http://www.athloncarlease.com/athlon-nl/).

1. Peak hours

If the EVs and PHEVs are being charged during peak hours, this will lead to extra electricity demand from electric vehicles of 0.5–4.4 GW in peak hours and result in a total capacity demand of approximately 55–100 GW during peak hours (Figure 24).

Figure 24 Peak load time, Germany



We foresee the following possible developments in meeting additional electricity demand from electric vehicles during peak hours:

1. More production from existing *low efficient* lignite/coal-fired power plants.
   The marginal costs from these plants are relatively high compared to more modern plants. They will be set for full operation.
2. More electricity production from gas fired power plants.
   Most gas fired power plants are suited for delivering peak electricity[45]. When electricity demand in peak hours cannot be met by the existing park, new gas fired power plants are likely to be built. As long as wind energy capacity is not sufficient to become a demand driven source, wind energy will not be the marginal power plant for fully supplying the electricity for peak load demand from electric vehicles (see section 4.3). In the future (after 2020), with smart metering or electricity storage, for example, in the batteries of electric cars[46], wind energy and other renewable sources may become a more important source of peak load supply for electric cars.
3. An increase of interconnection capacity.
   Interconnection capacity is expected to increase and might be used especially to meet peak hour demand. This interconnection capacity might come from renewable sources (e.g., hydro power from Norway).

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[45] To some extent modern coal-fired power plants are also able to provide flexibility when necessary.

[46] See also: Electric Vehicles' contributions to reaching EU policy goals, recommendations and the ongoing standardisation initiative (2009, Eurelectric).

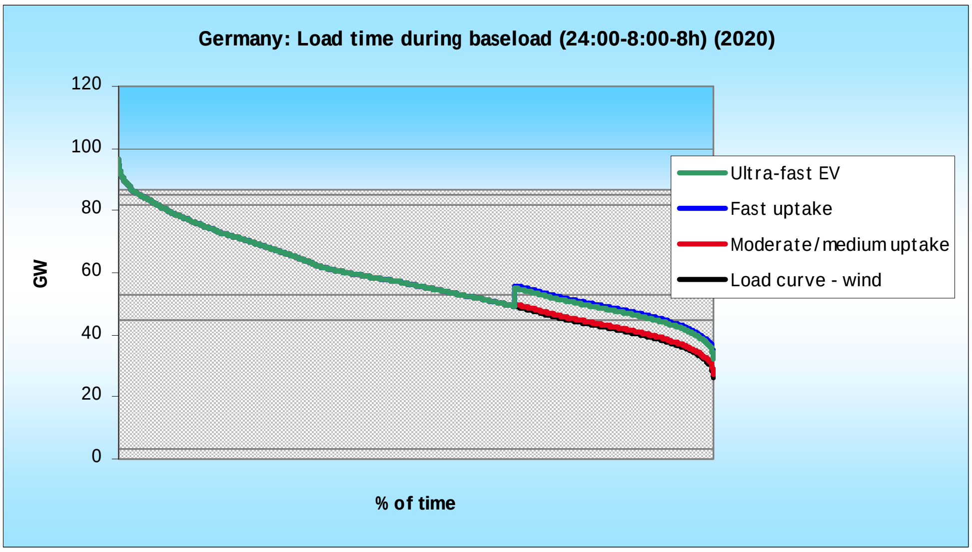
In the first option, the demand by electric cars will result in substantial CO_2 emissions as a result of the high CO_2 emissions from low-efficient lignite/coal-fired power plants (see chapter 3). Also, air pollution from older plants is higher than air pollution from more modern plants, which will have a negative environmental effect. In the second option, net CO_2 emissions will be substantially lower. For the third option, extra emissions depend on the source of electricity production in the country of origin. Renewable sources (i.e., hydro power from Norway) will result in negligible emissions and coal-fired electricity production in substantial emissions.

The expectation is that since the share of renewables is growing, it is likely that peak demand in 2020 and beyond will be met more and more by electricity production from renewable sources like wind capacity, which can be switched off (in Germany itself), in combination with gas-fired power plants/modern coal plants (perhaps with CCS) or interconnection capacity.

2. Base load hours

Extra electricity demand of 0.7-6.7 GW from electric vehicles during base load hours will result in a total capacity demand of approximately 25-55 GW during base load hours (Figure 25).

Figure 25 **Load time during base load, Germany**



In base load hours we expect that low-efficient coal and lignite-fired power plants will be the main source for the extra electricity needed to meet demand from electric vehicles. Given the large net CO_2 emissions of these power plants, this will result in substantial emissions of CO_2.

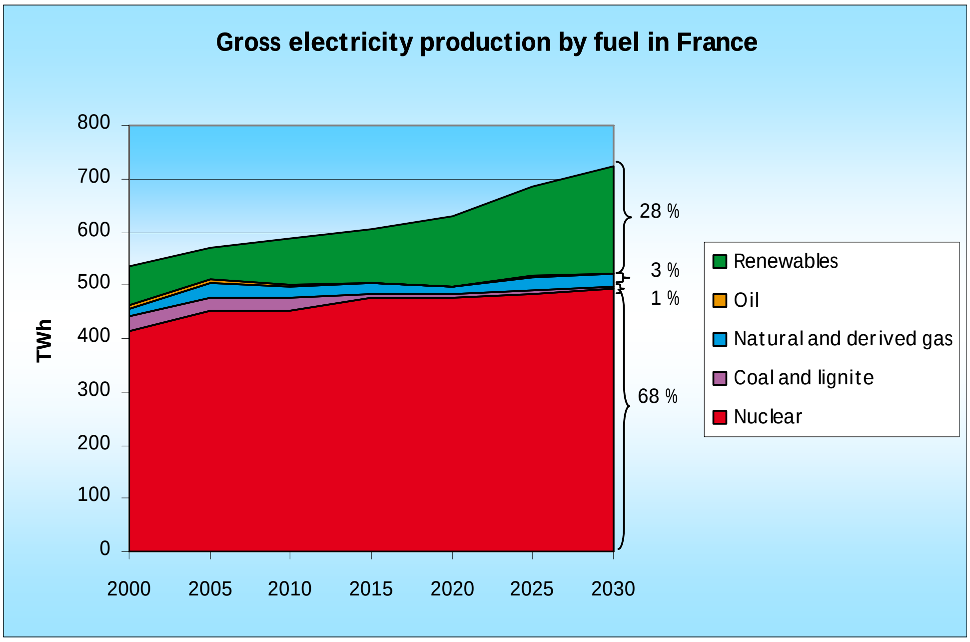
Given the growing capacity in Germany, large-scale renewable (wind) energy is also expected to become an important source in meeting integral additional electricity demand from electric cars due to its must-run character and priority access to the grid (see also section 4.3).

Annex B Case study 2: France

B.1 Current electricity generation and developments until 2020

As shown in Figure 26 nuclear power is the main source of electricity production in France, contributing 76% of total electricity production (Capros et al., 2008). Electricity production in France is mainly controlled by one company, Électricité de France (EDF), but some new companies have also entered the market (e.g. POWEO, GDF SUEZ). Electricity production in France exceeds domestic consumption, resulting in global net exports, but imports are increasing due to a chronic deficit of electricity in certain peak hour periods during the winter. Forecasts of POLES estimate the following composition of electricity production in France in 2020 and 2030 and a share of 28% of renewable electricity in 2030 (Figure 26).

Figure 26 **Gross electricity production (in TWh/yr) by fuel, France**



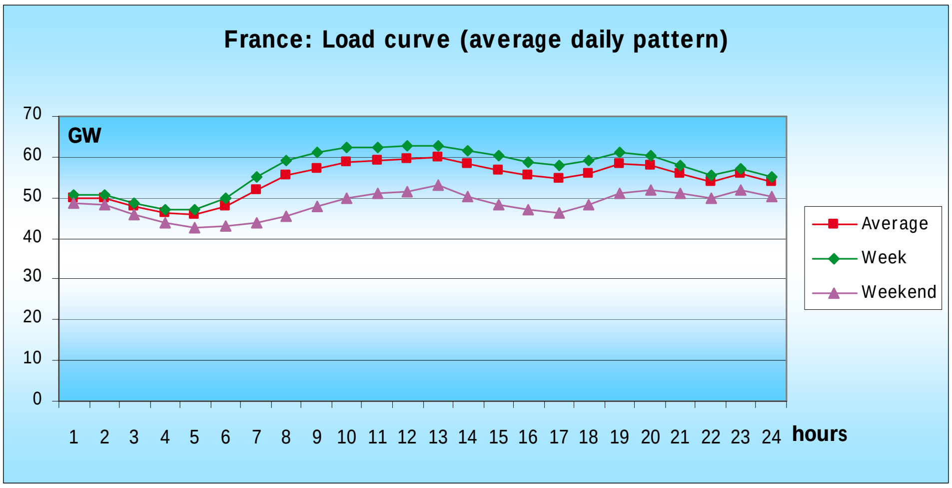
Source: Capros et al., 2008.

In France renewable energy is 13.3% of total electricity consumption (2007) and 10.1% of this is large hydro. According to the renewables directive, the share of *renewable energy* in total energy consumption will have to increase to 23% by 2020 in order to meet the target. This means the share of *renewable electricity* will have to grow to between 35 and 40%.
A large part of the nuclear power production park was built in the 1960s and 1970s, indicating that several installations are reaching the end of their lifetime. In the coming years upgrades or closures can be expected. One large new 1,650 MWe nuclear power plant is being built in Flamanville (expected

year of completion: 2012)[47] and another one is being planned. This illustrates that in France nuclear power remains an important source of power production. Also, half of the coal-fired power plants will have to shut down before 2015[48].

In order to give some insight into the way the electricity demand in France is met we first look at the average pattern of electricity demand during the week and in the weekend (Figure 27). The highest demands are during the week between approximately 08:00 and 20:00. At night demands are about 23% lower.

Figure 27 Load curve, France[49]



Source: Entsoe, 2009.

If we combine the technically available generation capacity in France for 2006 with Figure 28, which depicts the average electricity demand during the day, we get Figure 28 with the following load curve.

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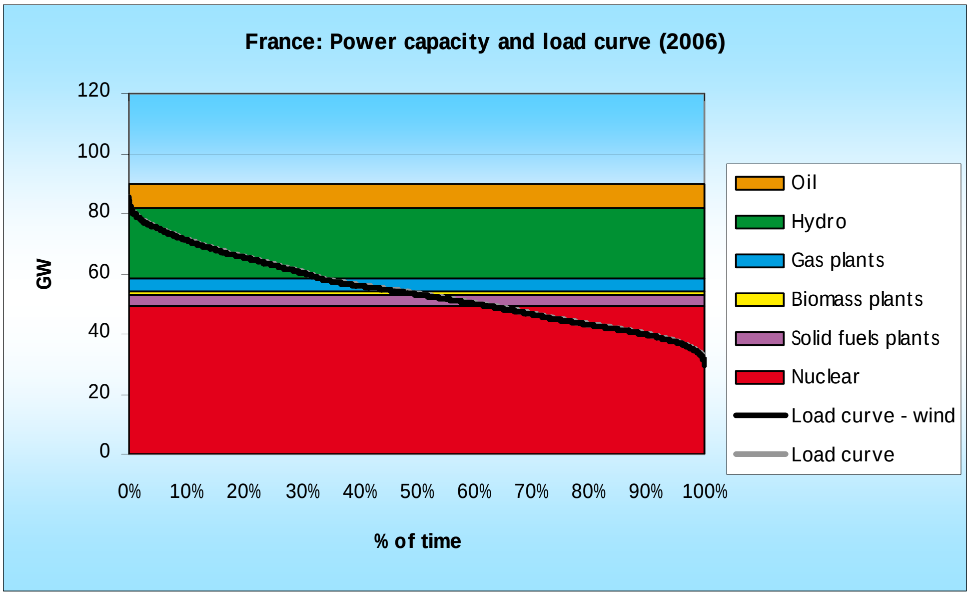
[47] Also see: http://www.economist.com/displayStory.cfm?story_id=12832060.

[48] Source : PPI 2009. http://www.developpement-durable.gouv.fr/energie/politiqu/synthese_commune_2009.pdf.

[49] The figure depicts the average daily load curve. In reality the pattern of the load curve in winter will be influenced, for instance, by increasing electricity demand due to electric heating and in summer due to increasing electricity demand for air conditioning.

Figure 28 Power capacity available for consumption and load curve 2006, France



Source: Power capacity based on Capros et al. (2008) and IEA (2009), load curves based on Entsoe (2009).

As can be seen from Figure 28 the minimum capacity demand ('base load' demand), which occurs all year round (100% of the time), is approximately 30 GW.

The Figure shows that for nuclear power the largest part of the production park (approximately 30 GW) provides capacity for demand that has to be met by demand-drive sources 100% of the time. Hydro provides production capacity to meet demand for approximately 35% of the time. As described earlier (case study Germany), we assume that 90% of installed capacity is available throughout the year and the only time a plant is shut down is because of maintenance[50]. Distribution losses, electricity uses of the energy sector and exports are taken into account.

As described earlier, the merit order (ranking order) of the power plants, which will meet the demand, is based on the degree of flexibility and marginal cost for providing the marginal unit(s) of extra electricity demand at a specific moment in time. In general, the least flexible and cheap options provide base load and if capacity demand increases other installed capacity will be switched on, or power plant capacity will be increased. Gas-fired plants are often more flexible in meeting short-term fluctuations than, for example, nuclear or lignite/coal-fired power plants[51]. Also the 'must-run' character of different sources plays a role in making production capacity inflexible[52]. In

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[50] In reality available nuclear capacity lies around 83% instead of 90% (Source: http://www.senat.fr/rap/r06-357-1/r06-357-117.html)

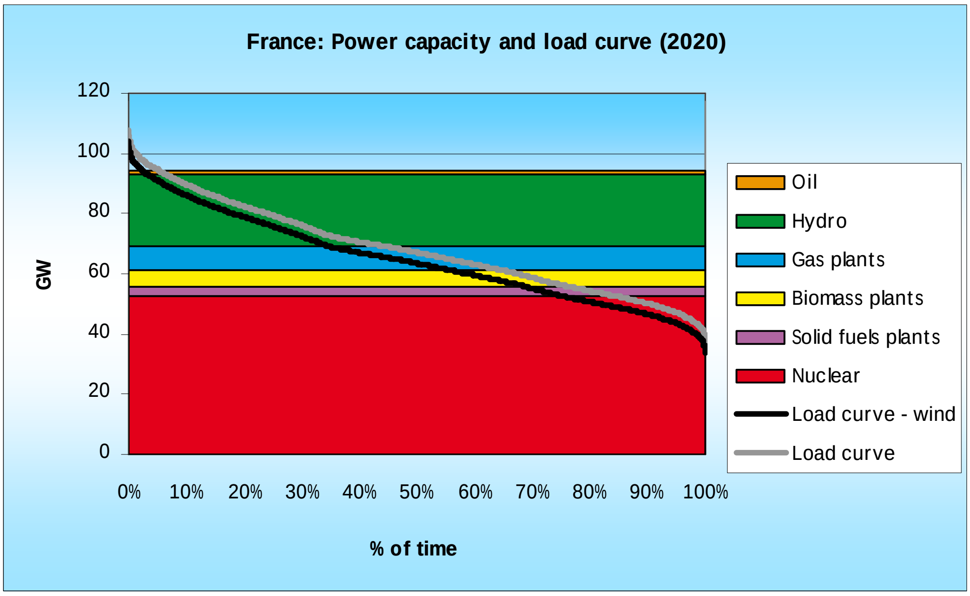
[51] This is not the case for every gas-fired power plant though. CCGT plants need some time to start up (one or two hours). When running, they can be quite responsive in ramping up and down between full load and partial load, but their efficiency deteriorates more quickly at part loads than that of most coal plants, and most CCGT plants become operationally unstable once you fall to between 50% and 70% of full load.

[52] If, for example, a CCGT (combined gas-fired power plant) is producing heat it will also be producing electricity. This is called 'must-run'.

France nuclear, hydro and wind energy (when available) are the main supply sources for base load electricity demand (they come first in the merit order), followed by coal, gas and oil-fired power plants. Pump storage hydro is used to meet very short and high peak demands.

In Figure 29 below the expected load curves and production capacities for the year 2020 are given.

Figure 29 **Power capacity available for consumption and load curve 2020, France**



Source: Power capacity based on Capros et al. (2008) and IEA (2009), load curves based on Entsoe (2009) with the assumption that the electricity consumption will increase by 2%/yr until 2010 and by 1.5%/yr from 2010-2020.

B.2 Effects of electric vehicles on power supply

Given the dominant position of nuclear power in power production in France, it seems reasonable that in peak - as well as in base load hours - nuclear energy will be the main source of electricity supply, followed by hydro and wind energy[53] (base load).

We distinguish three scenarios for the growth of the number of electric cars:
1. Moderate/medium uptake scenario.
2. Fast uptake scenario.
3. Ultra-fast EV scenario.

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[53] See also: http://clients.rte-france.com/lang/fr/visiteurs/vie/vie_stats_conso_inst.jsp for more information on merit orders and relative (marginal) costs.

Table 9 **Effect of the three scenarios for the growth of electric cars in France**

	Moderate/medium uptake		Fast uptake		Ultra-fast EV	
	EV	PHEV	EV	PHEV	EV	PHEV
Number of cars (million)	0.1	0.2	0.7	2.3	3.8	1.0
Electr. needed (GWh)	1,250		13,111		11,083	
%El. Production (2007)	+ 0.2%		+ 2.3%		+ 1.9%	
Power needed (GW)	0.1		1.5		1.3	

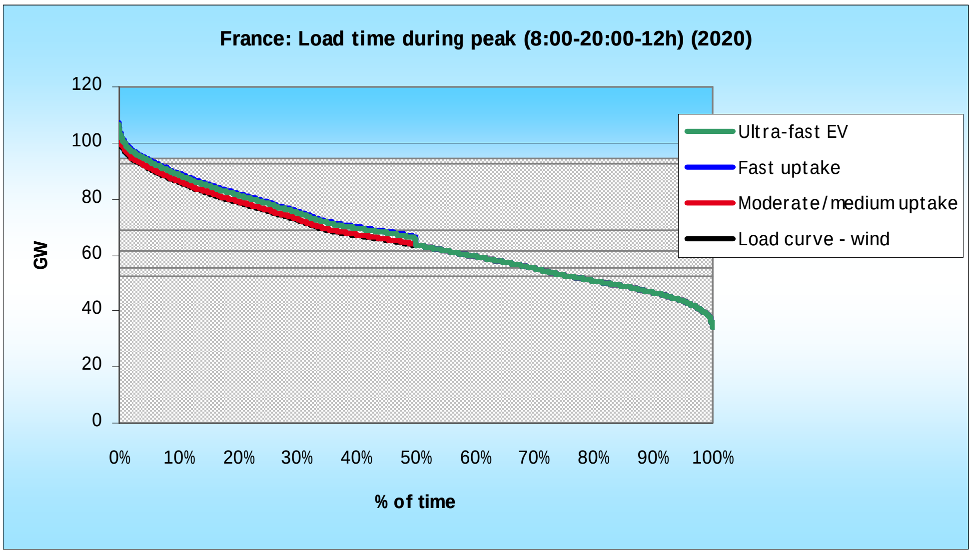
As shown in Table 9, the additional electricity consumption for electric cars in France in 2020 will be in the range of 0.2 to 2.3% of the French electricity production in 2007.
The additional electrical power needed as given in Table 9 is the capacity if the charging of cars is spread evenly over the entire day. So every hour of the day 1/24 part of the electric car fleet is charged. In practice, this will not be a realistic assumption since car charging will probably be concentrated at certain time intervals: when everybody gets home at 18:00, during the working day, or at night. To get better insight into the effects of different charging scenarios we distinguish two scenarios for extra electricity demand of electric cars:

1. An increasing electricity demand as depicted in Table 9 during peak hours (08:00–20:00).
2. An increasing electricity demand as depicted in Table 9 at night (24:00–08:00).

1. Peak hours

An extra electricity demand from electric vehicles of 0.3–3.0 GW in peak-hours will result in total capacity demand of approximately 65-110 GW during peak hours (Figure 30).

Figure 30 **Load time during peak hours, France**

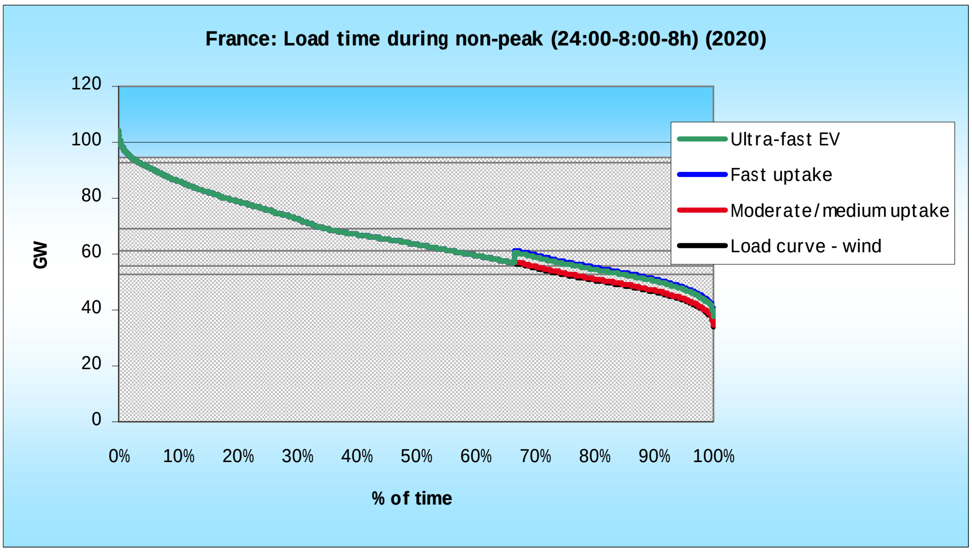


Although it remains difficult to predict which types of electricity generation will meet extra electricity demand in peak hours, we expect that extra electricity demands will most likely be met by additional production from the present park (mainly nuclear energy). In this respect, the fact that new nuclear power plants of the third generation are better equipped for flexible power generation might be an important development('Delta Energie, startnotitie MER kerncentrale Borsele', 2009). Also pump storage hydro is used for very short and high peak periods. It is possible that renewable energy will contribute to increasing electricity demand. However, renewable energy will have to compete with nuclear capacity but controllable renewable capacity, like hydro power, is not (yet) sufficient to meet demand that exceeds the (minimum) base load level. Therefore, it cannot be said that controllable renewable capacity can fully supply the electricity for peak load demand from electric vehicles. Furthermore, wind energy cannot provide peak load capacity since (at this moment) it is a non controllable (must-run) source (see section 4.3.). At the moment, during the winter period there are some days when electricity consumption (demand) exceeds electricity generation from nuclear and renewables. Also, all year long there are some daytime hours when electricity demand exceeds carbon neutral electricity generation (mostly nuclear) due to air-conditioning in the summer and electric heating in the winter. This means that additional generation from other (flexible) plants (gas, coal and oil) will be necessary to meet demand. As electricity demand grows, this share could increase if not enough renewable alternatives become available[54]. In that case there will be a negative influence on CO_2 emissions.

2. Base load hours

Extra electricity demand of 0.4–4.5 GW from electric cars in base load hours will result in total capacity demand of approximately 35-60 GW during base load hours (Figure 31).

Figure 31 **Load time during base load hours, France**



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[54] Enjeux, consommations électriques, emissions CO_2 des transports électriques à l'horizon 2020 – 2030 (ADEME, 2009) and Strategies et Etudes n°21 at http://www2.ademe.fr/servlet/getBin?name=31AAD5B85646E545182A56FB00F480061248947993001.pdf.

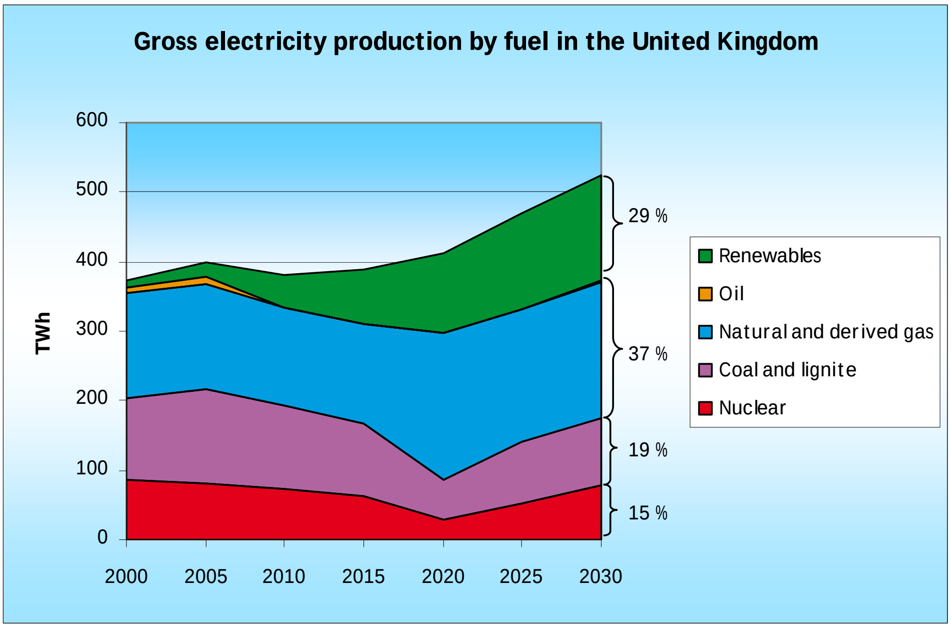
Higher demand during base load hours can be expected to be met mainly by electricity generated by nuclear power. It is possible that renewable energy will contribute to an increasing electricity demand (integral electricity mix). However, as stated before, renewable energy will have to compete with nuclear capacity. It is expected that must-run wind capacity will become relatively more important (growing share in integral electricity mix meeting base load demand).

Annex C Case study 3: United Kingdom

C.1 Current electricity generation and developments until 2020

Figure 32 shows the contribution of different sources to electricity production in the UK. Nuclear, coal and gas-fired plants make up the largest share in electricity production. From the 1980s onwards electricity generation by gas-fired power plants has increased in the UK due to the discovery of gas in the British part of the North Sea. The share of renewable electricity, mainly electricity from wind energy, is projected to increase to 29% by 2030.

Figure 32 **Gross electricity production (in TWh/yr) by fuel, United Kingdom**



Source: Capros et al, 2008.

Due to The Large Combustion Plant Directive (LCP directive) old oil and coal-fired plants will be expected to shut down (early) around 2015 or so because they do not meet modern air pollution requirements[55]. It is expected that, until 2020, 20 GW of installed coal and nuclear capacity will be shut down because they are at the end of their (economic) lifespan. It is estimated that this capacity will be replaced by 32 GW of wind energy capacity, 11 GW of gas-fired production capacity, 3 GW from new coal plants (probably with partial CCS)[56] and 3 GW from new nuclear plants.

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[55] The LCP directive is currently being revised, however, which might mean that shut-downs could be postponed, depending on the outcome.

[56] Another source mentions a figure of over 9 GW of newly installed coal-fired capacity based on a survey, a difference can probably be explained by the fact that the survey was partly based on requests for connection capacity. This could lead to double counting if an investor requests connection capacity for the same plant at different locations. The expectation is that any new coal plant will have to capture approx 25% of its emissions (there is currently an ongoing debate on this issue).

The likely composition of the production park in 2020 is shown in Table 10.

Table 10 **Composition of UK installed electricity generation capacity**

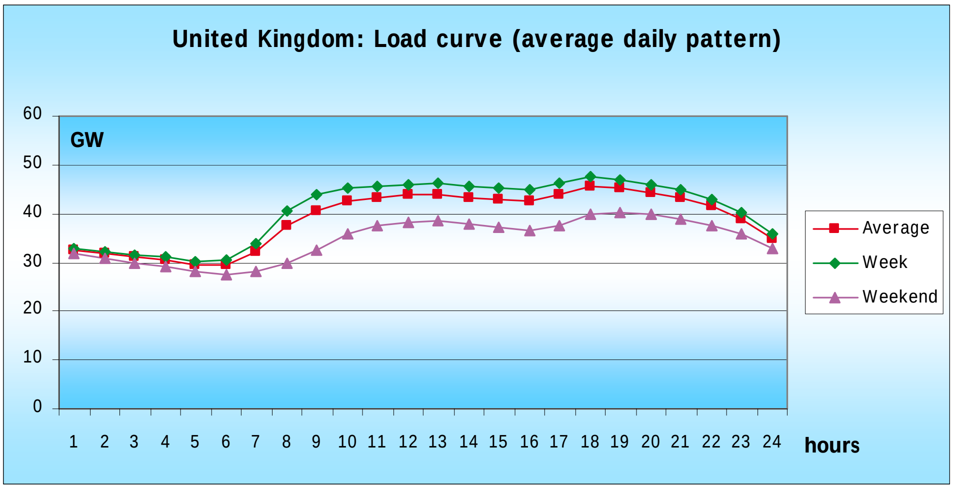
Type of production capacity	Installed capacity in GW in 2020
Gas fired	43
Wind energy	27 (around 20 GW off shore)
Coal (with CCS)	7
Biomass	12
Nuclear	4
Other (wave/tidal energy, pump storage hydro)	11
Total	**106**

In the UK renewable electricity now contributes to 5.1% of total electricity consumption (2007) of which 1.3% is wind energy, the rest being from landfill gas and old hydro-electric plants. Currently substantial investments are planned and being made in wind energy, especially offshore in the North Sea (around 20 GW). It can be expected that in the UK, wind energy will be the dominant source of renewables. According to the renewables directive, the share of *renewable energy* will have to increase to 15% by 2020. It is expected that around 30% of *electricity generation*, and perhaps more, will have to come from renewable sources to meet this target.

It is also accepted, and indeed the case, that there is no technical barrier to the amount of renewables that can be connected to the grid. There may be additional modest costs. Also the national grid is able to manage fluctuating input from wind power as the electricity system is already designed to manage fluctuations in supply and demand as well as planned and unplanned outages from intermittent power plants such as coal and nuclear power.

In order to give some insight into the way the electricity demand in the UK is met we first look at the average pattern of electricity demand during the week and in the weekend (see Figure 33). The highest demands are during the week between approximately 08:00 and 20:00. At night demands are about 35% lower.

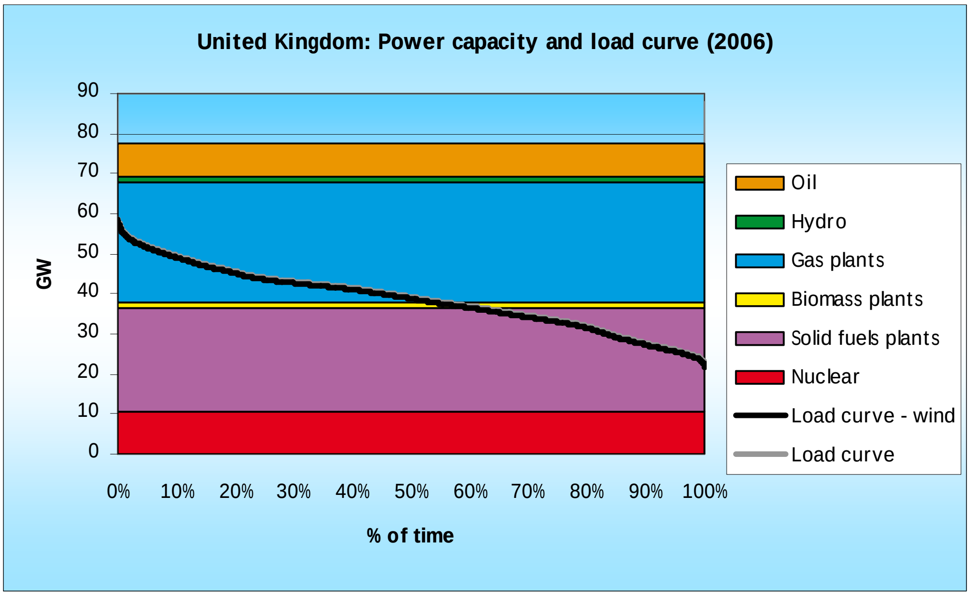
Figure 33 **Load curve United Kingdom**



Source: National Grid, 2009.

If we combine the technically available generation capacity in the UK for 2006 with Figure 33, which depicts the average electricity demand during the day, we get Figure 34 with the following load curve.

Figure 34 **Power capacity available for consumption and load curve 2006 in the UK**



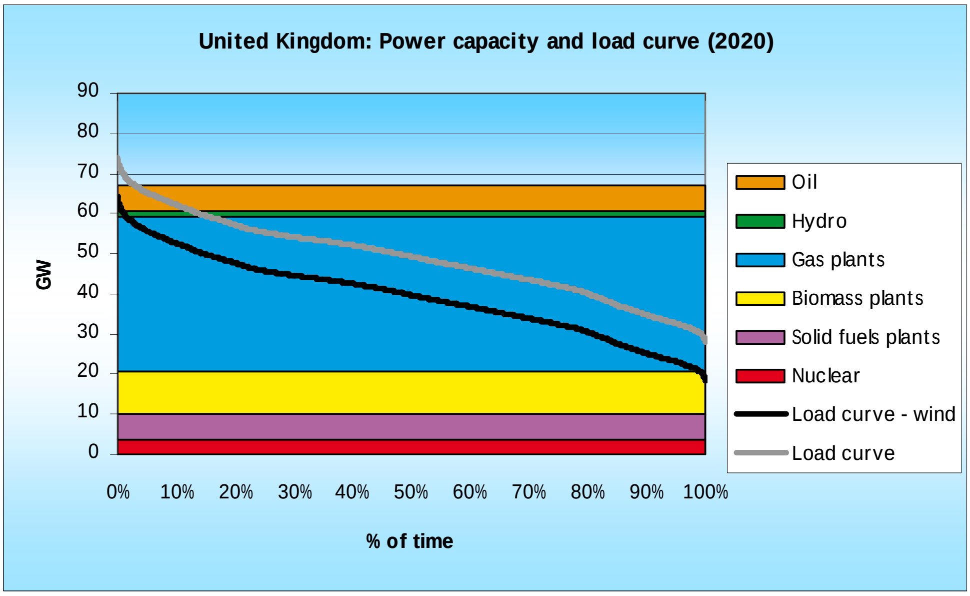
Source: Power capacity based on Capros et al. (2008) and IEA (2009), load curves based on Entsoe (2009).

As can be seen from Figure 34 the minimum capacity demand, which occurs all year round (100% of the time), is approximately 20 GW. This is the so called base load demand. Figure 34 shows that nuclear energy provides capacity for demand that has to be met by demand driven sources 100% of the time, as well as part of the capacity of solid fuel plants (approximately 10 GW). As described earlier we assume that the 90% of installed capacity is available throughout the year and the only time a plant is shut down is because of maintenance. Distribution losses, electricity uses of the energy sector and exports are taken into account.

In the UK nuclear and coal-fired power plants are the main sources to provide base load electricity demand (coming first in the merit order, after wind energy must-run, if available). After that increasing demand is met by gas and oil-fired power plants.

In Figure 35 below the expected load curves and production capacities for the year 2020 are given.

Figure 35 Power capacity available for consumption and load curve 2020 in the UK



Source: Power capacity based on Capros et al. (2008) and IEA (2009), load curves based on Entsoe (2009) with the assumption that the electricity consumption will increase by 2%/yr until 2010 and by 1.5%/yr from 2010-2020.

C.2 Effects of electric vehicles on power supply

Given the composition of electricity supply in the UK, it seems reasonable to expect coal, gas, renewables and nuclear power to supply extra electricity needed to feed electric vehicles when their electricity demand grows[57].

At any given moment in (charging) time the origin of the electricity fed into the cars will depend on the availability and marginal costs at that specific moment. Due to a growing share of must-run wind capacity, in combination with priority access to the grid, charging cars when it is windy will lead to a growing share of integral electricity demand from electric cars being met by wind energy. However, wind energy will not be the marginal source (see section 4.3). The relatively modern British gas-fired power plants have the advantage of being very flexible, which makes them well suited for peak hours as well as for compensating renewable sources when these are not available.

We distinguish three scenarios for the growth of the amount of electric cars:

1. Moderate/medium uptake scenario.
2. Fast uptake scenario.
3. Ultra-fast EV scenario.

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[57] However, the necessity to decarbonise the UK economy means that in future electricity from unabated coal-fired plant is not an option and so efforts will focus on a clean, sustainable energy regime, such as renewables (wind, wave, solar and sustainably sourced biomass).

Table 11 **Effect of the three scenarios for the growth of electric cars in the UK**

	Moderate/medium uptake		Fast uptake		Ultra-fast EV	
	EV	PHEV	EV	PHEV	EV	PHEV
Number of cars (million)	0.1	0.2	0.7	2,2	3,6	1,0
Electr. needed (GWh)	1,639		16,528		15,222	
%El. Production (2007)	+0.4%		+4.1%		+3.8%	
Power needed (GW)	0.2		1.9		1.7	

As shown in Table 11, the additional electricity consumption for electric cars in the UK in 2020 will be in the range of 0.4% to 4.1% of UK electricity production in 2007.

The additional power needed (Table 11) is the generating capacity needed if charging the cars is spread evenly over the entire day. So 1/24 part of the electric car fleet is charged every hour of the day. In practice, this will not be a realistic scenario since car charging will probably be concentrated at certain time intervals: when everybody gets home at 18:00, during the working day, or at night.

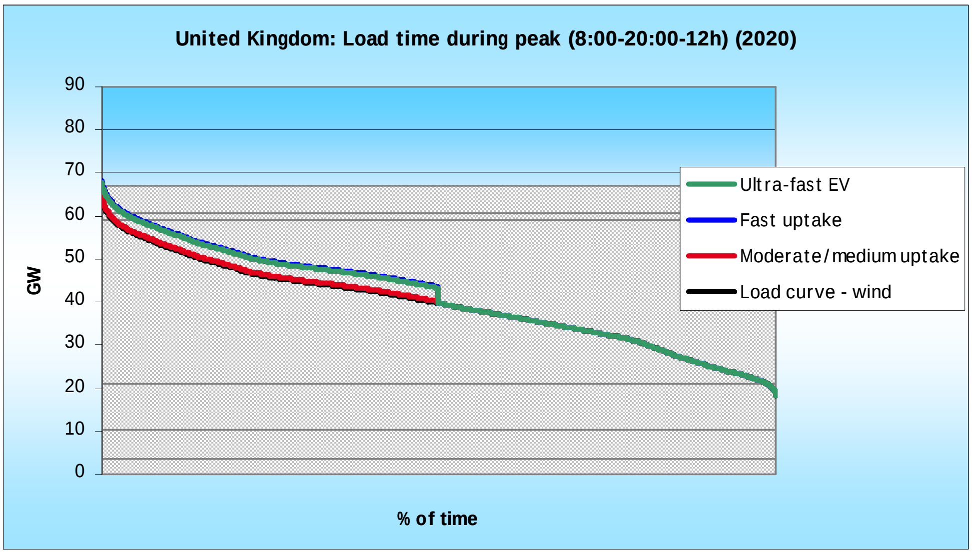
To get better insight in the effect of different charging scenarios we distinguish two scenarios for extra electricity demand of electric cars:

1. Consumption of electricity during peak hours (08:00–20:00).
2. Consumption of electricity at night (24:00–08:00).

1. Peak hours

An extra capacity demand coming from electric vehicles of 0.4–3.8 GW in peak hours will result in a total capacity demand of approximately 40-65 GW during peak hours (Figure 36).

Figure 36 **Load time during peak hours, UK**

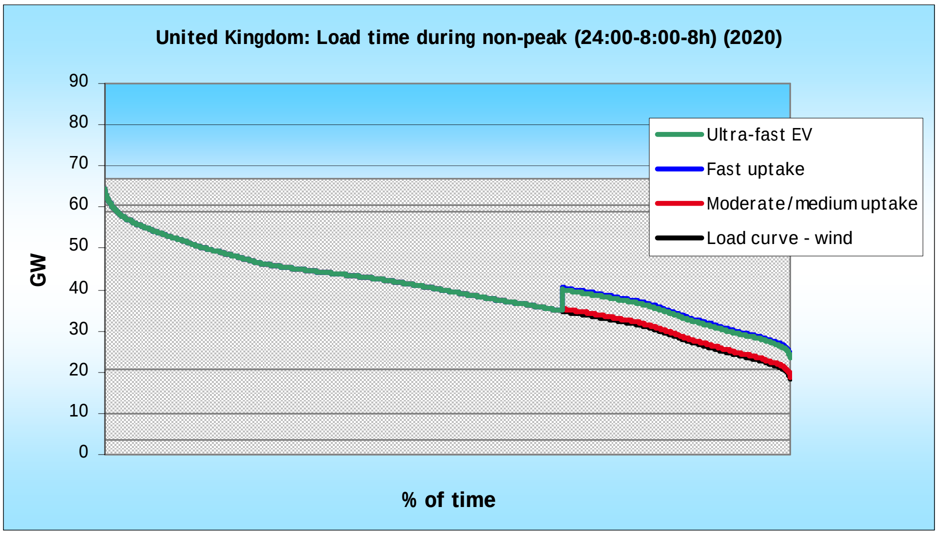


Given the present production park there are indications that charging cars during peak hours (especially between 18:00 and 22:00) might imply that this extra electricity demand will be met by low-efficient coal plants. The reason is that during these hours peak demand is already a relatively high and there is little spare capacity. It remains difficult to predict exactly from what sources the additional electricity needed will originate. We also expect that a large part will come from gas-fired power plants (and perhaps renewable distributed generation). Available wind capacity (10 GW[58]) will not be enough to contribute to the growing electricity demand from electric vehicles since this 10 GW will not exceed the current minimum base load electricity demand during the day (20 GW).

2. Base load hours

Extra electricity demand of 0.6–5.7 GW from electric vehicles in base load hours will result in a total capacity demand of approximately 20–40 GW during base load hours (Figure 37).

Figure 37 **Load time during base load hours United Kingdom**



A higher demand during base load hours will possibly be met either by base load capacity (coal and nuclear) or by gas-fired production capacity. This will be determined by the specific marginal costs of the diverse options. Due to The Large Combustion Plant Directive oil and coal fired plants are/will be subject to tight air pollution constraints which will lead to an (early) shut down of older power plants. This production capacity will be replaced mainly by gas-fired power plants and (must-run) wind energy, which together are expected to contribute more and more to (additional) base load demand.

Section 4.9 contains a summary of the results and conclusions of the different case studies (Germany, France UK).

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[58] This figure is derived by multiplying the projected wind capacity (32 GW) by the (average) load factor.