# Impacts of Electric Vehicles - Deliverable 5

## Impact analysis for market uptake scenarios and policy implications

**Final Report**
Delft, April 2011

**Author(s):**
Bettina Kampman (CE Delft)
Huib van Essen (CE Delft)
Willem Braat (CE Delft)
Max Grünig (Ecologic)
Ravi Kantamaneni (ICF)
Etienne Gabel (ICF)

Ecologic Institute
Berlin
Brussels
Vienna
Washington DC

# Publication Data

**Bibliographical data:**
Bettina Kampman, Huib van Essen, Willem Braat (CE Delft)
Max Grünig (Ecologic)
Ravai Kantamaneni, Etienne Gabel (ICF)
Impacts of Electric Vehicles - Deliverable 5
Impact analysis for market uptake scenarios and policy implications
Delft, CE Delft, April 2011

Electric vehicles / Effects / Market / Analysis / Policy / Scenarios

Publication number: 11.4058.07

CE-publications are available from www.cedelft.eu

Commissioned by: European Commission.
This study has been produced by outside contractors for the Climate Action Directorate-General and represents the contractors' views on the matter. These views have not been adopted or in any way endorsed by the European Commission and should not be relied upon as a statement of the views of the European Commission. The European Commission does not guarantee the accuracy of the data included in this study, nor does it accept responsibility for any use made thereof.

Further information on this study can be obtained from the contact person Huib van Essen.



CE Delft
Committed to the Environment

CE Delft is an independent research and consultancy organisation specialised in developing structural and innovative solutions to environmental problems.
CE Delft's solutions are characterised in being politically feasible, technologically sound, economically prudent and socially equitable.

# Contents

# Summary

Electric Vehicles (EVs) are a promising technology for reducing the environmental impacts of transport. To acquire an overview of the possible impacts of the introduction of EVs in the EU, DG CLIMA commissioned CE Delft, ICF and Ecologic to study the status and prospects of EV technology, the potential market uptake of EVs and their likely impacts. This study focuses on passenger cars and light commercial vehicles and covers the various types of EV: full electric vehicles, plug-in hybrid EVs and EVs with range extenders. It includes an assessment of impacts on both the transport and electricity sector. This report is the final deliverable of the study and covers the assessment of impacts of EVs and policy considerations.

The assessment was made for three scenarios with different assumptions on EV and conventional car developments and one Reference Scenario:
- Scenario 1 reflects the most likely developments; it assumes about 3 million EVs in the EU in 2020, rapidly increasing to 50 million in 2030.
- Scenario 2 assumes a technology breakthrough for internal combustion engine vehicles (ICEV) and relatively pessimistic EV developments and costs, resulting in only 2 million EVs in 2020 and 20 million in 2030.
- Scenario 3 is an EV breakthrough scenario assuming rapid EV technology development and cost decrease, resulting in almost 6 million EVs in 2020 and 93 million in 2030.
- The Reference Scenario can be regarded as the most pessimistic EV scenario, as it does not include any EVs until 2030.

## Impacts of market uptake of Electric Vehicles

In all three scenarios, **total transport fuel consumption** decreases significantly, especially in the longer term. Petrol and diesel use by passenger cars in 2030 was found to decrease by about 12 and 20% in scenarios 1 and 3, respectively, compared to the Reference Scenario. This lower fuel consumption results in lower **exhaust $CO_2$ emissions** from passenger cars. In 2020 these reductions are expected to be only a few per cent in all scenarios. However, in 2030 they are significant: 15% in Scenario 1 and 27% in Scenario 3. Uptake of EVs could therefore lead to substantial cuts in exhaust $CO_2$ emissions post-2020.

Scenario 2 illustrates that alternative technology pathways with only slow uptake of EVs could also result in significant cuts in passenger car $CO_2$ emissions. Strong development of ICE technology combined with relatively pessimistic assumptions on EV trends could deliver similar reductions to those in the EV technology breakthrough Scenario 3.

In all the scenarios the increase in overall **electricity demand** is relatively small: even in Scenario 3 it is only 5 % in 2030. In all three scenarios, most of the additional electricity is expected to be generated from gas and coal. Taking into account the emissions deriving from electricity consumption, the EV scenarios 1 and 3 achieve overall $CO_2$ cuts of 4 and 9% of passenger car emissions in 2030. The ICEV breakthrough Scenario 2 has stronger impacts: 21% lower $CO_2$ emissions in 2030. Part of the remaining $CO_2$ emissions from power production will automatically fall under the EU ETS and will therefore have to be compensated elsewhere. If we assume that the greenhouse gas (GHG) emissions from additional electricity demand are zero because of the ETS, the $CO_2$ reduction is equal to the reduction in exhaust emissions cited above: 15% in Scenario 1 and 27% in Scenario 3.

The other impacts of EV uptake are estimated as follows:

- Particle emissions are reduced, but $NO_x$ emissions increase. Total air pollution costs decrease by between 2 and 10% in 2030. Note that the exact impacts depend much on emissions policy vis-à-vis power generation.
- Overall impacts on noise levels are likely to be very small in the coming decades, although in specific cases local effects might be significant.
- The additional demand for lithium and certain specific rare earth metals can probably be met by global reserves, but production will need to expand significantly after 2020 if EV uptake accelerates.
- The net impact on tax revenues is likely to be negative: lower revenues from taxes on energy and vehicles are only partly compensated by higher VAT revenues from higher vehicle purchase prices. For the EU, the net loss in tax revenues in 2030 is estimated at 18 billion Euro in Scenario 1, up to 33 billion Euro in Scenario 3 and even 38 billion Euro in Scenario 2.
- Investments in charging infrastructure are significant and amount in total roughly 30 to 150 billion in the EU till 2030, depending on the number of charging points required. These costs could be covered by a mix of public and private investments.
- Until 2030, impacts on primary energy use will be small, while fossil fuel imports might slowly decline. Changes in fuel imports from outside the EU are uncertain and probably relatively small.

### Policy implications

In the short term, at least over the next five years, EV technology will not reach maturity and government support is needed to speed up innovation. In this phase, however, it is important to avoid unfair competition with other types of energy-efficient vehicle and sustainable biofuels. To prepare for the longer term, a consistent overall fiscal and regulatory framework should be developed, providing consistent treatment and coverage of EVs and all competing technologies. In this light, we make the following policy recommendations:

- Extension of the current $CO_2$ regulation for cars and vans to a system covering well-to-wheel GHG emissions for both ICEVs and EVs. The key challenge here is to develop a set of GHG intensity figures for all energy carriers. For electricity, particularly, this requires further study.
- Development of a more detailed accounting methodology for EV electricity consumption, in the light of the Fuel Quality Directive and the Renewable Energy Directive (RED), and possibly also for their renewable electricity consumption. Additionally, to prevent unfair competition, the RED-multiplier of 2.5 for renewable electricity used for EVs should be re-examined once actual electricity consumption data are available.
- In the short term, impacts on the EU ETS are likely to be negligible. but changes should be considered for post-2030, once more accurate predictions of EV market uptake and power consumption can be made.
- Options for compensating potential losses of tax revenues, like raising energy taxation levels for both electricity and transport fuels and/or road charging, should be studied further. In this light it is recommended to assess options for separate metering and taxation of electricity for EVs. Harmonisation of the various circulation and purchase tax differentiations should also be considered.
- To ensure that local distribution grids become EV-ready, the European Commission can initiate best-practice exchange and support pilot and demonstrations projects. Regulations could be developed obliging power generators to implement smart charging at a certain stage, e.g. when the share of EVs in the vehicle fleet in their distribution district reaches 5%.
- Common plug and charging standards and protocols for data exchange need to be developed as soon as possible.

# 1 Introduction

## 1.1 Introduction to the project

Electric Vehicles (EVs) are a promising technology for drastically reducing the environmental burden of road transport. More than a decade ago and also more recently, they were advocated by various actors as an important element in reducing $CO_2$ emissions of particularly passenger cars and light commercial vehicles as well as emissions of pollutants and noise.

At the same time, EVs are still far from proven technology. There exist many uncertainties with respect to crucial issues like:
- The battery technology (energy capacity in relation to vehicle range, charging speed, durability, availability and environmental impacts of materials).
- Well-to-wheel impacts on emissions.
- Interaction with the electricity generation.
- Cost and business case of large scale introduction.

For EU policy makers, it is important to get a reliable and independent assessment of the state of the art of these issues in order to develop targeted and appropriate GHG reduction policy for transport. Therefore DG CLIMA commissioned CE Delft, ICF and Ecologic to carry out a study on the potential impacts of large scale market penetration of EVs in the EU, with a focus on passenger cars and light commercial vehicles. This study includes an assessment of both the transport part (e.g. composition of vehicle fleet) and electricity production and the impacts on well-to-wheel GHG emissions, pollutant emissions, other environmental impacts, costs, etc.

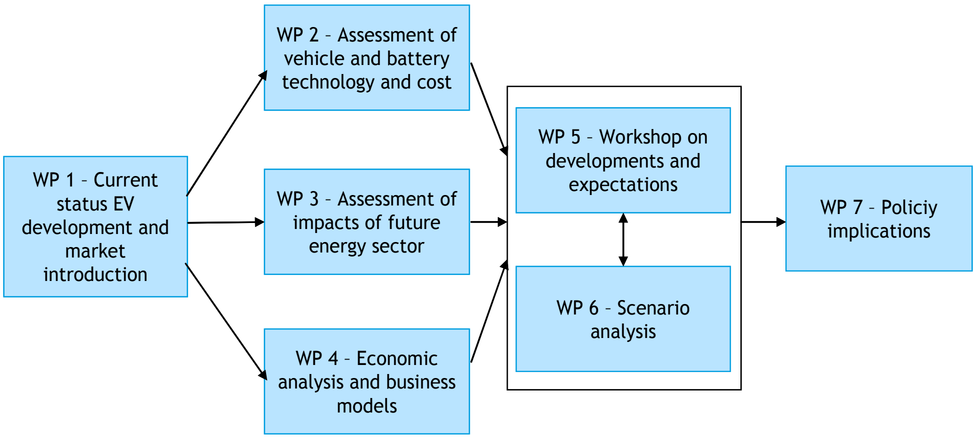
In this study three types of EVs are distinguished:
- Full Electric Vehicles (FEVs) that have an electric engine and no internal combustion engine (ICE).
- Plug-in Hybrid Electric Vehicles (PHEVs) that have both an ICE and an electric engine, with a battery that can be charged on the grid.
- Electric Vehicles with a Range Extender (EREVs) that have an electric engine and an ICE that can be used to charge the battery and so extend the vehicle's range. The battery of an EREV can be charged on the grid.

The results of the study should help the Commission with developing GHG policy for transport, in particular in the field of EVs and in relation to the wider EU transport policy and EU policy for the electricity sector.

The project is organised around seven work packages (WPs):
WP 1 Current status of EV development and market introduction.
WP 2 Assessment of vehicle and battery technology and cost.
WP 3 Assessment of impacts on future energy sector.
WP 4 Economic analysis and business models.
WP 5 Workshop on developments and expectations.
WP 6 Scenario analysis.
WP 7 Policy implications.

The following graph (Figure 1) gives an overview of the main interactions between the various WPs. The approach for each WP is explained in the following paragraphs.

**Figure 1 Project overview**




The results of this project are presented in five deliverables. This report is the fifth and final deliverable of the project and includes the results of Work Package 6 and 7. It builds on the results of WP 1 to 4, which can be found in Deliverable 1 to 4. Also the results of the stakeholder workshop (WP 5) which was held on October 14th, 2010 has contributed to the work that has been carried out for this deliverable. In addition there is a summary report, briefly summarising the main results of the entire project.

## 1.2 Scope and approach

In view of the still very significant uncertainties in future cost and performance of electric vehicles, government policies, oil and electricity prices, it is not an easy task to predict the future of these vehicles with reasonable accuracy. Nevertheless, all stakeholders involved, including the EU and Member State governments, the car industry and the electricity sector, need to make decisions on how to respond to the current and possible future developments.

A scenarios analysis is an important tool to assess the potential impact of these upcoming technologies and to consider what actions should be taken. Even if it is uncertain what the future will look like, a scenario analysis can enable policy makers to assess:
- The robustness of policy options: are policies effective in the various different circumstances that may arise?
- The risk of certain policy options: do they create undesired lock-in effects, is there a risk that certain investments will be ineffective or even counterproductive?
- The barriers that need to be removed to achieve a desired outcome, and the opportunities that can be harvested.

We have therefore developed a number of scenarios that reflect various possible futures. For each scenario we have assessed the impacts on issues such as vehicle fleet, electricity and transport fuel use, electricity production, government revenues, transport cost, $CO_2$ and air pollution emissions. The aim of these scenarios is to describe the possible playing field, based on the developments described and the data gathered in the previous work phases.

To achieve this, the key variables that impact the development but are currently still uncertain can be varied in these scenarios:
- Cost of the vehicles and/or batteries, in combination with the vehicle and battery lifetime.
- Customer response to cost and ranges of PHEVs, EREVs and FEVs.
- Charging point availability and grid limitations to charging.
- Government policy.
- Battery and EV production capacity limitations.
- Oil and electricity price.

In addition, assumptions are made regarding the distribution of battery charging over the day: will batteries be charged mainly in the evenings, when many car owners return from work, during the day, or will there be some sort of 'smart charging', where a large part of the charging will take place at times of low electricity demand, during night time?

This scenario analysis is carried out using CE Delft's newly developed model MELVIN, described in Annex D, in conjunction with the IPM model of ICF (see Deliverable 3), that can model the impact of the additional electricity demand on electricity production in the EU. The time frame of the scenario analysis is 2010-2030.

The modelling is limited to passenger cars only. This does not seem to create a significant gap in the analysis, at least for the coming 10-15 years, as most EVs will be passenger cars or small (delivery) vans, and the latter are somewhat comparable to large diesel passenger cars. In the longer term, however, EVs might also enter the heavy duty market. At that time, impacts of electrification of these vehicles may need to be assessed in more detail.

The TREMOVE baseline scenario (version 3.3.1) is used as a reference for our scenario analysis. This scenario takes recent policies into account, including the $CO_2$ regulation of cars, but it does not contain any EVs. For the electricity sector, a Reference Scenario was developed with the IPM model. This was discussed in Deliverable 3 of this project.

Three EV scenarios were developed in which the various types of EVs are brought onto the market, to replace part of the ICEVs of the baseline. Key input variables such as the ones listed above are varied, leading to different market uptake developments over time of FEVs, PHEVs and EREVs.

## 1.3 Report structure

In Chapter 2 of this report, the scenario design is discussed. Chapter 3 shows the impacts of the various scenarios on a broad range of indicators. In Chapter 4 the policy implications are discussed. Finally, Chapter 5 summarises the main conclusions and recommendations. The annexes contain input data used for the assessment and more detailed results.

# 2 EV scenario design

## 2.1 Introduction

In order to assess the potential impacts of EV cost developments and government policies on a number of scenarios were developed. For each scenario the main impacts were assessed, such as impacts on vehicle fleet, electricity and transport fuel use, cost, $CO_2$ and air pollution emissions. The aim of the scenarios is to describe the possible playing field, based on the developments described and data gathered in the previous work phases. A detailed description of the modelling approach and calculations can be found in Annex D.

Each scenario distinguishes between 12 vehicle types:
- Internal Combustion Engine Vehicle (ICEV) or conventional vehicle: small, medium, large.
- Plug-in Hybrid Electric Vehicle (PHEV): small, medium, large.
- Electric Range Extender Vehicle (EREV): small, medium, large.
- Full Electric Vehicle (FEV): small, medium, large.

For each vehicle type, the following cost and performance data were defined:
- Catalogue price, vehicle registration tax, VAT, perhaps purchase subsidies (these add up to the up-front vehicle purchase cost to car buyers).
- Vehicle circulation tax, annual insurance and maintenance cost of the vehicles (annual cost per vehicle).
- Vehicle lifetime or residual value after x years.
- In case the batteries of Electric Vehicles have lower lifetime than the rest of the car (i.e. batteries need to be replaced after some years): battery cost and lifetime[1].
- Kilometres per vehicle, per year.
- Average fuel use and/or electricity use per kilometre.

In addition, energy prices (equal for all vehicle types) are estimated:
- Electricity price (consumer price, i.e. inclusive taxes).
- Fuel price (also incl. VAT and excise duties).

These variables may change over time and are provided for the years 2010, 2015, 2020, 2025 and 2030.

In order to develop scenarios with internally consistent and well-founded parameter sets, we have built the parameters on so-called ‘storylines’. These storylines describe the future developments in a quantitative way, outlining key developments and assumptions for a given scenario. The individual parameters are then derived from these storylines.

It should be realised that the scenarios that are described and used in this report are not intended to represent precise predictions of the future, but rather provide means to assess the range of the various impacts that could be expected from EVs in the coming decades. As the EV technology and industry is

[1] In case battery cost are not included in the vehicle cost, but car owners lease (or rent) the batteries, the annual cost of the batteries should be added to the other annual cost items listed above.

still very much under development, and there is still only very limited experience with the actual use of these vehicles, their real life energy efficiency, battery lifetimes etc., many of the input data are quite uncertain. Where input data were still unknown and uncertain, it was decided to use quite crude assumptions (for simplicity, but also to improve transparency).
For example, little is known about the actual annual mileage of the various types of EV. Looking at FEVs, their limited range might suggest that they are mainly attractive to users with limited annual mileage. However, the high purchase price and low energy (i.e. kilometre) cost makes them especially attractive for car owners that drive high annual mileages. As actual usage data are still limited, we have decided to leave the annual mileage of the FEVs (and other types of EV) equal to that of ICEs of the same size.
The modelling itself can thus only provide a rough approximation of reality (for the same reasons).

Nevertheless, as the three scenarios describe three very different but all potentially feasible futures, they provide useful insight into the potential impacts and underlying mechanisms, drivers and trends. In addition they show the main uncertainties in impacts that are linked to the uncertainties in the developments and costs of new technology. The next sections list the main assumptions for the three scenarios.

## 2.2 EV Scenario 1: The ‘most realistic’ estimates of WP 1-5

This scenario is intended to provide the ‘most realistic’ outlook of EV developments, based on the state-of-the-art information that was gathered in the previous work phases of this project. The main assumptions in this scenario can be described as follows.

- Input parameters regarding cost, energy use and oil price are all estimated as realistically as possible, using the best estimates of the project team, as determined in the earlier work phases of the project and presented in WP 4 (see Annex A of that report).
- Government incentives for EVs are assumed to continue roughly as currently in place. A number of EU countries provide significant subsidies or tax exemptions, others do not.
- ICEV development is roughly in line with expectations from the Vehicle Emissions project by Ricardo/TNO. ICEV fuel efficiency improves are in line with the $CO_2$ and cars regulation until 2015, after that real-life improvements are expected to remain somewhat lower than the test cycle improvements required by the regulation. This results in efficiency improvements of 18% between 2015 and 2020, which is lower than the 27% that would correspond with meeting a test cycle value of 95 g/km[2]. After 2020, it is assumed that ICE efficiency improves with 5% every 5 years.
- Most consumers are reluctant to switch to EVs, as long as the total cost of ownership (TCO) is higher and drive ranges are lower:
  - We assume that only the ‘innovators’ will be interested, as long as the TCO of the EVs is higher than that of comparable ICEVs. This group of users represents about 5% of the car buyers. This group is, however, still price sensitive, which is modelled using a price elasticity.
  - We distinguish between urban innovators that are mainly interested in FEVs and EREVs, and non-urban innovators that are mainly interested in PHEVs and EREVs.

[2] The reasoning behind this is that the 'real life' emissions of cars could be less strong than the reductions during type approval. Also, EVs will contribute to the target.

- The rest of the consumers will only start buying EVs once their TCO can compete with that of ICEVs. They will also be price sensitive: the larger the cost benefit, the larger the market share.

– Production capacity and charging opportunities will be limited at first, and increase over time. It is assumed that it will take until 2025 before production capacity and charging can be fully developed and do not provide limitations on market uptake.
– Energy prices (diesel, petrol and electricity) are assumed to develop in line with the price trends depicted in 'EU Energy Trends to 2030' (EC, 2010i).
– It is assumed that EVs replace ICEVs, i.e. that the number of vehicle sold and their annual mileage will be the same as in the baseline.

Based on this storyline, the input data need for the scenario calculations (vehicle cost and performance data for the various vehicle types, consumer behaviour assumptions, etc.) were derived. An overview of the input data used for this scenario can be found in Annex A.2.

Regarding the charging profiles (i.e. at what time of day will the batteries be charged), we assume that:
– Charging will be mainly unmanaged in the years 2010-2017.
– Part of the vehicles will be charged 'smartly' between 2018 and 2022.
– All EVs will be able to apply smart charging from 2023 onwards, resulting in a relatively high share of charging during night times.

The reasoning behind this development is that it will take some time to develop a common smart charging methodology, but as the number of EVs increases, the benefits of charging management/smart charging and therefore the need to implement and use this technology will increase.

The charging profiles for Scenario 1 are summarised in Table 1.

**Table 1** **Charging profiles assumed (share of electricity charged per time period)**

| | Evening<br>6 pm-12 pm | Night<br>12 pm-6 am | Day<br>6 am-6 pm |
|---|---|---|---|
| Unmanaged case (2011-2017) | 60% | 20% | 20% |
| Transition case (2018-2022) | 40% | 40% | 20% |
| Managed case (2023 onwards) | 20% | 60% | 20% |

## 2.3 EV Scenario 2: ICE breakthrough

The key storyline of this scenario is as follows.
– Costs of batteries reduce less fast than anticipated in Scenario 1, there is relatively limited technological progress.
– Successful further development of ICEVs, leading to significant $CO_2$ efficiency improvements at reasonable cost. Fuel efficiency of ICEVs is expected to reduce in line with the $CO_2$ and cars regulation (appr. -10% between 2010 and 2015 and 27% reduction between 2015 and 2020). Between 2020 and 2030, efficiency is assumed to increase further, by 10% every 5 years.
– Government incentives for EVs reduce of time, insufficient to compensate the higher total cost of ownership compared to ICEVs.
– Consumer interest remains limited to a relatively small market (innovators and some niche markets).

– TCO of FEVs remains high compared to ICEVs, resulting in a low market uptake:
  - Batteries remain expensive.
  - Oil price and electricity price as in baseline scenario.
  - Governments provide some subsidies and tax exemptions in many EU countries, but not enough to achieve competitive TCO.
– PHEVs will successfully enter the market, but their electric range remains limited and consumer interest as well, due to limited charging possibilities.
– EREVs will not enter the market, as they will remain expensive and offer little advantage over other types of vehicles.
– Energy prices are assumed to develop in line with the price trends depicted in 'EU Energy Trends to 2030' (EC, 2010i) – as in Scenario 1.

Based on this storyline, the input data need for the calculations of Scenario 2 were derived. These are shown in Annex A.3.

Regarding the charging profiles, we assume that charging will be mainly unmanaged throughout the period we analyse here (2010-2030), in line with the unmanaged profile described in the previous section. As the number of EVs remains limited, the need for smart charging is limited and few efforts are made to encourage smart charging.

## 2.4 EV Scenario 3: EV breakthrough

This scenario is the most optimistic one, from the EV development perspective. The story line is as follows:
– R&D leads to a rapid decrease of battery cost and increase of battery lifetime, from 2015 onwards.
– From that time onwards:
  - TCO of medium-size PHEVs becomes almost competitive with ICEVs in part of the urban transport, and in non-urban transport (equal TCO is achieved around 2020). The share of electric driving with PHEVs increases compared to the baseline, as their electric range increases.
  - In parallel, FEVs become competitive in the small vehicle segment and urban transport. After 2020, their market share also increases in the medium-size vehicles sales as the ranges of FEVs increase and cost decrease.
  - In the larger vehicle market and non-urban vehicle use, PHEV and EREVs gain quite rapid market share from 2020 onwards, as their TCO also gets competitive. The driving range of EREVs also increases over time.
– From 2025 onwards, fast charging will be offered throughout the EU, practically removing all range anxiety and range limitations.
– Apart from cost issues, in the first decade, 2010-2020, market share increases are limited by production capacity, scepticism of consumers, electricity infrastructure bottlenecks, etc.
– Government incentives for EVs are high at first in some countries and will be rapidly reduced after 2015 as costs go down.
– ICE development (regarding fuel efficiency and cost) and energy costs are assumed to be the same as in Scenario 1.

The detailed input data for this scenario are given in Annex A.4.

Regarding the charging profiles, we assume that charging will be mainly unmanaged in the years 2010-2017 and that after a transition period, smart charging will become more common in the years from 2023 onwards, as the number of EVs increases and the benefits of charging management/smart charging increase. As this is very similar to the charging assumptions in Scenario 1 (see Table 1), we use the same profiles and the same development over time as described in Section 2.2.

# 3 Impact analysis

## 3.1 Introduction

For each of the scenarios described in the previous chapter, the impacts were calculated, assuming current policies remain in place.

The following are the key impacts that were calculated quantitatively using the vehicle market uptake model MELVIN and the electricity production model IPM:
- Energy demand of the EU passenger car fleet (divided into petrol, diesel and electricity demand).
- $CO_2$ emissions (from electricity and fuels).
- $NO_x$ and $PM_{10}$ emissions (distinguishing between emissions from electricity production, and emissions from petrol and diesel).
- Government revenues (from vehicle taxes, excise duties and VAT).

Impacts on air quality and noise were only estimated roughly, because more accurate estimates are not feasible with the still high uncertainties in vehicle use and cost. The economic impacts on the car manufacturers and petroleum companies could not be estimated within the scope of this project.

As noted before, these results should not be taken as precise predictions of the future, but are meant to provide insight in what might happen in the coming decades when EVs enter the market. From this scenario analysis, conclusions can be drawn about potential positive and negative impacts and potential policy areas to be further developed. They are also an illustration of the uncertainties that still exist: the scenarios range from a rather pessimistic view of the future developments of EVs, in combination with very favourable developments of ICEs (Scenario 2) to a very optimistic one, where cost and performance of EVs start to outperform ICEVs at the end of the coming decade (Scenario 3).

## 3.2 Impact on vehicle sales and fleet

The first result from the scenario analysis is the market uptake of the various vehicle types.

The model first calculates the share of the various vehicle types in total passenger car sales. This is done for three government incentive groups (high, medium and low), as described in Annex D.5.5, the resulting shares are then converted to number of vehicles sold in each EU Member State[3]. The overall result, the total numbers of EVs sold in the EU-27 in the various scenarios, are shown in Figure 2, Figure 3 and Figure 4[4]. The shares of the various EV types in the total passenger car sales are depicted in Table 2 (some other, detailed data are given in Annex C).

---

3 The Member States are divided over the inventive groups, in line with the current policy situation, see Annex D.5.5.

4 Even though only overall EU-27 results are shown here, the scenario analysis and resulting impact analysis takes much more detail into account, distinguishing between small, medium and large vehicles and between diesel and petrol, and providing detailed data for all EU Member States.

Clearly, production volumes of these vehicles and their batteries need to increase very significantly in some of these scenarios, especially after 2020. These cars will all need to be charged, so a significant effort is required in that area as well: the number of charging points will have to increase in line with these developments and the grid will have to be adapted to be able to facilitate these developments (see Deliverable 3). Especially Scenario 3 shows a very strong reduction of ICEV sales after 2020, as in this case, society quickly switches to electric transport once the EV and battery costs reduce and charging issues are resolved. Smart charging will have to be implemented in most EVs at that point, to minimise grid problems and to utilise the opportunities of these vehicles for grid stabilisation and temporary renewable energy overproduction.

**Figure 2** **Scenario 1: Passenger car sales in the EU-27, in comparison with the Reference (TREMOVE 3.3.1 alt), in million vehicles**

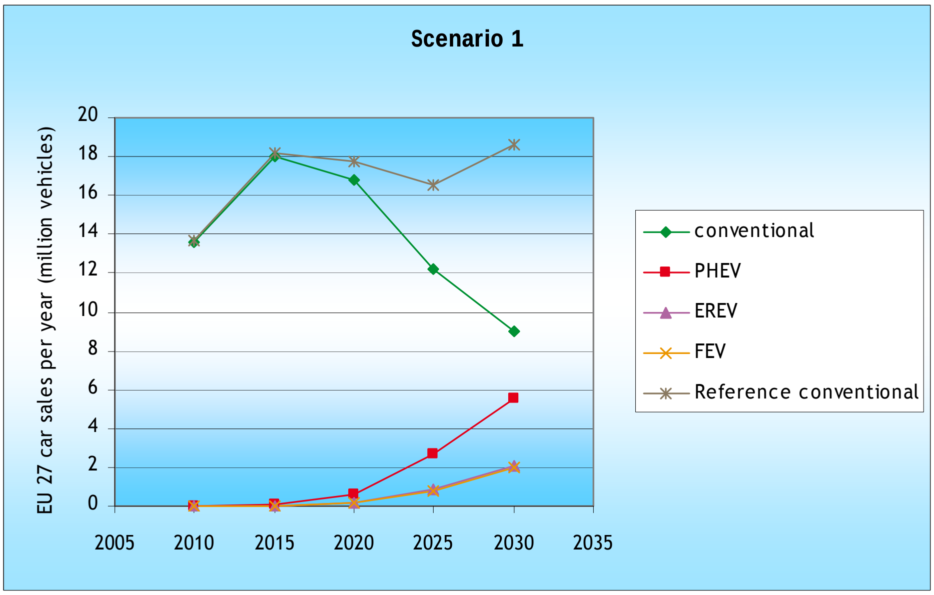


**Figure 3** **Scenario 2: Passenger car sales in the EU-27, in comparison with the Reference (TREMOVE 3.3.1 alt), in million vehicles**

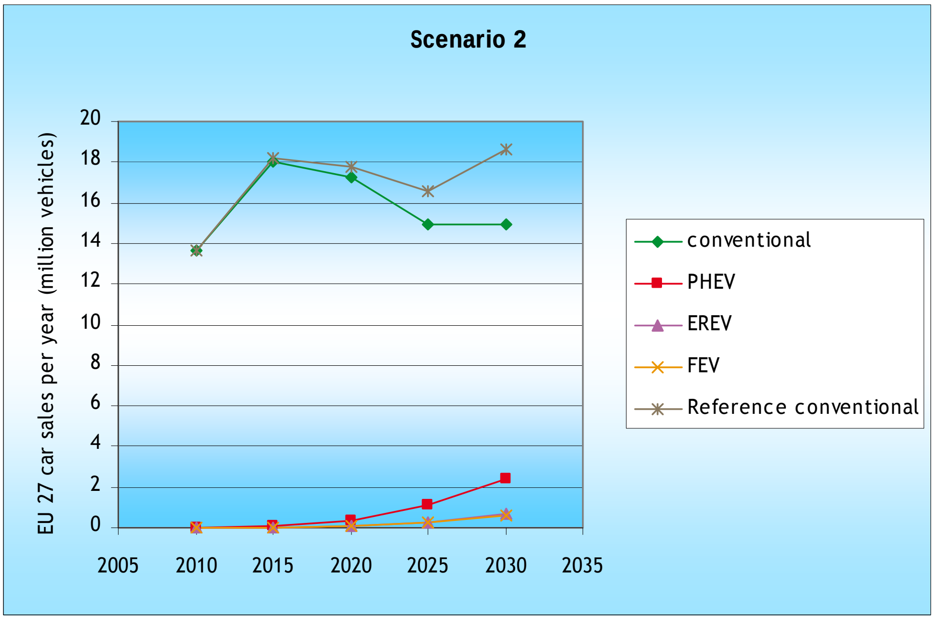



**Figure 4** **Scenario 3: Passenger car sales in the EU-27, in comparison with the Reference (TREMOVE 3.3.1 alt), in million vehicles**

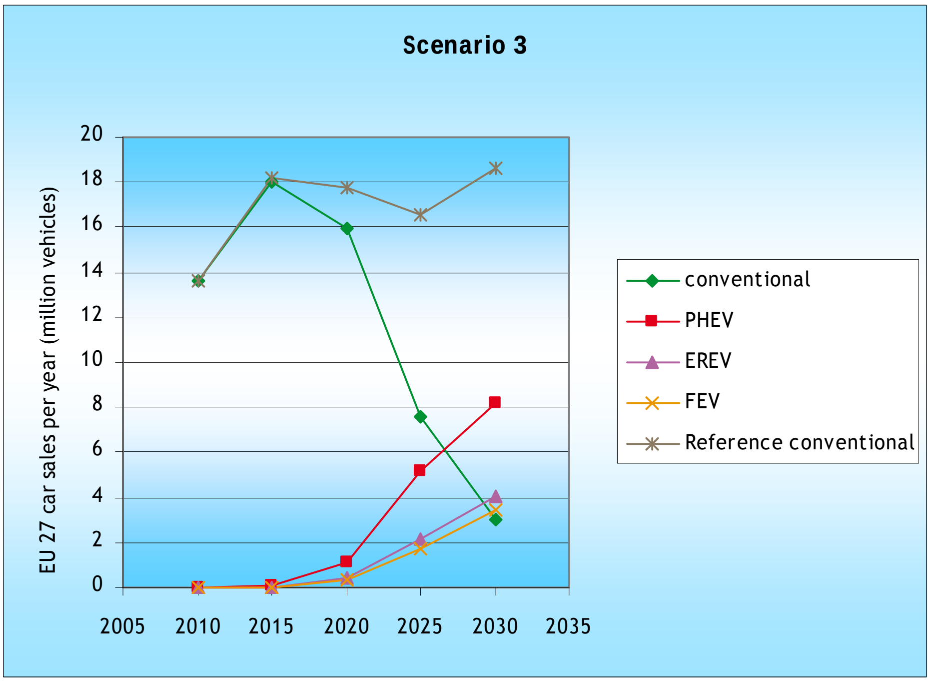


**Table 2** **EU-27 annual car sales, expressed in % of each vehicle type in the total sales**

| **Scenario 1** | **2010** | **2015** | **2020** | **2025** | **2030** |
|---|---|---|---|---|---|
| Conventional | 100% | 99% | 95% | 74% | 48% |
| PHEV | 0% | 1% | 3% | 16% | 30% |
| EREV | 0% | 0% | 1% | 5% | 11% |
| FEV | 0% | 0% | 1% | 5% | 11% |
| **Scenario 2** | **2010** | **2015** | **2020** | **2025** | **2030** |
| Conventional | 100% | 99% | 97% | 90% | 80% |
| PHEV | 0% | 0% | 2% | 7% | 13% |
| EREV | 0% | 0% | 1% | 2% | 3% |
| FEV | 0% | 0% | 0% | 2% | 3% |
| **Scenario 3** | **2010** | **2015** | **2020** | **2025** | **2030** |
| Conventional | 100% | 99% | 90% | 46% | 16% |
| PHEV | 0% | 1% | 6% | 31% | 44% |
| EREV | 0% | 0% | 2% | 13% | 22% |
| FEV | 0% | 0% | 2% | 10% | 18% |

Looking at the more detailed results, we can conclude that the plug-in hybrid electric vehicles have the highest share in the medium and large vehicles segment, and lower sales volumes in the small segment. The EREV type vehicles are found to have similar shares in all vehicle segments. Full electric vehicles have their highest shares in the small vehicle market in Scenario 3, but this is not the case in Scenario 1 and 2. This is due to the assumptions regarding parameters such as purchase cost and annual mileage: these vehicles are most competitive in the segments with higher annual mileage (the medium and large vehicle segments).

From these results for vehicle sales, the composition of the car fleet in the EU Member States could be calculated. Results for the EU-27 are shown in Table 3 (absolute numbers) and Table 4 (in % of the total). The total number of cars increases over time and is assumed to be the same in all scenarios.
In all three scenarios, the share of EVs remain very limited in the first 5-10 years, but sales increase after that resulting in a rapid increase of the number of these vehicles in some scenarios. Clearly, the number of EVs increases fastest in Scenario 3, where the share of EVs in the car fleet increases to 33% in 2030, with 18% PHEVs, 8% EREVs and 7% FEVs. The EV shares of 2030 in the other scenarios are 19% in Scenario 1 and only 7% in Scenario 2.
As it takes quite some time to replace the car fleet (average lifetime of cars is about 14-15 years), a significant amount of conventional vehicles (driving on diesel and petrol only) will remain on the road in 2030, also in Scenario 3.

Note that in all three scenarios, the Plug-in Hybrid is found to be the most successful type of EV. With the cost assumptions used here, their cost are typically significantly lower than that of the other electric vehicle types for a large share of car owners. In addition, their driving range does not pose any practical limitations, which is expected to be an important issue for especially non-urban car owners.

**Table 3** EU-27 car fleet, million cars. The Reference Case is TREMOVE version 3.3.1 alt

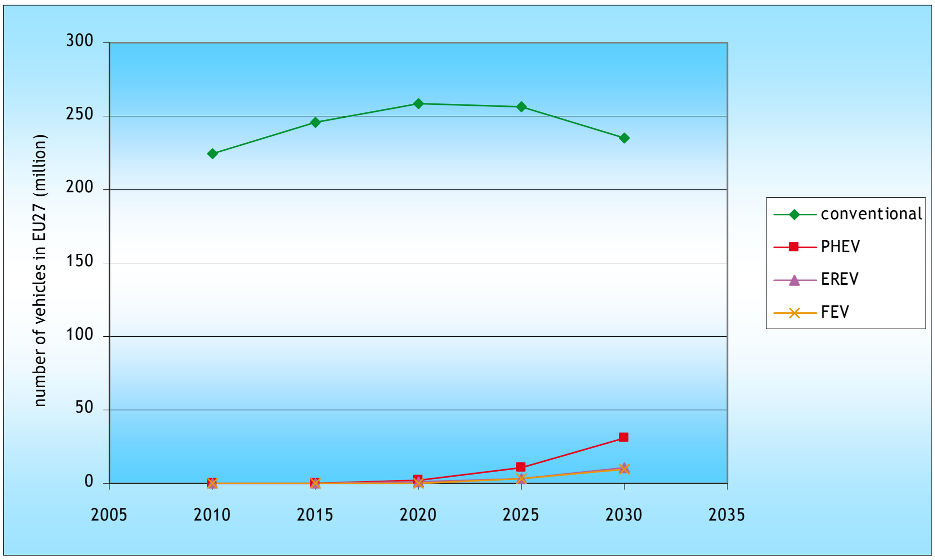
| Reference | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|
| Conventional | 224 | 247 | 262 | 273 | 287 |
| **Scenario 1** | **2010** | **2015** | **2020** | **2025** | **2030** |
| Conventional | 224 | 246 | 259 | 257 | 235 |
| PHEV | 0.0 | 0.3 | 2.1 | 10.3 | 30.9 |
| EREV | 0.0 | 0.1 | 0.7 | 3.5 | 10.9 |
| FEV | 0.0 | 0.1 | 0.5 | 2.7 | 9.7 |
| **Scenario 2** | **2010** | **2015** | **2020** | **2025** | **2030** |
| Conventional | 224 | 246 | 260 | 266 | 266 |
| PHEV | 0.0 | 0.3 | 1.3 | 4.8 | 13.6 |
| EREV | 0.0 | 0.1 | 0.4 | 1.3 | 3.7 |
| FEV | 0.0 | 0.0 | 0.2 | 1.0 | 3.1 |
| **Scenario 3** | **2010** | **2015** | **2020** | **2025** | **2030** |
| Conventional | 224 | 246 | 257 | 241 | 193 |
| PHEV | 0.0 | 0.3 | 3.4 | 19.0 | 52.3 |
| EREV | 0.0 | 0.1 | 1.2 | 7.6 | 23.0 |
| FEV | 0.0 | 0.1 | 0.9 | 5.9 | 18.7 |

**Table 4** EU-27 passenger car fleet, expressed in share of each vehicle type in the total

| Scenario 1 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|
| Conventional | 100% | 100% | 99% | 94% | 82% |
| PHEV | 0% | 0% | 1% | 4% | 11% |
| EREV | 0% | 0% | 0% | 1% | 4% |
| FEV | 0% | 0% | 0% | 1% | 3% |
| **Scenario 2** | **2010** | **2015** | **2020** | **2025** | **2030** |
| Conventional | 100% | 100% | 99% | 97% | 93% |
| PHEV | 0% | 0% | 0% | 2% | 5% |
| EREV | 0% | 0% | 0% | 0% | 1% |
| FEV | 0% | 0% | 0% | 0% | 1% |
| **Scenario 3** | **2010** | **2015** | **2020** | **2025** | **2030** |
| Conventional | 100% | 100% | 98% | 88% | 67% |
| PHEV | 0% | 0% | 1% | 7% | 18% |
| EREV | 0% | 0% | 0% | 3% | 8% |
| FEV | 0% | 0% | 0% | 2% | 7% |

The development of the car fleet in Scenario 1 is graphically depicted in Figure 5.

**Figure 5** **Development of the passenger car fleet in the EU-27, Scenario 1 (in million vehicles)**




When we compare the projections made here for EVs on European roads in the coming decade with the announcements made by Member States (see Section 3.3 of Deliverable 1), we see that the latter are generally higher. The calculations made for the impact assessment suggest 0.4 to 0.5 million EVs on European roads in 2015 (see Annex C), while the sum of all announcements made and targets set by EU Member States sum up to 1.3 million EVs in 2015. In 2020, the projections are more in line with each other: the announcements by Member States sum up to 4.8 million EVs, which is between the estimates of Scenario 1 (3.3 million EVs) and Scenario 3 (5.5 million EVs). In general, the announcements made by Member States seem at the high end, which is not surprisingly as they are usually meant as ambitious targets.

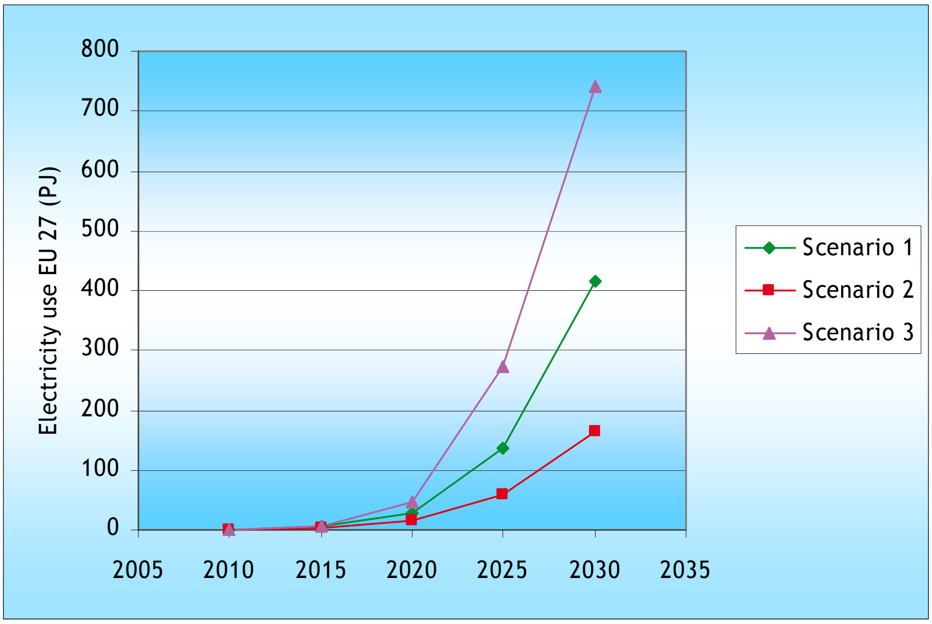
Also in Deliverable 2 of this project we presented some projections of EV sales in various parts of the world. If we compare the projections made for the impact assessment with these projections of D2, which were based on expectations from manufacturers (in particular Limotive), we see that these are generally quite well in line. In Deliverable 2 of this project, we estimated the share of EVs in new car sales in Western Europe in 2020 at about 4% which is quite well in line with the 5% of Scenario 1. There is however a remarkable difference in the ratio between FEVs and PHEV/EREV. In Deliverable 2, we estimated that about three quarter of the EVs sold in Europe in 2020 will be FEVs while in the impact assessment of this deliverable we estimated FEVs to be only about one quarter of the total EV sales. The explanation is that the analysis behind this report is much more refined and takes into account both range, cost levels and cost structures of the various types of EV. Therefore, we regard the projection in split between various types of EV made in this report to be more reliable than the ones based on Limotive data, as presented in Deliverable 2.

## 3.3 Impact on fuel and electricity demand, and final energy consumption

The increasing share of EVs will result in a reduction of diesel and petrol use, and an increase of electricity demand. Using the assumptions for vehicle kilometres and fuel and electricity use per kilometre of the various scenarios (detailed in Annex A), these changes can be calculated from the market uptake results. Results are shown graphically in the figures below, for electricity, petrol and diesel separately (detailed results can be found in Annex C).

In the years 2010-2020, the impact of the EVs on the petrol and diesel use is negligible, but after 2020, the use of conventional fuels starts to reduce slowly as electricity use increases. Scenario 2 has notably lower petrol and diesel use than in the Reference Case already in the medium term, but this is not due to EVs but due to the faster fuel efficiency improvements of the ICEVs that are assumed in this scenario.

**Figure 6 Development of electricity use in scenarios, in the EU (PJ/year)**




NB: In the Reference Case (TREMOVE 3.3.1 alt), electricity use of passenger cars is zero.

**Figure 7** **Development of petrol use in the scenarios, in the EU (PJ/year)**

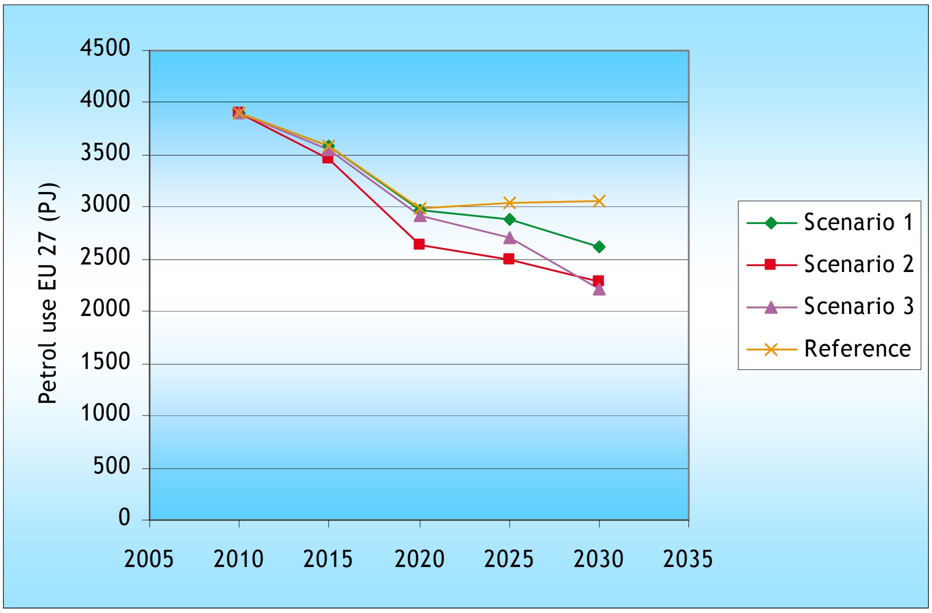
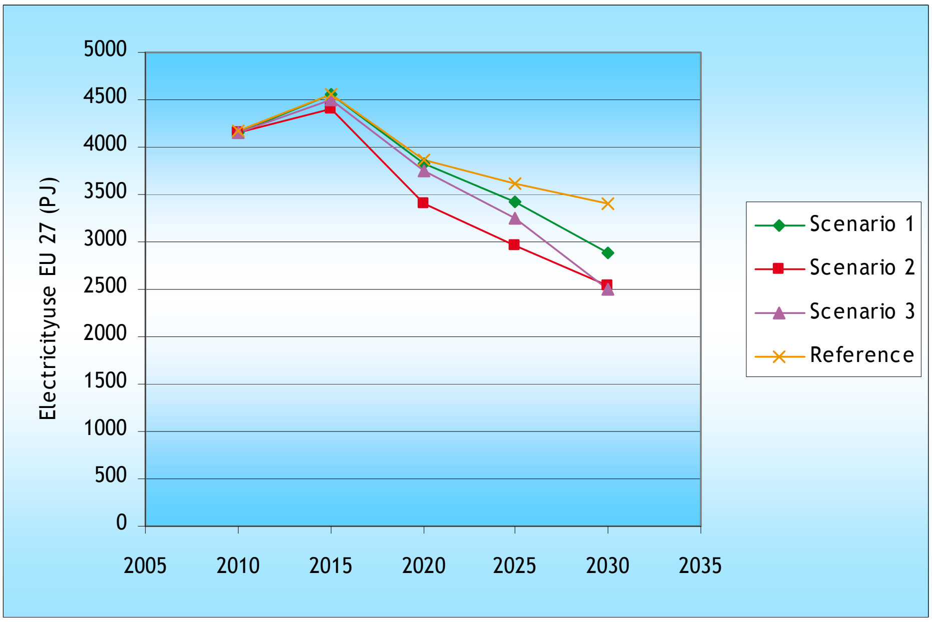


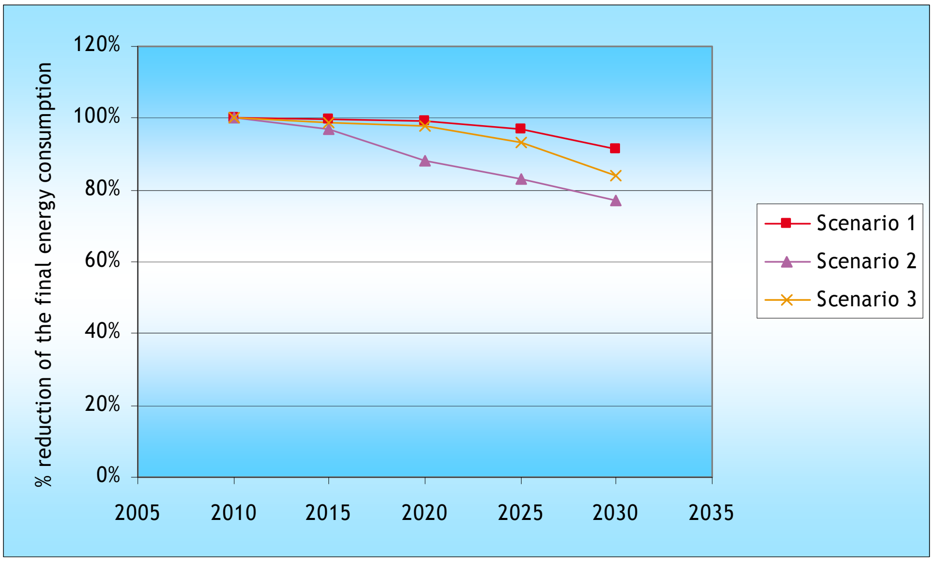

**Figure 8** **Development of diesel use in the scenarios, in the EU (PJ/year)**




Looking at the overall impact on final energy consumption, the three scenarios lead to various degrees of energy reduction, as can be seen in Figure 9. Throughout the period of investigation, Scenario 2 achieves the highest reduction in energy consumption, followed by Scenario 3 and then 1. In 2030, Scenario 2 achieves about 23% energy reduction, Scenarios 3 and 1 achieve 16 and 9% respectively. The impacts on the primary energy use and energy imports will be discussed in Section 3.11.

The impact of the EVs on the diesel/petrol demand ratio is found to be negligible.

**Figure 9** **Reduction of total final energy consumption of passenger cars in the EU-27, in % compared to the reference case (reference = 100%)**



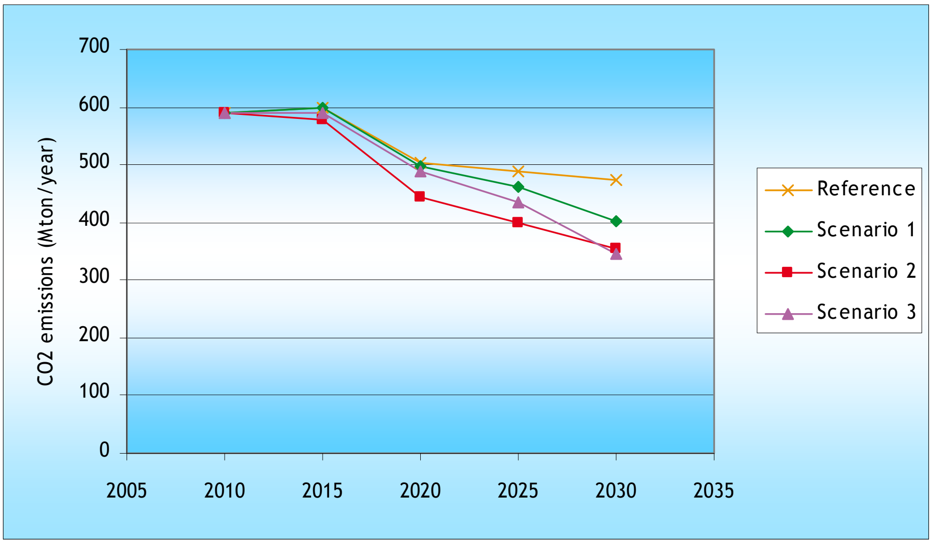

## 3.4 Impact on vehicle emissions

The effect of reduced diesel and petrol use on the **vehicle** emissions in the transport sector can now be calculated. The total effect on emissions, including the impact on the power production and upstream petroleum production and refining, will be shown in Section 3.6. Note that real life emissions are estimated here, which often differ significantly from test cycle emissions. $CO_2$ emission factors used can be found in Annex A, $NO_x$ and $PM_{10}$ emission factors were taken from TREMOVE v3.3.2alt.

The results for the impact of the $CO_2$ exhaust emissions of EU passenger cars are given in Figure 26. In line with the car fleet energy use results presented in Section 3.3, $CO_2$ emissions of Scenario 2 decline relatively fast in the medium term, as that scenario assumes that the fuel efficiency of conventional cars improves faster than in the Reference Scenario. These reductions, increasing to 25% of passenger car emissions in 2030 (almost 120 Mton), are therefore only to a small part due to EVs.

In the other Scenarios 1 and 3, $CO_2$ emissions of the passenger cars follow the curve of the Reference Case until 2015, as the market share of EVs remains very low (and ICEV fuel efficiency was assumed to be the same as in the Reference Case). After 2015, the GHG emissions reduce due to the market uptake of EVs. In 2030, Scenario 1 achieves 72 Mton $CO_2$ emission reduction, Scenario 3 results in almost 130 Mton reduction – all exclusive electricity production and upstream (well-to-wheel) fuel emissions. Reductions are larger in Scenario 3 than in Scenario 1 due to the higher uptake of EVs in Scenario 3.

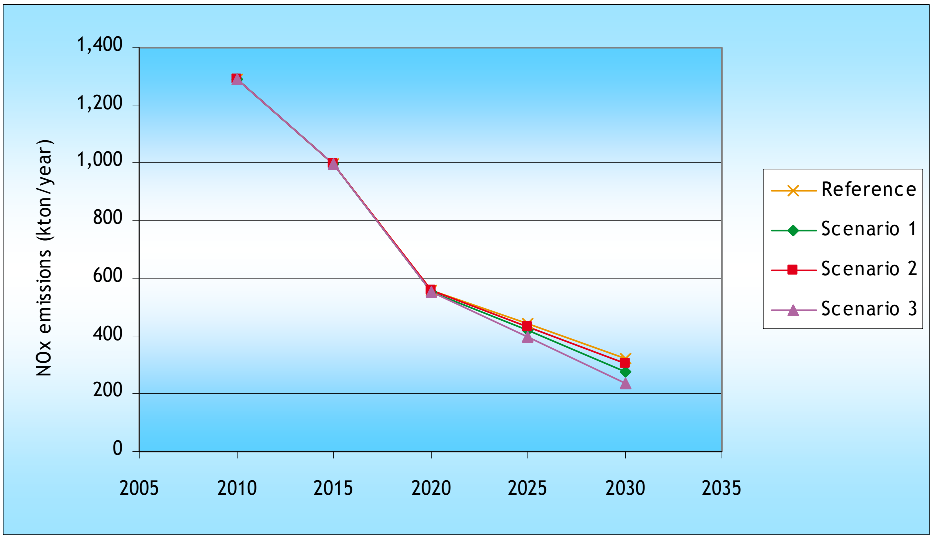
**Figure 10** **Direct $CO_2$ emissions of passenger cars in the EU, in the three scenarios and the Reference Case**




NB. Emissions shown here are vehicle emissions only, excl. emissions due to fuel production.

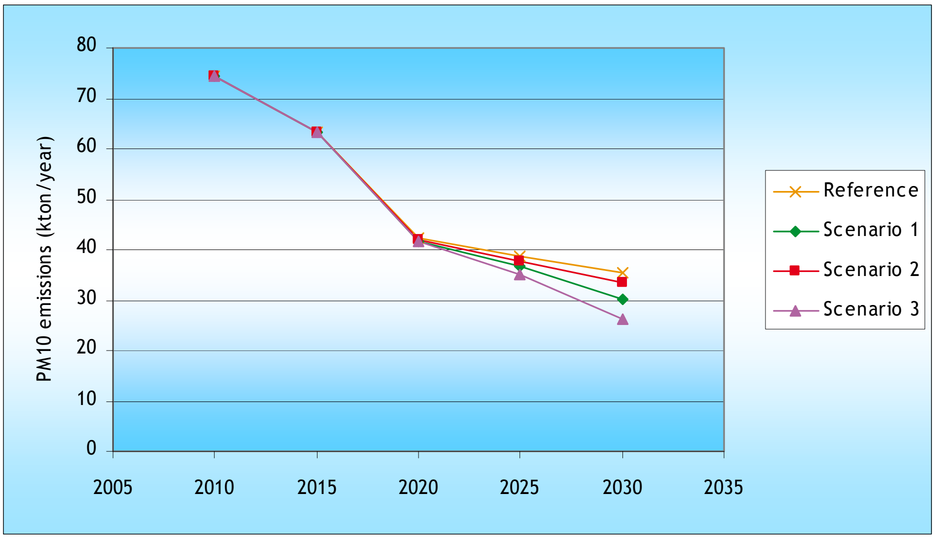
The development of $NO_x$ and $PM_{10}$ emissions of passenger cars in the EU is shown in the following two graphs (Figure 11 and Figure 12) – again excluding electricity production and upstream (well-to-wheel) fuel emissions. Clearly, both emissions are expected to reduce significantly due to the tightening of EU emission regulations. Replacing conventional cars with EVs will further reduce these emissions. $NO_x$ and $PM_{10}$ emissions of passenger cars are expected to reduce max. 1% in 2020, and about 6-26% in 2030 - depending on the EV market uptake. Again, these graphs show vehicle emissions only, i.e. do not include emissions due to electricity generation.

**Figure 11** **$NO_x$ exhaust emissions of passenger cars in the EU, in the three scenarios and the Reference Case**




NB. Emissions shown here are tank-to-wheel only, well-to-tank $NO_x$ emissions are not included.

**Figure 12** **$PM_{10}$ emissions of passenger cars in the EU, in the three scenarios and the Reference Case (exhaust plus tyre/vehicle emissions)**




NB. Emissions shown here are tank-to-wheel only, well-to-tank $NO_x$ emissions are not included.

## 3.5 Impacts on electricity production

### 3.5.1 Scenario modeling and charging assumptions

From the market uptake and electricity demand results, the impact of the EVs on electricity production could be determined using the IPM model (see Deliverable 3 for a description of this model). Each scenario varies from the Reference Case, which is described in Deliverable 3, only in the additional demand for electricity resulting from electric vehicle (EV) deployments. This demand increase is expressed in terms of the annual average electricity needs of EV, and through the hourly load profile assumed for charging each day. The Reference Scenario was calibrated to the PRIMES baseline model, as shown in Deliverable 3 (and thus meets EU targets, for example regarding renewable energy). In this section and the following subsections we present the results for the whole EU. Regional results can be found in Annex B.

The charging profiles in the three scenarios are summarised below (see also the scenario descriptions in Chapter 2), with more detailed descriptions following the summary:

1. Scenario 1 (S 1) assumes ‘most realistic’ EV deployments (based on current knowledge and estimates). An unmanaged charging profile in the nearer term (i.e. charging periods aren’t optimised with regards to power market supply/demand dynamics) transitions into a managed program for the EV fleet in the longer term (i.e. charging exploits intra-day market fluctuations in pricing).
2. Scenario 2 (S 2) assumes low EV deployments and a charging pattern for EV that remains unmanaged.
3. Scenario 3 (S 3) assumes high EV deployments and an unmanaged charging profile for the EV fleet that is transitioned into a managed program in the longer term.

The Electric Vehicles’ annual average demand for electricity, as assumed in each of the scenarios, was presented in Figure 6. Electric needs remain low relative to non-EV total demand. By 2030, EV demand equates to 3% of the Reference Case electricity demand under Scenario 1, 1% under Scenario 2, and 5% under Scenario 3.

The unmanaged versus managed load profiles for the increased demand from EV will have an impact on electricity prices and generation patterns. As stated above, in the early stages of EV penetration and throughout Scenario 2, the load profile for charging is considered unmanaged. Thereby, it is assumed that most EVs would be charged uniformly across days of the year but intra-daily the charging would occur mainly in the evenings, extending or increasing the typical peak demand times. Scenarios 1 and 3 assume however that the load profile will evolve as EV penetration progresses. Both scenarios have a transitional period occurring over 2018-2022 where the peak evening period for EV charging is lessened and off-peak periods compensate. In the managed stage occurring beyond 2022, charging is still uniformly spread across days of the year but most of the charging occurs overnight (i.e. in off-peak periods).

Figure 13 show the assumed EV load profile for each scenario in 2015. All three have similar shapes and are unmanaged. Note that there is quite an abrupt jump in electricity demand around midnight as most vehicle charging is assumed to take place between 6 and 12 pm.

**Figure 13 EV intra-day demand for electricity in 2015, by scenario**

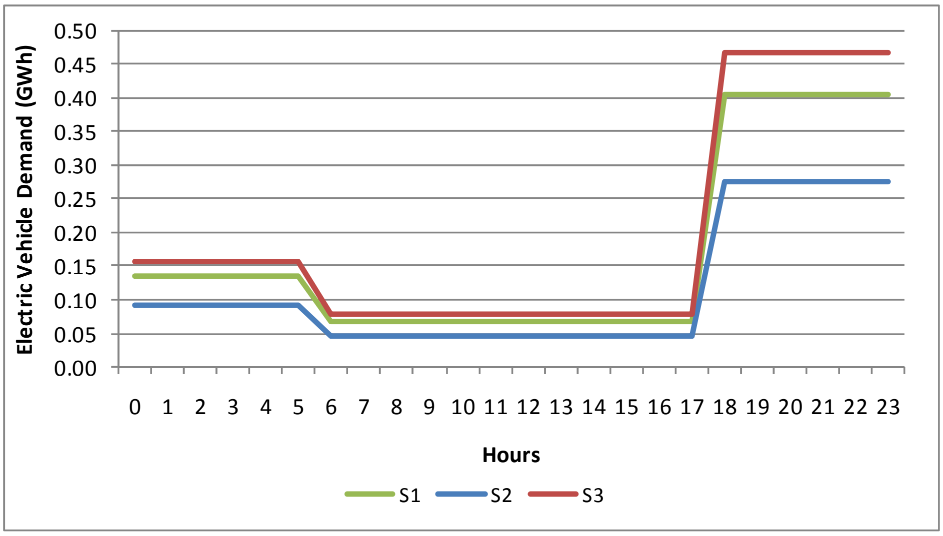
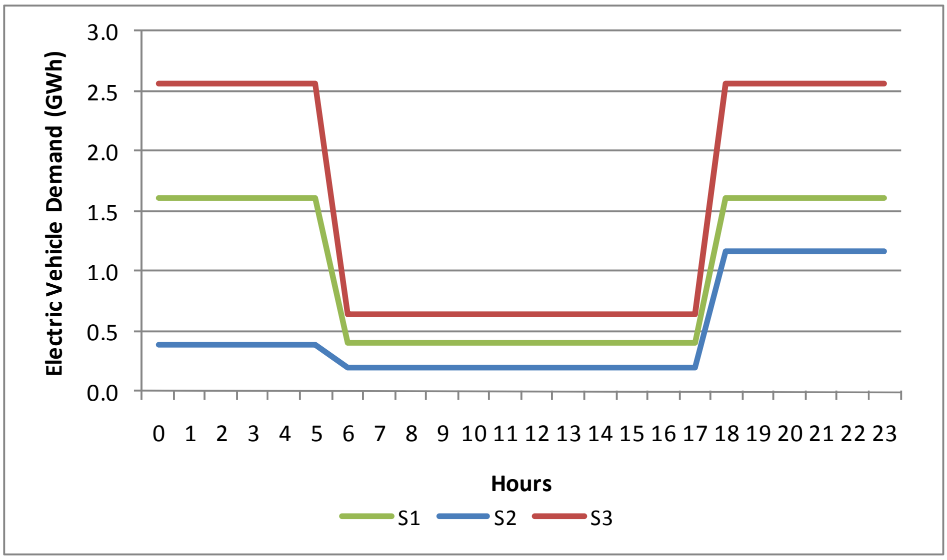


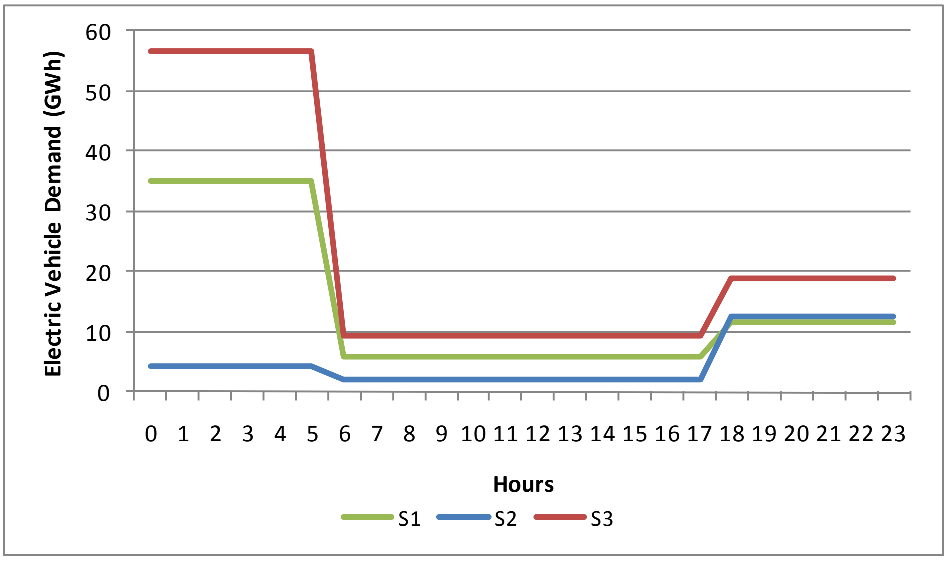

Figure 14 shows the EV load profile for each scenario in 2020. Scenarios 1 and 3 have similar load profiles because they are in the transitional stage. In this stage EV charging is largely spread between peak demand evening hours and off-peak night hours.

Figure 14 EV intra-day demand for electricity in 2020, by scenario




Lastly, Figure 15 shows the EV load profile for each scenario in 2030. Scenarios 1 and 3 have similar load profiles as they consider a managed charging stage. In the managed stage EV charging will occur during hours of lowest demand on the grid, typically, early mornings (between midnight and 6 am). Scenario 2 continues to be unmanaged, evident by the relatively high demand in the evening hours.

Figure 15 EV intra-day demand for electricity in 2030, by scenario




### 3.5.2 Impact on EU capacity mix

Figure 16, Figure 17 and Figure 18 illustrate that by 2030, under Scenarios 1, 2 and 3, additional plant construction totalling 18, 11 and 27 GW respectively, is required by 2030 compared to the Reference Case, which is described in detail in Deliverable 3. This correlates to the differing EV penetration rates, and associated electricity demand, modeled in the three scenarios.

Generally, the proportional increase in capacity across types is similar in Scenarios 1 and 2, as gas-fired generation is the favoured new entrant. The largest variation relates to gas and coal capacity: Scenario 1 shows less displaced coal and gas, as the additional demand provides a market for their continued presence. However, in Scenario 2, larger needs for peaking capacity are reflected in the share of 'other' builds (in this case oil/gas based peakers) principally in 2020 and 2025, as unmanaged EV charging requires greater flexibility within the system.

Under Scenario 3, although some capacity types benefit from the greater demand more than others, the growth in supply is wide-ranging. For example, renewable capacity grows as a share of the total capacity from 29 to 34% between 2025 and 2030. Relative to the Reference Case, wind and natural gas results are the most different, with gas nearly 13 GW higher and wind over 6 GW higher.

**Figure 16 Net changes in the EU capacity mix forecast between Scenario 1 and the Reference Case**

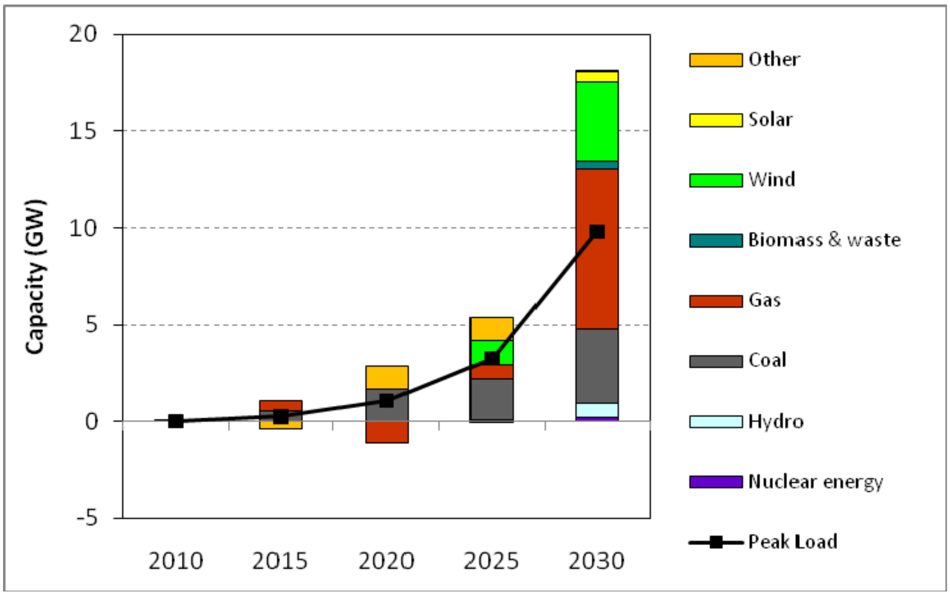



**Figure 17 Net changes in the EU capacity mix forecast between Scenario 2 and the Reference Case**

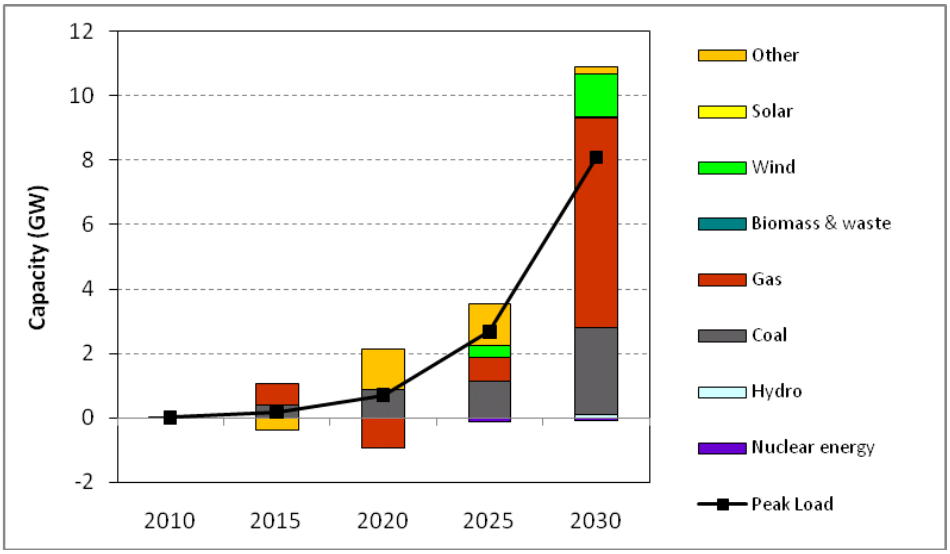
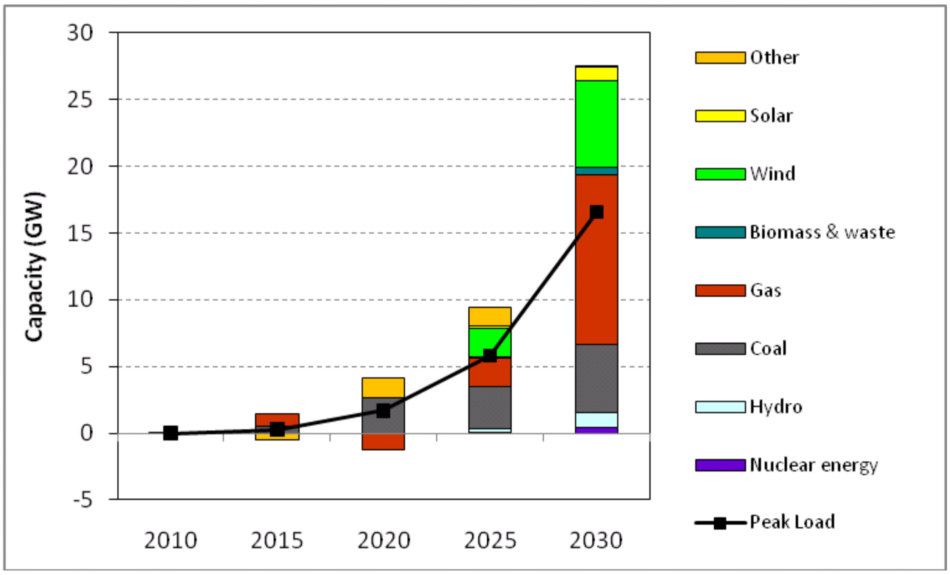


Figure 18 Net changes in the EU capacity mix forecast between Scenario 3 and the Reference Case




### 3.5.3 Impact EU generation mix

Under Scenarios 1, 2 and 3 (Figure 19, Figure 20 and Figure 21), by 2030, the EU generates more than 128, 67, and 190 of electricity, respectively, compared to the Reference Case. In Scenario 1, gas-fired dispatch composes the greatest share of the additional generation needed relative to the Reference Case. Specifically, by 2030, it provides nearly 70 worth of additional output. Similarly to the capacity mix, increases in coal and wind generation are also observed. However, the contribution of coal to the overall EU generation mix decreases by over 25% between 2025 and 2030. Other renewable generation types (hydro, solar and biomass) are largely unaffected by the growth in electricity demand ensuing from EV deployments. Under Scenario 3, the fuel types contributing most to the increases are natural gas, coal and wind. However, while natural gas increases its share of the EU generation mix from 50% to 57% between 2025 and 2030, coal decreases to 27% from 37%.

2030 generation in Scenario 2 is higher relative to the Reference Case for all fuel types except solar and hydro. Coal capacity competes with gas for the additional generation needs caused by EV, as the technologies' reliable availability better fits the demand peaks brought on by unmanaged EV charging.

Figure 19 Net changes in the EU generation mix forecast between Scenario 1 and the Reference Case

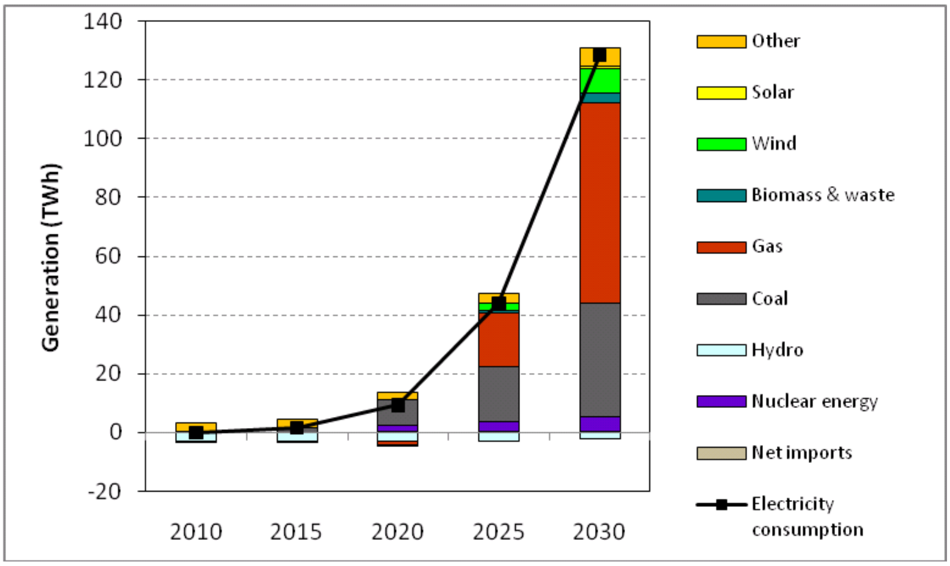



Figure 20 Net changes in the EU generation mix forecast between Scenario 2 and the Reference Case

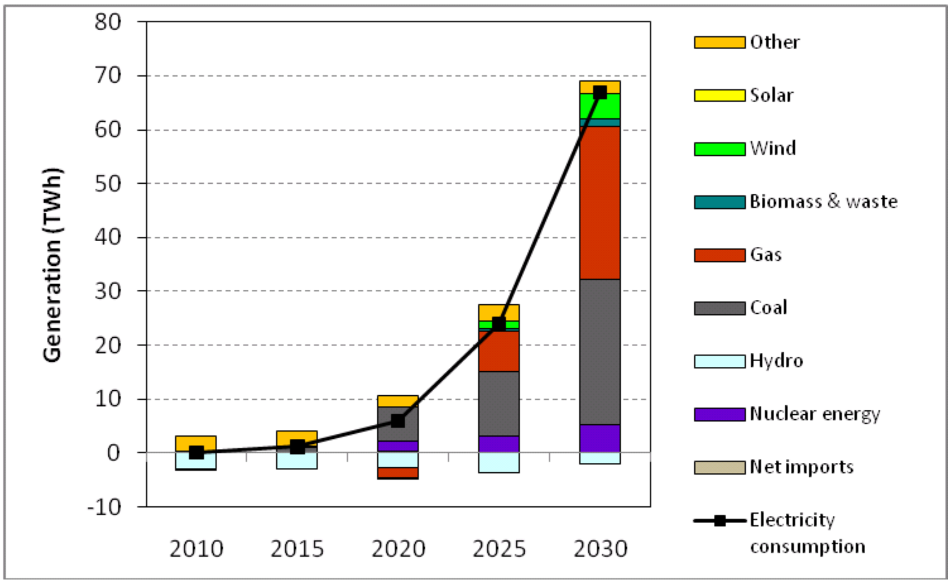
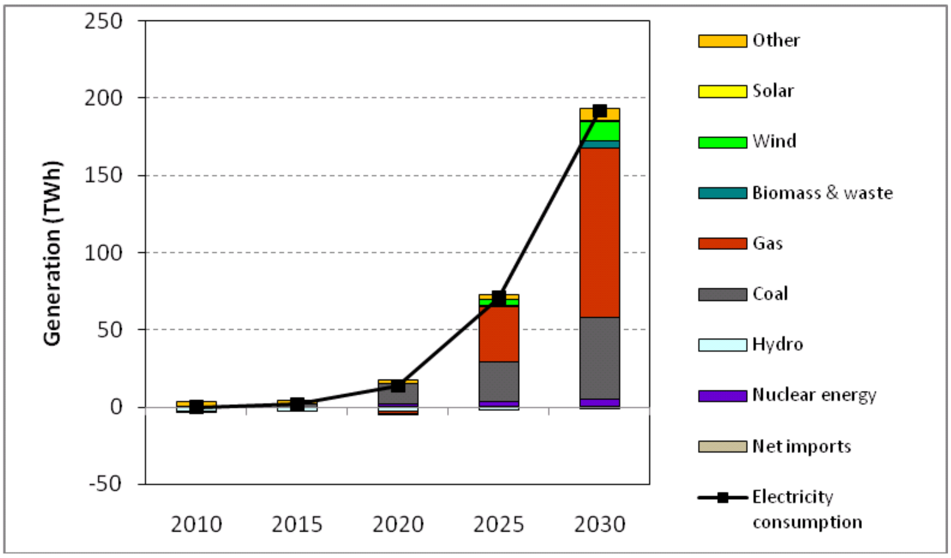


**Figure 21** **Net changes in the EU generation mix forecast between Scenario 3 and the Reference Case**




Overall, the results highlight the impact of managed and unmanaged EV charging on future electricity capacity and generation needs. The managed case, assuming smart charging infrastructure, enables the greater use of gas and wind generation to handle additional peak load requirements. However, in the unmanaged situation (Scenario 2), coal tends to benefit most, as it's relaibility is best suited to handle the unmanaged demand profiles brought about by EV charging.

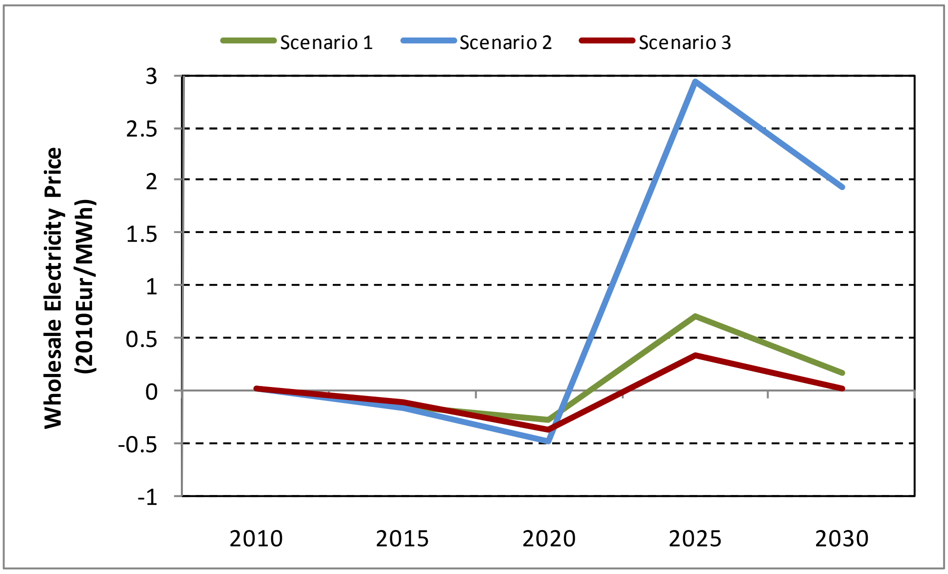
### 3.5.4 Impact on electricity prices and emissions

*Peak and base load wholesale electricity price spread*

Figure 22 and Figure 23 show the variations in wholesale price trajectories for peak and base load power relative to the Reference Case, for the average EU.

In Scenario 1, peak prices remain fairly close to the Reference Case, with only a slight increase as supply/demand tightness is raised with the supplemental EV demand. Similar peak prices are expected in Scenario 3; however, the higher demand generated by the EV deployments is not expected to create price spikes as the demand is better managed and concentrated so as to flatten the load profile. Under Scenario 2, peak prices remain fairly close to the reference view until 2020 but then climb nearly 3 €/MWh higher, as a direct result of unmanaged EV charging at peak demand times (i.e. evening periods).

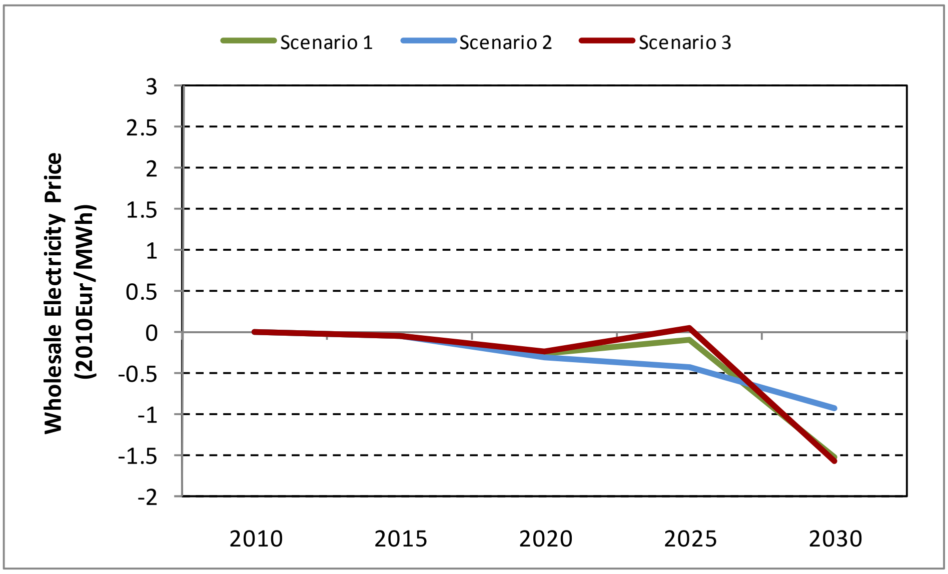
**Figure 22 Differences in the peak electricity prices between Scenario 1, 2 and 3 relative to the Reference Case**




In Scenario 1 and 3, base load prices remain close to the Reference Case through 2025. This is logical given the small share of EV in total assumed demand. In general, for both scenarios, power prices are slightly lower across the years relative to the reference view. The higher demand late in the study period allows further investments in new entrant renewable and gas capacity, which due to their timing are more efficient units at low capital costs. Although the supply/demand balance in the market tightens with the EV incremental demand, the managed distribution of EV electricity requirements to flatten the overall load profile compensates the potential for price climbs. For Scenario 2, base load prices remain close to the Reference Case through 2020 but then decrease when efficient new entrants of choice appear in larger numbers.

Note that these impacts on electricity price were not incorporated in the modelling of the total cost of ownership of EVs and their market uptake.

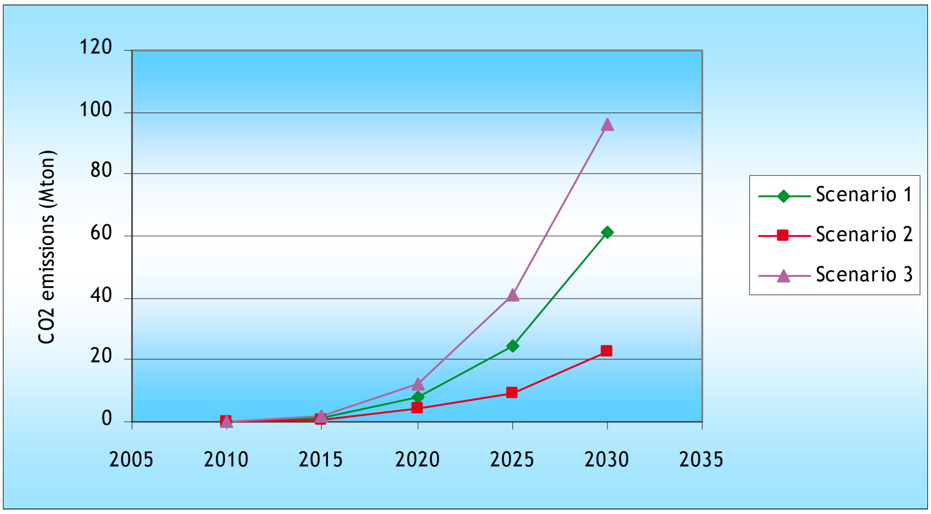
**Figure 23** **Differences in the base load electricity prices between Scenario 1, 2 and 3 relative to the Reference Case**




### *$CO_2$ emissions from the electricity sector*

Figure 24 shows emission differences for Scenario 1, 2 and 3 relative to the Reference Case. As expected, $CO_2$ emissions from the power sector show strong correlation with increasing EV penetration rates, due to increasing electricity demand. By 2030, $CO_2$ emissions are 8, 5 and 2% higher in Scenario 3, 1 and 2 respectively, when compared to the Reference Case. This does not represent a significant increase above the EU ETS capped allowances, and highlights the opportunity for a partial expansion of the EU ETS to road transport without increasing the cap.

**Figure 24** **Electricity sector $CO_2$ emissions due to EVs, difference between Scenario 1, 2 and 3 and the Reference Case**



In terms of $CO_2$ emissions, the economic decisions that the IPM model takes are about:

a Fuel switching.

b Retiring old dirty plants and building newer cleaner plants in their place. Or

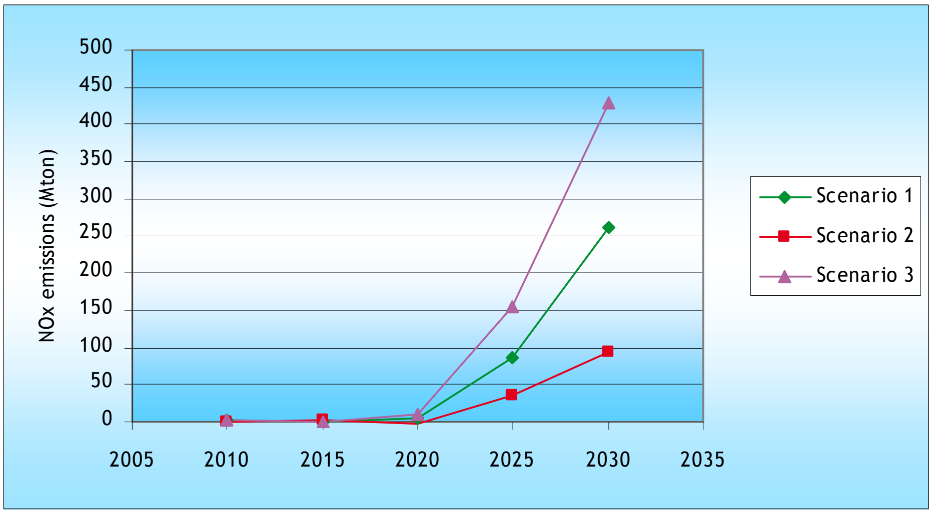
c Implementing CCS on coal plants.

At the $CO_2$ price levels assumed in this analysis CCS is not economical so a) and b) are implemented. As such, the costs of implementing a) and b) are taken into account (i.e. capital costs, fuel costs and carbon costs), along with all other system costs and policy constraints (such as renewable generation targets). The model then solves to minimise system costs of meeting electricity demand throughout Europe and through time.

*$NO_x$ emissions from the electricity sector*

Since electricity demand rises with the deployment of EV, the electricity generation increase as a response is likely to lead to further $NO_x$ emissions. Results are shown in Figure 25.

**Figure 25 Electricity sector $NO_x$ emissions due to EVs, difference between Scenario 1, 2 and 3 and the Reference Case**




However, the uncertainty regarding these results are relatively high, for a number of reasons:

- First, the complexity of the various $NO_x$/$SO_x$ scrubbing technologies in use (activated carbon injection, fabric filters, selective catalytic reduction, wet or dry flue-gas desulfurization, etc.) Each one has its own emission reduction potential, and its own cost level (which will determine if the unit stays online and emits or not).
- Second, due to the many different ways in which member states limit the emissions of these pollutants. The policies vary from cap-and-trade schemes to command-and-control, and some countries apply emission limits that are more stringent than the EC directives, while other don't. This level of detail is not implemented in the model.
- There is no clear overview of current level of emission reduction technology applied in the various power plants throughout the EU, which further complicates the modelling.

Emissions would decline with EV deployment if a) the added demand from EVs were met with non-emitting generation sources, and/or b) the generation mix employed to meet the rest of demand (i.e. the demand of the reference case) changed to lower emitting sources as a response to EV deployments and the change in load shape. Although the analysis doesn't lend to this conclusion on an economic basis, the uncertainties surrounding the change in total power sector emissions due to EV is fairly broad because EV demand is a small portion of the total load.

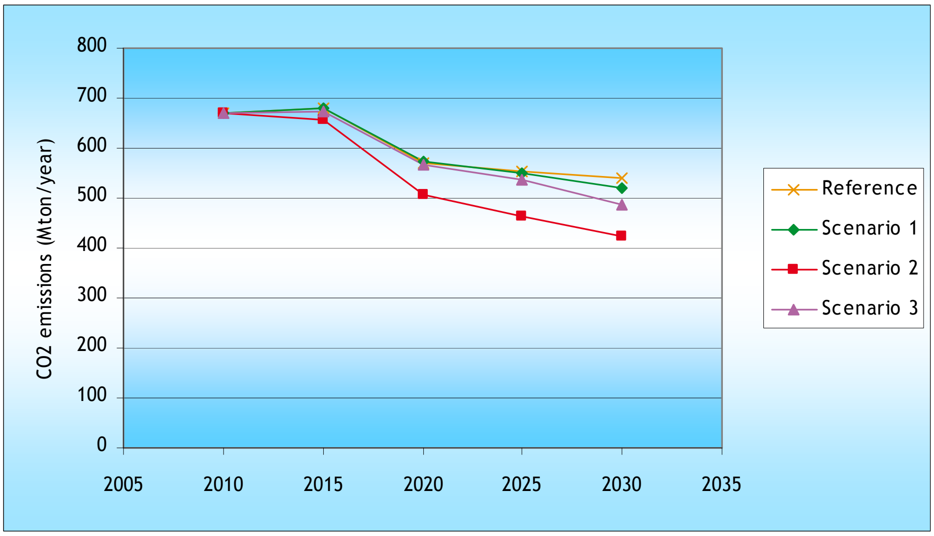
### 3.6 Overall impacts on emissions

The net effect of reduced diesel and petrol use on the one hand and increased electricity use on the other hand can now be calculated by combining the impact on vehicle emissions (Section 3.4) with the impact on the power sector (Section 3.5). In order to arrive a overall emission impacts, the upstream emissions of transport fuel production are also included (using emission data from TREMOVE version 3.3.2 alt).

The results for net the impact on the $CO_2$ emissions is given in Figure 26. This graph shows that the additional $CO_2$ emissions of the power sector are less than the $CO_2$ emissions saved from reduced diesel and petrol use in the transport sector itself: the increased market uptake of EVs leads to a net $CO_2$ reduction. In Scenarios 1 and 3, significant effects are not to be expected before 2020, as EV market uptake increases only slowly before that. The ICEV fuel efficiency improvement in Scenario 2 (which was assumed to be higher than in Scenario 1 and 3) lead to more immediate results.

In 2030, Scenario 1 achieves an overall 21 Mton $CO_2$ emission reduction, Scenario 2 reduced $CO_2$ emissions by 116 Mton, and Scenario 3 results in 53 Mton reduction. Compared to the $CO_2$ emissions of EU passenger cars in the Reference Case, this amounts to reductions of about 4, 21 and 9% in 2030. Reductions are larger in Scenario 3 than in Scenario 1 due to the higher uptake of EVs in Scenario 3, the high reduction in Scenario 2 is due to both the EV penetration and the improved ICEV fuel efficiency.
It should be noted that these figures do not take into account that the electricity sector emissions are part of the EU ETS, and should thus be 'automatically' compensated by emission reductions elsewhere in the ETS. If these emissions are considered to be zero due to this effect, only direct emissions result, as shown previously, in Figure 10.

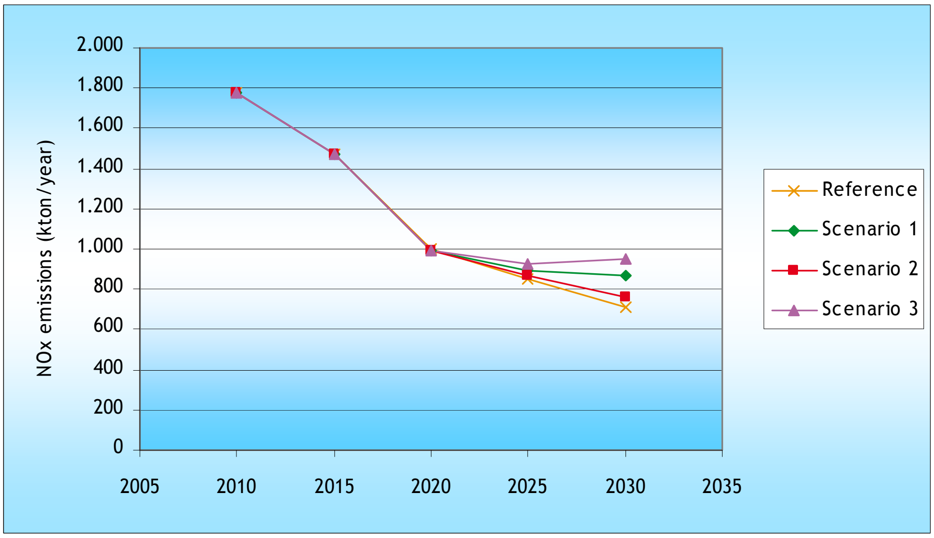
Figure 26 Net impact on $CO_2$ emissions from passenger cars in the EU (excl. effects of the EU ETS)




NB. Emissions from petrol and diesel are well-to-wheel, emissions from electricity include power production emissions only (not emissions due to, e.g. coal mining or gas production).

The development of overall $NO_x$ and $PM_{10}$ emissions from passenger car transport in the EU is shown in Figure 27 and Figure 28. Clearly, in all scenarios, the additional $NO_x$ emissions from power production are higher than the emissions reduced by the reduced use of ICEVs. In these scenarios, the net effect of the electric vehicles is therefore an increase of overall $NO_x$ emissions in the EU, of about 150, 50 and 240 kton $NO_x$ in 2030, for the three scenarios respectively.

Figure 27 Overall impact on $NO_x$ emissions of passenger car transport in the EU, emissions from both vehicles and power production

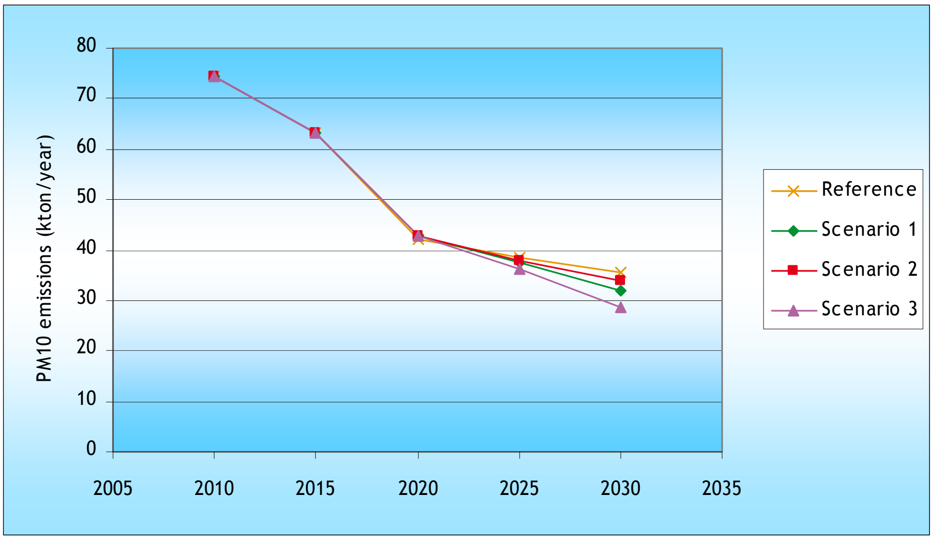



NB. Emissions from petrol and diesel are well-to-wheel, emissions from electricity include power production emissions only (not emissions due to, e.g. coal mining or gas production).

These results may raise the question whether these additional $NO_x$ emissions are mainly due to EV use (i.e. electricity demand) in some specific regions or member states of the EU. However, as explained in Section 3.5.4, the modelling representation of the regulatory constraints on conventional pollutant emissions (namely the Large Combustion Plant Directive and Industrial Emissions Directive) is not considered precise enough to identify clearly the impact of EV deployments on regional $NO_x$ emissions. The small increase in electricity demand caused by EV deployments signifies that $NO_x$ emissions are only marginally affected. At the same time, Member State implementation of European Commission directives on conventional pollutant emissions are complex and wide-ranging enough that details are not fully captured in the modelling framework. However, it is conceptually likely that the $NO_x$ emissions caused by EV deployments will vary by region, due to geographic differences in the sources of generation likely employed to meet the EV demand. Regions more likely to meet the additional demand with coal dispatch, principally in Eastern Europe, are likely to see a higher impact on power sector $NO_x$ emissions.

The development of overall $PM_{10}$ emissions from passenger car transport in the EU is shown in Figure 28. The additional $PM_{10}$ emissions of the power sector are found to be relatively small, compared to the reduction of direct vehicle emissions, so that the EV are found to result in a net reduction of $PM_{10}$ emissions.

**Figure 28 Overall impact on $PM_{10}$ emissions of passenger car transport in the EU, emissions from both vehicles and power production**




NB. Emissions from petrol and diesel are well-to-wheel, emissions from electricity include power production emissions only (not emissions due to, e.g. coal mining or gas production).

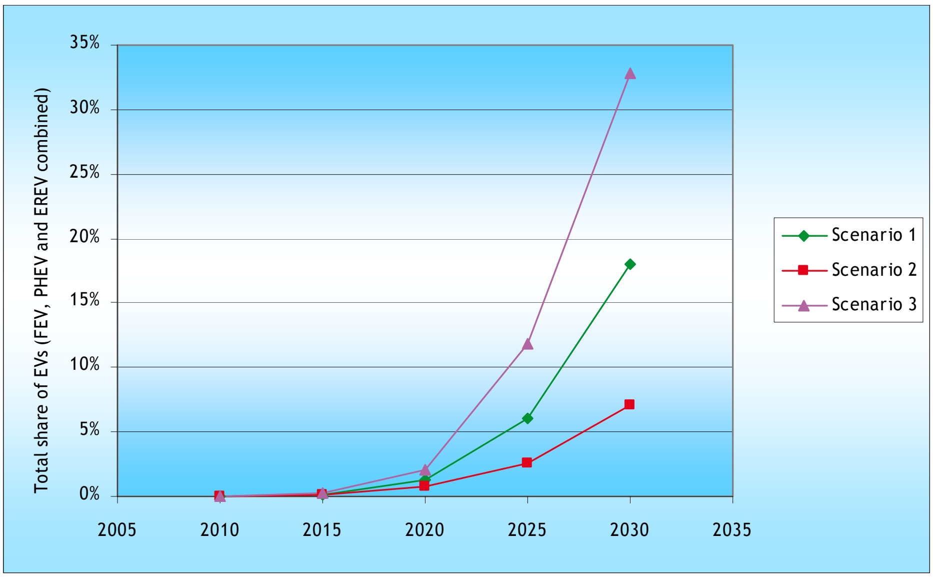
## 3.7 Impacts on air quality

The impacts on air quality depend on the impacts on pollutant emissions, the location of these emissions and, in the case of particle emissions, the size and type of emissions.

Whether or not the air quality in a region (or a specific street) will benefit from the market uptake of EVs will depend on a number of factors. Firstly, it may be expected that the EV market uptake will not be evenly distributed over the EU, but rather start in specific cities or regions with favourable circumstances (e.g. with high government incentives, high density of charging points, high income population, etc.). In these regions, positive impacts on noise may occur much earlier than in regions with less EVs.
Secondly, the impact of electrification of passenger cars will also depend on the share of these cars in total air pollution. For example, in locations with relatively dense goods transport, air quality will not reduce significantly if passenger cars drive electrically.

A first indication of what local impacts can be expected may be derived from the expected share of EVs in the overall car fleet: the EU-average shares in the various scenarios is shown in Figure 29. If these cars were evenly distributed throughout the EU, significant impacts on air quality should not be expected before 2025/2030 – at that time, emissions of ICEs have reduced so much that air quality problems are thought to be solved. If EV 'hot-spots' can be achieved at specific locations, i.e. if high shares can be realised in specific regions or (parts of) cities, positive impacts might be possible at an earlier stage. However, how high this share must be to achieve any significant impacts requires a detailed analysis of local circumstances[5].

**Figure 29 Overall share of EVs in the EU car fleet, FEVs, PHEVs and EREVs combined**




5 If governments want to improve local air quality with EVs, it would be advisable to also investigate the possibility of electric goods transport, as heavy goods vehicles typically have relatively high emissions of $NO_x$ and $PM_{10}$.

In order to estimate the overall air quality impacts, we value the various emissions, distinguishing:

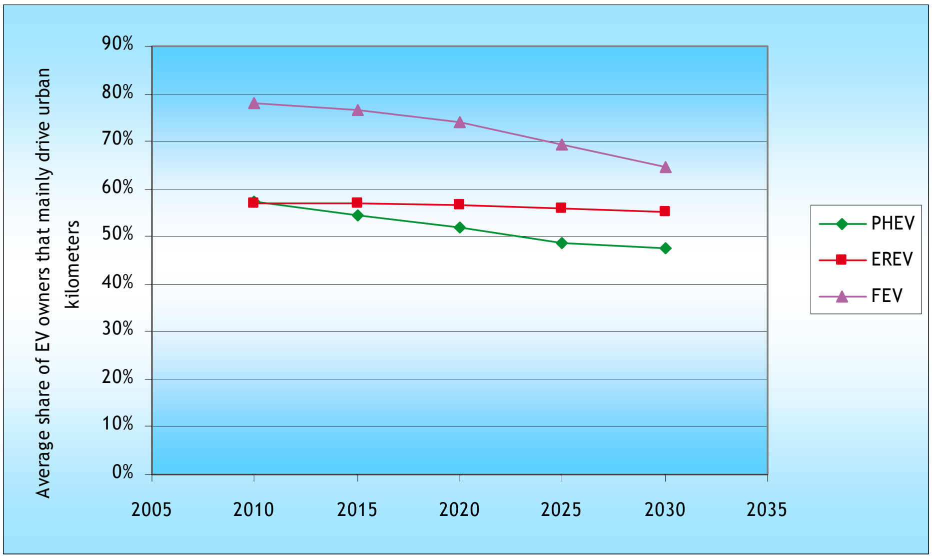
- $NO_x$ emissions.
- PM emissions from electricity plants.
- PM emissions from ICEs.
- PM emissions from brakes and tyres.

For particle emissions, the location where emissions take place is very important. In densely populated areas the impacts of pollutants is much higher than in less populated areas. For assessing air quality impacts, we distinguish the area types: metropolitan areas, urban areas and rural areas. This is mainly relevant for ICEV emissions as electricity plants are usually outside built-up areas.

In the scenario calculations, a distinction is made between car owners that drive mainly in urban regions, and those that mainly drive in non-urban regions and longer distances. For the latter, vehicles with limited range (and relatively long charging times) will not be very practical and attractive. They will rather opt for PHEVs and EREVs than for FEVs as long as the range of the latter is much more limited. This results in differences in sales of EVs for these groups, resulting in higher shares of FEVs driving in urban areas than in non-urban areas.

Emission reductions, and therefore (positive) impacts on air quality, can thus be expected to be higher in urban areas than the average EV shares and impacts may suggest. To illustrate this effect, the share of urban driving as calculated for Scenario 1 is given in Figure 30. These results show that with the assumptions used in this scenario, the large majority of FEVs and almost 60% of PHEVs and EREVs are expected to drive in urban areas. These shares reduce somewhat over time, especially those of FEVs, due to cost reductions, increasing ranges and availability of charging points. Since most of the EVs in the car fleet are PHEVs, we can see from the graph that in this scenario, about 50-60% of the EV kilometres are estimated to be on urban roads. Results for the other scenarios are similar to this and are given in Annex C.

**Figure 30 Scenario 1: the share of EVs expected to drive mainly in urban regions**



The impact on air quality in urban areas further depends on which share of the urban kilometres of the PHEVs and EREVs will be driven electrically, in stead of with their ICE – only the first will reduce local emissions. For the impact calculations, we have assumed that 90% of the urban driving of PHEVs and EREVs will be electric (no reliable data on actual driving patterns are available yet). It is further assumed that all power generation emissions will be in non-urban areas.

The overall impact of the various scenarios on the external cost of air pollution is negligible up to 2020. In 2030 the air pollution cost slightly decrease compared to the Reference Scenario because the benefits of the lower PM emissions (see Figure 28) outweigh the cost of the higher $NO_x$ emissions (see Figure 27). The decrease in air pollution costs in 2030 is estimated at about 2% in Scenario 1, 10% in Scenario 2 and 5% in Scenario 3.

## 3.8 Impacts on noise emissions

Impacts on noise emissions are very difficult to estimate, as this will typically depend on local and regional circumstances – similar to those discussed in the previous section on air quality impacts. In addition to the issues described there, noise emissions depend on vehicle speed: the higher the speed, the more noise will come from the tyres rather than from the engine. Noise emissions will thus reduce more if traffic at low speeds is electrified, at higher speeds the impact will be much less. Therefore significant noise impacts are likely to be limited to urban areas where driving speed are relatively low. And, finally, noise emissions depend on whether the EVs indeed drive electric: part of the kilometres driven by the PHEVs and EREVs will be driven with conventional propulsion.

Table 5 shows the impacts of the various scenarios on the total external costs of traffic noise in urban areas. These estimates should be regarded as rough estimates and are based on noise cost valuation from the IMPACT project and the assumption that EV in urban areas produce half the noise emissions intensity of a conventional car (based on DGMR, 2010). We assumed that the noise levels of other vehicles than passenger cars remain unchanged.

**Table 5 Indicative estimate of traffic noise impacts in urban areas**

| | 2020 | | | 2030 | | |
|---|---|---|---|---|---|---|
| Scenario | 1 | 2 | 3 | 1 | 2 | 3 |
| Share of EV in car fleet | 1.2% | 0.7% | 2.1% | 18.0% | 7.1% | 32.8% |
| Total noise costs | -0,1% | -0.1% | -0.2% | -1.7% | -0.7% | -3.2% |

The impacts are relative small compared to the share of EV for various reasons:
- In all scenarios Heavy Goods Vehicles (HGVs) remain 100% conventional and they have a relatively large share in the noise costs.
- EVs have lower, but no zero noise emissions.
- The impacts of changes in noise emissions on overall noise levels and costs are highly non-linear, due to the nature of noise levels.

The impacts of EV on traffic noise in non-urban areas will be even smaller than in urban areas: because of the higher average driving speed in rural areas, the contribution of engine noise is relatively limited.

## 3.9 Impacts on materials and waste

As discussed in the report on WP 2, EV batteries contain materials that are either rare or difficult to mine, such as rare earth elements and lithium. Combining the number of EVs in the scenarios with the estimated amounts of these materials per vehicle can give an indication of the quantities of these materials that are needed for the batteries in these cars.

The amount of rare earth elements required for battery production is still very uncertain and depends on further battery design developments. Lithium content can be predicted with more certainty.

The results for total lithium use in EVs are given in Figure 26. Depending on the scenario (i.e. on the EV uptake), total lithium use in EVs can increase to 20,000 to 105,000 ton in 2030. This figure does not include any additional battery production, such as for battery replacement in existing cars, or for battery swap systems. This would further increase lithium demand for EVs. These figures can be compared to total known global lithium reserves, which are estimated at 28 million tons (probably a conservative estimate). Potential availability of lithium thus does not seem to be a restriction to the developments predicted here.

However, lithium *production* might need to increase after 2020 at considerable speed. Estimates on the annual lithium demand for new EVs in the three scenarios are given in Figure 32. Demand remains limited until 2020 (ranging from 400 to 2,000 ton/year, depending on the scenario), but demand may increase to 3,000-20,000 ton/year in 2030 (again depending on the scenario). When these data are compared with the current annual lithium production of 27,000 ton, it will become clear that global production will have to increase significantly after 2020 if these scenarios come true.

Note that as the composition of the batteries is still under development and the future battery capacity in the vehicles is still unknown, these data are relatively uncertain and should be seen as an indication only. The assumptions regarding battery capacity per vehicle are provided in Annex D.7. The uncertainty margins in the graph represent uncertainty in the amount of lithium needed per battery (0.1-0.13 kg lithium/kWh).

**Figure 31** **Total amount of lithium in the EU fleet of Electric Vehicles in the scenarios**

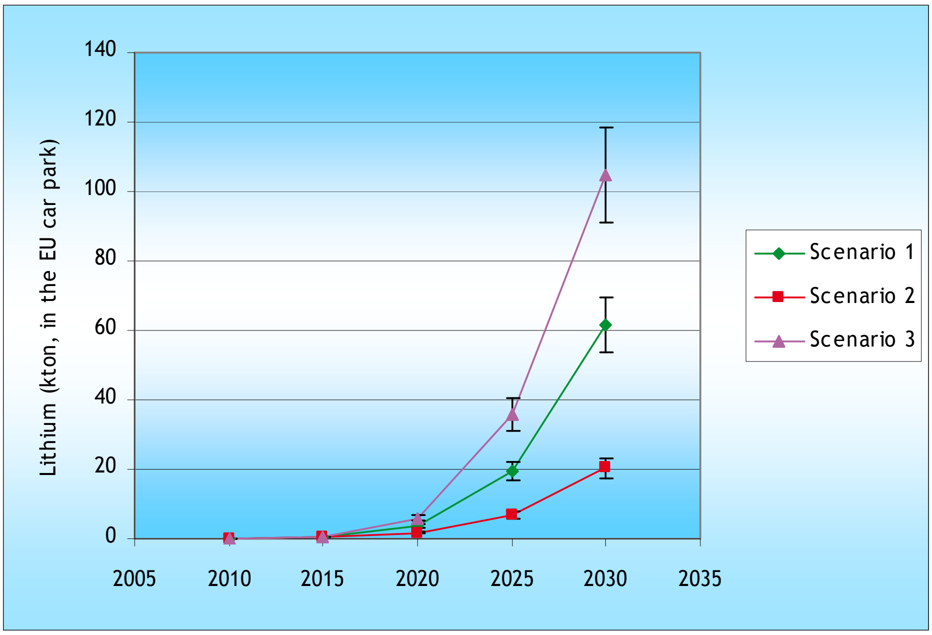
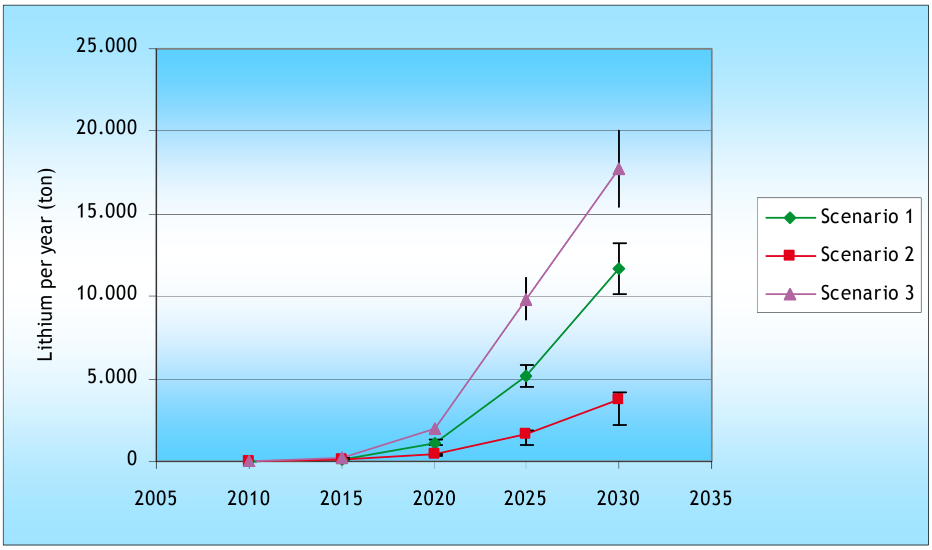



**Figure 32** **Annual demand for lithium for EU Electric Vehicles sales in the scenarios**




## 3.10 Economic impacts

The economic impact of the EV uptake in the three scenarios will depend on the perspective: governments, car manufacturers, car owners, electricity companies and companies in the petroleum industry will all be affected by the developments, but in different ways and to a different extent.

First, government revenues will be affected due to changes in:
- Excise duty and VAT revenues on fuel and electricity - excise duties on transport fuels are typically higher than on electricity (per GJ and even more so per km).
- VAT revenues of vehicle sales – these may increase due to the higher catalogue price of EVs compared to ICEVs.

- Vehicle purchase and registration tax and company car tax revenues – in many EU Member States, these are differentiated to $CO_2$ emissions, in some countries EVs are exempt and fall into lower tax categories.
- Subsidies – in some Member States, car buyers are eligible for subsidies when they buy an electric vehicle.
- Charging points – various cities and regions offer subsidies for charging points to EV owners or offer charging points that are publically available.

Car manufacturers may be affected economically due to a number of developments, such as:
- Costs of R&D.
- Investments in EV production lines, training of personnel, etc.
- Different profit margins on EVs, compared to conventional cars.
- Costs or profits of battery lease services (if applied).
- If changes take place quickly: early write-off of ICEV production lines.
- Changes in total vehicle sales and market shares.

Car owners or drivers are affected due to:
- Changes in vehicle cost (incl. taxes).
- Changes in fuel/energy cost (incl. taxes).
- Investments in charging points (if car owners need to provide their own charging point, some may be able to use existing sockets in their home or use publically provided charging points).
- potential changes in insurance and maintenance cost.

Companies in the electricity sector may be affected due to:
- Investments in charging points (if applicable).
- Investments in (local) grid expansion.
- Costs of additional electricity production.
- Increased revenues from increasing electricity sales.

Companies in the petroleum sector may be affected due to reduced sales of diesel and petrol.

Within the scope of this project, it is impossible to determine all these cost items for the different scenarios, and provide reliable predictions of the economic impacts for the various stakeholders. However, it is possible to provide estimates of some of these impacts, as some can be derived from the data that have been gathered and calculated. These results are given below.

### 3.10.1 Impact on government revenues

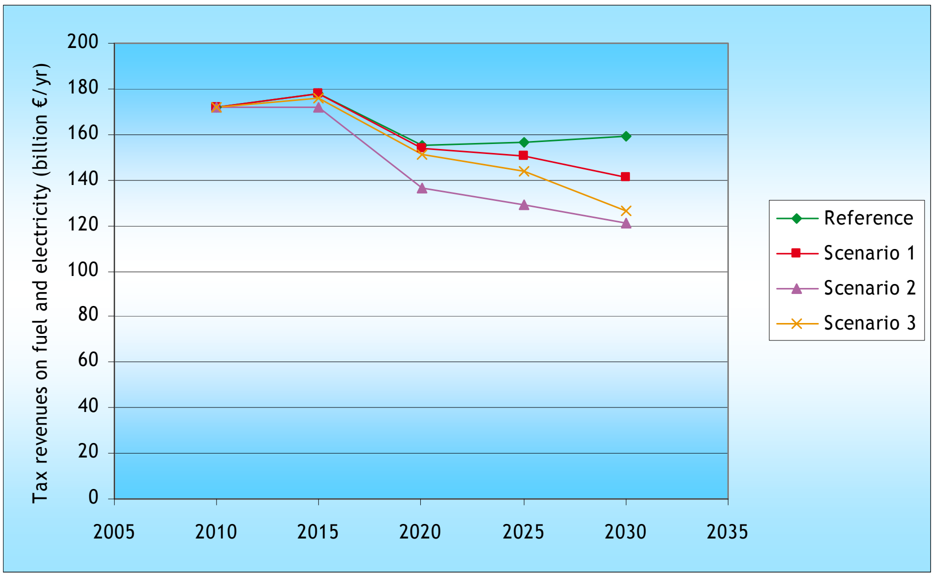
Various government revenues are likely to change once the scenarios evolve, namely:
- Excise duty and VAT revenues from fuel and electricity sales.
- VAT revenues from vehicle sales.
- Revenues from registration and circulation tax, and from company car taxation.

Assuming that the current tax levels remain the same over the coming 20 years (costs are expressed in terms of 2010 €), the impacts on fuel and electricity tax revenues and on vehicle VAT revenues can be estimated, as well as the impact on vehicle registration and circulation tax revenues. It is worth noting, however, that especially the estimate of the latter impact should only be considered to be a quite crude estimate, as the actual vehicle taxation systems could not be modelled in detail as they are quite complex (and variable) in many EU member states[6].

The impact on tax revenues from transport fuel and electricity are depicted in Figure 33. In Scenarios 1 and 3, the effect of the market uptake of EVs on energy tax revenues can be clearly seen to start to become significant after 2020, when the sales of EVs start to increase. This results in an annual revenue loss of about € 1 to 3.5 billion in 2020, which increases to € 18 to 38 billion in 2030 if the taxes are held constant at the current levels (with Scenario 1 resulting in the lower value and Scenario 3 in the higher value).

In Scenario 2, fuel tax revenues decrease right from the start – compared to the reference – as the fuel efficiency of the ICEVs is assumed to reduce faster than in the other scenarios. This reduces $CO_2$ emissions, as shown in Section 3.4, but it also reduces revenues from fuel taxes in the EU-27, by about € 18 billion in 2020 and € 38 billion in 2030.

**Figure 33** **Annual revenues of fuel and electricity excise duty and VAT in the EU-27, for the three scenarios and the Reference Case**

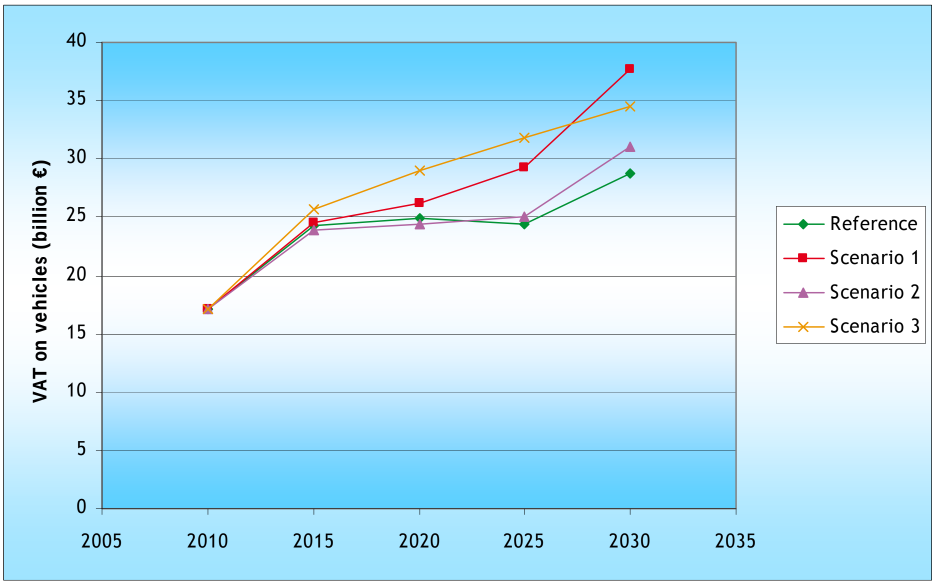



The impact on VAT revenues from the sales of passenger cars is also affected by the market uptake of EVs, from 2015/2020 onwards. Increased EV sales can be expected to increase government revenues, due to the higher catalogue price of the EVs when compared to ICEVs of the same size. Assuming that about 50% of the electric vehicle buyers pay VAT (i.e. assuming that 50% of these vehicles are sold to companies), the VAT revenues on vehicles within the EU-27, as calculated in our model, can be found in Figure 34. As it is assumed in all scenarios that the cost of ICEV increases in the period 2010-2020 due to the required fuel efficiency improvements and the vehicle sales are assumed to increase as well, the VAT revenues are expected to increase in that period. Compared to the Reference Case, these revenues are found to decrease slightly in Scenario 2 in the period up to 2023, due to the more favourable cost developments of ICEVs that are assumed here (and the low market share of

6 See Annex D.5.5 for an explanation of how the various vehicle taxation systems and levels were modelled in this impact analysis.

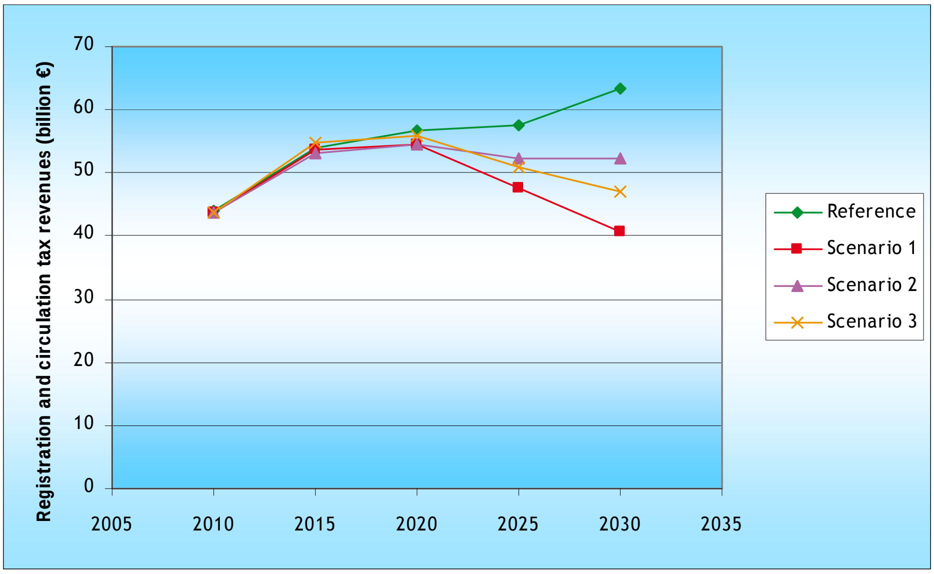
EVs). After 2023, increased VAT revenues of the EVs counteract that effect, resulting in about 2 billion additional VAT revenues in 2030.
In Scenarios 1 and 3, the VAT revenues are expected to increase by € 1.5 to 4 billion in 2020, and € 9 to 6 billion respectively in 2030.

**Figure 34 Annual revenues of VAT on passenger cars sales in the EU-27, for the three scenarios and the Reference Case**



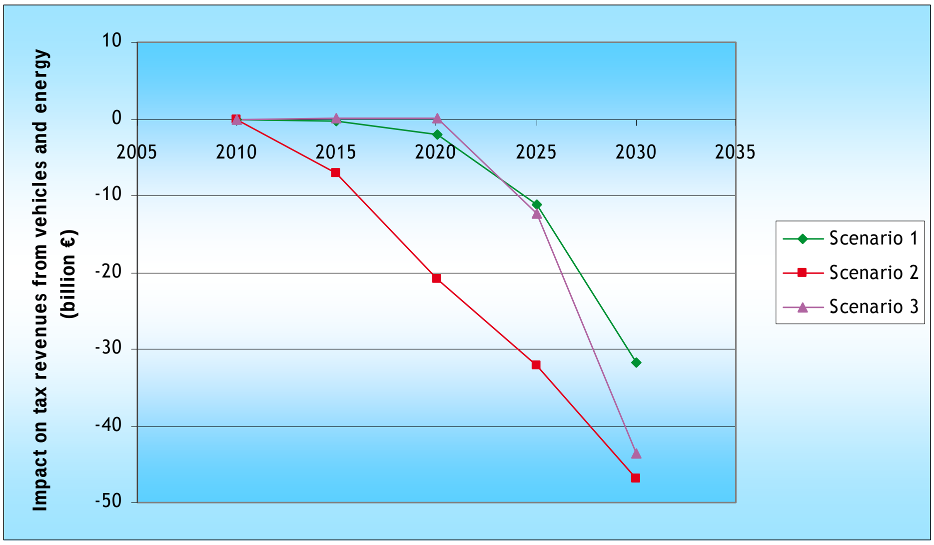

And finally, a rough estimate of the impact on the annual revenues from circulation and registration taxes throughout the EU-27 is depicted in Figure 35. These data also include direct subsidies or tax exemptions for EV buyers or owners, in place in several EU countries. In the modelling, the assumptions on vehicle taxes are largely based on current taxation policies throughout the EU, where $CO_2$ differentiation of these taxes is becoming very common. The revenues can be seen to decrease with increasing shares of EV sales. The impact remains limited until 2020, but range from 11 to 23 billion € in 2030 (18-36%), depending on the EV market uptake.

Figure 35 **Annual revenues of registration and circulation taxes in the EU-27, for the three scenarios and the Reference Case**




The net impact of these three effects - reduced revenues from energy tax, registration and circulation taxes, and increased VAT revenues of vehicle sales – is shown in Figure 36. This loss of revenues will amount to about 13-20% of the total revenues from these taxes in 2030 (again, assuming current taxation will remain in place).

Figure 36 **Estimate of the annual impact on revenues of vehicle and energy (fuel and electricity) taxes in the EU-27, for the three scenarios**




Note that these impacts will not be evenly distributed over the various Member States. They will vary with the share of EVs, and therefore with the incentives that these vehicles receive in the various countries. Also, it has to be realised that these calculations are based on quite a number of assumptions and simplifications, the uncertainties in these data are therefore quite high.

### 3.10.2 Charging points investments

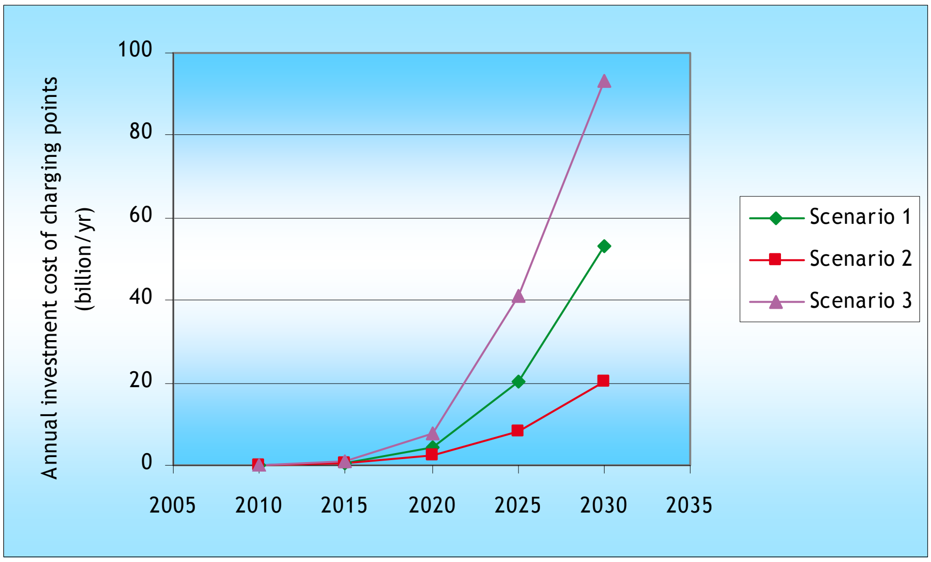
As the market penetration of EVs increase, sufficient charging points and/or battery systems need to be provided to the EV owners. As discussed in Deliverable 3, there are various options for charging being developed and applied, the main options are slow charging, fast charging, battery swap systems and induction charging. Each of these systems have different characteristics and cost.

Well-founded estimates about the number of charging points needed for a given number of cars are still scarce, but cost estimates per charging point are provided in Deliverable 3. The overall investment costs of charging points were then estimated, using the assumptions that:

- For each EV, one slow charging point is needed at cost of € 1,500 per outlet. And
- For each 2,000 EVs, a set of two fast charging power outlets is needed (at about € 30,000 per public outlet)[7].

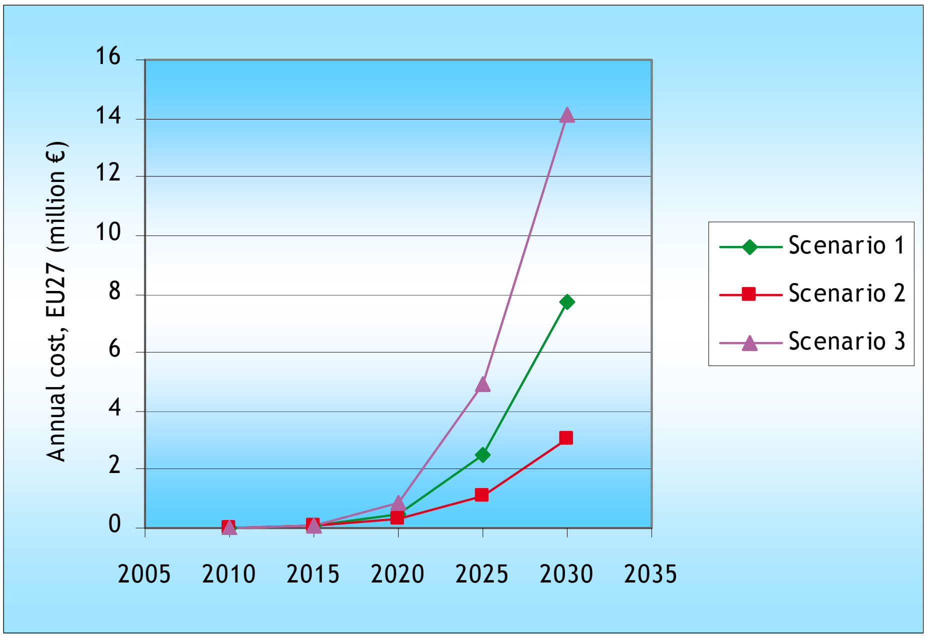
Results of this analysis are given in the following figures: estimates of the annual *investments* needed in new charging points are given in Figure 37, the resulting depreciation costs are given in Figure 38. In the latter, it is assumed that slow chargers will be depreciated over 15 years, fast chargers over 20 year. Depreciation rate is 5.5%. Operational and maintenance costs are not included. The vast majority of these costs (99%) are due to the slow chargers.

**Figure 37 Rough estimate of charging point investments (see text for assumptions, in billion Euro per year, for the EU-27)**




[7] For comparison: current petrol station density in the Netherlands is one per 1,650 cars. Each petrol station offers a (varying) number of fuel outlets.

Figure 38 Rough estimate of charging point costs using a depreciation rate of 5.5% (see text for further assumptions, in billion Euro per year, for the EU-27)




## 3.11 Impacts on primary energy sources and imports of fossil fuels

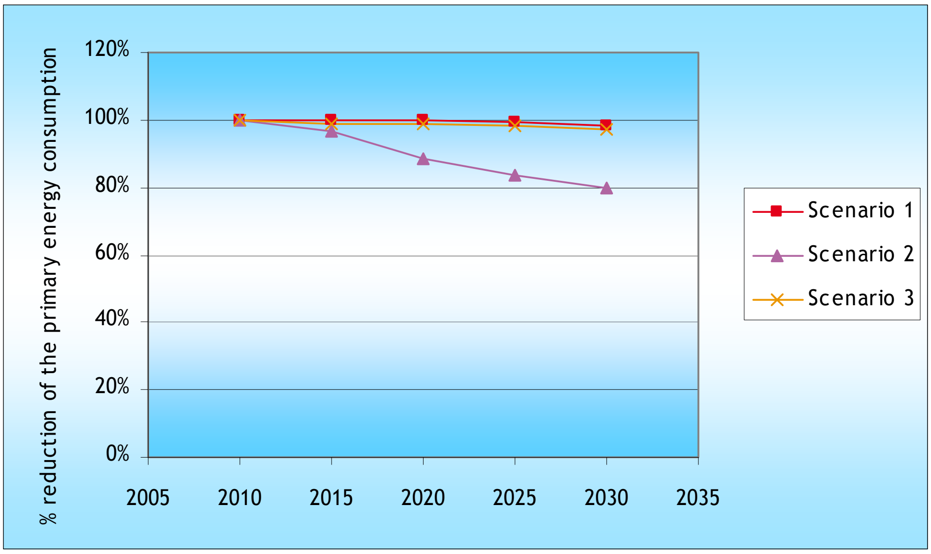
The take up of EVs leads to lower use of petrol and diesel and increased use of electricity, resulting in a net decrease in final energy use (see Section 3.3). The impact on the primary energy use is different, however, because the ratio between primary energy and final energy use is much higher for electricity than for diesel and petrol.

Figure 39 shows the impacts on primary energy consumption, assuming on average 35% efficiency for coal and gas electricity generation, and 85% efficiency for diesel and petrol production. Wind and solar energy are taken to be zero primary energy. Scenario 2 stands out because of its reduction in crude oil use, but Scenario 1 and 3 show hardly any impact. This is due to the high share of gas and coal in the mix of the additional electricity (about 85% in 2030, in all scenarios), and the relative low efficiency of power generation with these energy sources. Of course, if power generation efficiencies increase over time, the primary energy use of the electric vehicles would decrease as well[8].

---

8 This was not assessed further in this study.

**Figure 39** **Impact of the scenarios on primary energy use, assuming a 35% efficiency of gas and coal electricity generation (EU-27)**




Besides the impacts on primary energy use, also the changes in energy sources are important. The reduction in petrol and diesel directly translates to reduced oil dependency. At the same time, the additional electricity demand is expected to be generated by mainly gas and coal (see Section 3.5). So with the uptake of EVs, the overall oil consumption will decrease at the cost of higher dependency on gas and coal.

Currently most of the fossil fuels used in the EU are imported. In 2008, the overall share of fossil fuel use that was imported was 55%. For crude oil this share is 85%, while for gas this is about 62% and for coal it is estimated at 45% (source: Eurostat). In the next decades these data are likely to change, but the overall trend is that the share of fossil fuels that is imported increases.

For both oil, gas and coal, Russia is the largest external supplier. For gas and oil, also Norway and Northern Africa are important, while for coal South-Africa has a large share in the EU import[9].

A shift to electro-mobility resulting in a shift from petrol and diesel use (oil) to electricity use (gas and coal) will change the use and import of fossil fuels in the following ways:
- The impact on the overall use of fossil fuels (in terms of primary energy content) will be very limited. Oil consumption will decrease but that effect will be compensated for a large part by an increase in gas and coal (see the figure above).
- The overall effect on the import of fossil fuels is uncertain. Based on current import rates, the overall import might decrease because for oil the imported share is considerably higher than for gas and coal.
- It is impossible to predict how the dependency on various regions in the world would change without further, detailed study. Oil and gas are for a large part imported from the same regions (Russia, Norway and Northern Africa). Changes are likely to be small.

[9] See: http://www.eea.europa.eu/data-and-maps/figures/eu-27-imports-of-natural-gas-crude-oil-hard-coal-and-the-sum-of-these-by-country-of-origin-as-a-of-primary-energy-consumption.

– At the long run (after 2030) when electricity mix further develops towards renewable energy sources and petrol and diesel use decreases stronger, the dependency on oil imports is likely to decrease with further uptake of EVs.

# 4 Policy implications

## 4.1 Introduction

This chapter aims to provide an overview of the impact of Electric Vehicle penetration on EU policies and of the policy adjustments that could guide these developments and enhance the potential positive effects of these vehicles. Furthermore, this chapter delivers a rationale for policy intervention at EU and national level and considers links with other policy areas.

### 4.1.1 Relevant policy areas

The introduction of EVs is linked to various EU policy areas in particular on energy and climate, and on policies aimed at clean and energy efficient vehicles.

The EU seeks to mitigate climate change by reducing its GHG emissions. Already in 1996, the European Council imposed the political goal to reduce the increase in global temperatures to no more than two degrees (COUNCIL, 1996). The currently declared goal is to lower GHG emissions by 20% compared to 1990 by 2020, while at the same time improving overall energy efficiency by 20% and increasing the share of renewable energy in the EU to 20%. In order to reach these goals, a number of legislative actions have been taken in the context of the climate and energy package (2009).

The EU seeks to meet the shared energy and climate challenges of the Member States with a common strategy, manifested in the EU Climate and Energy package. The flagship initiative of 'Resource-efficient Europe' outlined in the Europe-2020 strategy promotes new technologies to modernise and decarbonise the transport sector, including clean and energy-efficient vehicles.

The European Commission presented 'A European strategy on clean and energy efficient vehicles' in April 2010. This strategy, which comes under the framework of the 2020 strategy, aims to encourage 'the development and market uptake of these vehicles'. The EU uses a dual approach to both promote clean and efficient traditional ICEVs as well as support the deployment of new energy-efficient vehicles such as EVs.

In addition to policy measures, the European Commission aims to support clean and energy-efficient vehicles with the Green Cars Initiative (GCI). The GCI provides financial support for research into green vehicle technologies. Such technologies can include cleaner and more efficient combustion engines, bio-methane, Electric and Hybrid Vehicles, as well as infrastructure. Under the GCI, grants for research are provided from the European Commission and loans can be obtained from the European Investment Bank (EC, 2010d).

Generally, policy instruments for passenger vehicles include measures to improve their efficiency, as well as measures to influence their use or purchase, i.e. push-and-pull strategies. However, EVs require additional consideration from a regulatory perspective. Existing vehicle policies are likely to require adjustment to include the specific characteristics of EVs. This could also include potential issues associated with EVs that are not relevant for conventional ICEVs.

This chapter addresses many different policy areas. The focus is on efficient and cost-effective environmental policies rather than on industry policy. Table 6 provides an overview of the policies that are considered, grouped per policy area.

**Table 6 Policies covered in this chapter**

| Policy | Description |
|---|---|
| **Vehicle regulation** | |
| $CO_2$ and Cars Regulation 443/2009 | This regulation sets emissions standards for passenger cars of 130 g/km from 2015. A target of 95 g/km is specified for the year 2020. Details of how this target will be reached are to be defined in a review to be completed no later than 2013 |
| $CO_2$ regulation for light commercial vehicles | In February 2011, the European Parliament approved legislation, on $CO_2$ emission standards for light commercial vehicles (vans): 175 g/km by 2017 and 147 g/km by 2020 |
| Framework Directive for Type-approval of Motor Vehicles, 2007/46/EC | Establishes the legislative framework for type-approval of motor vehicles and was extended to cover all road vehicles including alternative power train vehicles such as Full Electric and Hybrid Vehicles |
| Directive Relating to Consumer Information on Fuel Economy, 1999/94/EC | Specifies the use of a label, a showroom poster, a printed guide on fuel economy, as well as the inclusion of $CO_2$ information in promotional material to inform consumers about vehicle fuel economy |
| Directive to Promote Clean and Energy Efficient Vehicles, 2009/33/EC | Requires public authorities to include the environmental impact of vehicles into procurement decisions. Authorities are to consider the externalities linked to energy consumption, $CO_2$ emissions and other pollutant emissions during the entire operational lifetime of vehicles |
| **Regulation of energy carriers** | |
| Renewable Energy Directive (RED), 2009/28/EC | Sets a number of goals for fostering the share of renewable energy in the EU. Article 3 mandates a 10% share of renewable energy in the transport sector by 2020 |
| Fuel Quality Directive, 2009/30/EC | Aims at a number of improvements in the environmental impact of diesel and petrol transport fuels. Moreover, it requires fuel suppliers to gradually reduce the life cycle GHG intensity of energy supplied from road transport. Article 7 (a) stipulates a reduction of 10% by the end of 2020 |
| ETS Directive, 2003/87/EC | Defines a cap for total GHG emissions and allocates national emission rights to each Member State. Installations have to match their actual emissions with emission allowance rights which they either receive for free, auction or buy on the market |
| **Fiscal policies** | |
| Framework Directive for the Taxation of Energy Products and Electricity, 2003/96/EC | Sets minimum taxation rates for energy products and electricity and encourages more efficient use of energy to reduce dependence on energy imports and to limit greenhouse gas emissions |
| Eurovignette Directive, 2006/38/EC | Regulation on the charging of heavy goods vehicles for the use of certain infrastructure |

| Other relevant policies | |
|---|---|
| Raw Materials Initiative, COM (2008)699 | Aims at securing reliable and undistorted access to raw materials by means of access, recycling and resource efficiency |
| End-of-Life Vehicles Directive, 2000/53/EC | Aims at making vehicle dismantling and recycling more environmentally friendly. It sets clear standards for the reuse, recycling and recovery of vehicles and their components |
| Batteries Directive, 2006/66/EC | Prohibits the use of certain hazardous substances in batteries and sets goals for recycling of batteries |
| Directive on information in the field of technical standards and regulations, 98/34/EC | Provides procedures for the provision of information in the field of technical standards and regulations and reduces technical barriers to trade. Thus ensuring a smooth functioning of the internal market |

The various policies are discussed per policy area as indicated in Table 6 and in addition also regulation of charging infrastructure is discussed:
1. Vehicle regulation (Section 4.2).
2. Regulation of energy carriers (Section 4.3).
3. Fiscal policies (Section 4.4).
4. Policies related to charging infrastructure (Section 4.5).
5. Other relevant policies (Section 4.6).

We present the current situation and highlight need for change, then discuss policy options, and end with a recommended path of action.

There are various ways in which EV uptake and EU policies interfere. The assessment in the following subsections includes various perspectives:
- **The impact of existing policies on the market introduction of EVs**
  To what extent do existing policies foster the introduction of EVs and how could this be strengthened?
- **Impacts of the introduction of EVs on the effectiveness and impacts of existing policy**
  EVs can influence the impacts of various types of GHG, energy and fiscal policy, e.g. on the dependency on energy imports, air quality and the integration of renewable energies through EV electricity storage.
- **Avoiding harmful market distortions**
  There needs to be a balance between stimulation of new EV technology in order to help the market with overcoming initial barriers on the one hand and technological neutrality, preventing overstimulation and potential adverse effects on $CO_2$ emissions on the other[10].

[10] The latter may occur for example if the EV stimulation leads to additional vehicles and transport kilometres rather than replacement of ICEs, or if incentives such as super-credits lead to an increase of ICE emissions.

### 4.1.2 Policy timing: From initial support towards a consistent technology-neutral framework

The timing of policy measures is crucial in order to avoid harmful market distortions and ensure the functioning of the internal market. While subsidies and support schemes can be appropriate under certain conditions if they allow nascent technologies to become market ready, financial support mechanisms are not meant for long-term development of established technologies. This raises the question what is the right timing for switching from stimulation to overcome initial barriers of new technology to a sustainable long-term policy.

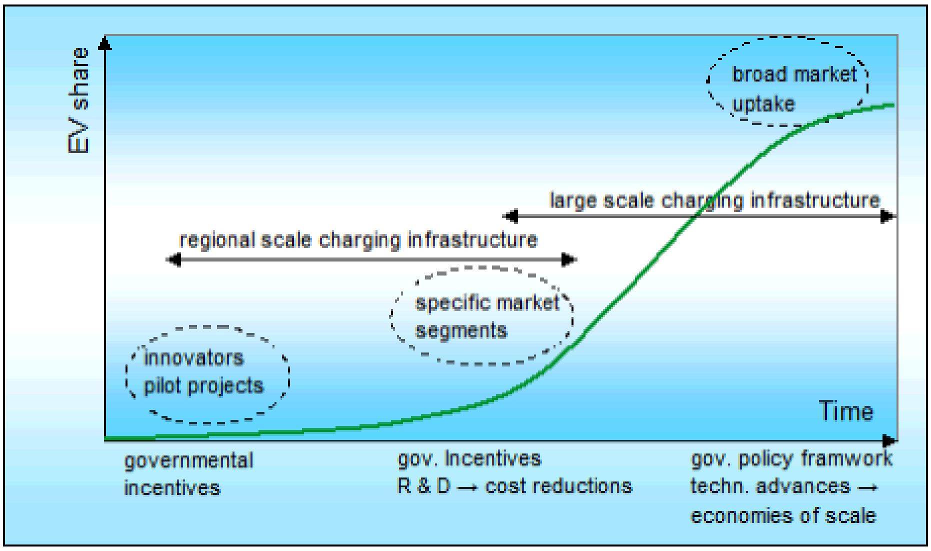
Governments can support new technologies in their initial phase if they believe that the technology is socially desirable but would not be able to mature without government intervention or would mature too late to provide the full extent of social benefits.

The market share of new successful technologies, products and services usually follows an S-curve, see Figure 40, which can be divided in three phases. In the first phase, the market share is low and the innovation is not yet mature and competitive. Therefore it may require governmental incentives and support to overcome initial barriers and set up pilot projects. As it is usually not clear which innovation can be beneficial to society and survive in a competitive market, governments should generally support various competing upcoming technologies or other innovations and not support single technology.

Once the initial barriers have been overcome, the market share of an innovation starts to increase rapidly. Still some incentives may be needed, but in order to avoid market distortions, they should be as soon as possible technology neutral. Part of this framework can be various regulations and policies, but also direct and indirect subsidies, either to manufacturers or to customers.

In the next phase, with increasing volumes, costs decrease because of economy of scale benefits. In this phase, the role of the government needs to adapt as well, to the higher volumes and impacts. As the market matures, supporting subsidies need to be scaled down and eventually withdrawn. Otherwise, these fiscal measures would distort the market equilibrium and in the long term would lead to an over-use of the given product or service.

**Figure 40 A schematic road map that illustrates how an increasing EV market share can be achieved**



It should be noted that the stylised S-shaped curve is only a theoretical approximation and will not be found in real-world retail data. Moreover, the second hump in the curve, the transition from niche to mass market, as well as the upper limit or plateau for the mass market ultimately depend on the absolute market potential for the technology.

In the case of EVs, the absolute market potential depends on a number of factors related to the technology and cost development of EVs and possibly competing technologies.

For the short term, at least the next five years, the EV technology is clearly not yet mature and governments could certainly support innovation. This may include pilot projects with various types of EVs and the required charging infrastructure. In this phase it is important to be aware of other possibly competing technologies. In the case of EV, particularly competition with other types of energy efficient vehicles should be considered, such as ICEVs and Hybrid Electric Vehicles. In addition, competition with other alternative energy carriers should be fair and non-biased e.g. competition with (second-generation) biofuels and hydrogen. A simultaneous support of the various innovations stimulates innovation and may help to avoid unfair competition.

Once the share of EVs becomes significant, government policy framework should adapt. This means that support schemes and (indirect) subsidies are slowly decreased or even abolished. Moreover, a consistent level playing field with fair technology-neutral regulation and pricing should come into force.

Maintaining support for EV for too long would result in over-simulation and market distortion. In that case EVs would be cheaper than socially desirable and road transport would expand compared to the status quo path, leading possibly to rebound effects, i.e. more congestion and more total energy use, possibly even more GHG emissions. Hence, even from a climate change mitigation perspective, government support for EVs has to be well balanced. Other reasons for curtailing financial support for EVs are the restrictions on public budgets as well as the drive towards austerity measures. When niche markets become mass markets, volumes for subsidies increase too and can become a severe burden.

Therefore, the coming year a consistent overall fiscal and regulative framework should be developed, covering EVs and all competing technologies consistently. The policy discussions in the next section can be regarded as a first step in that direction.

## 4.2 Vehicle regulation

Many of the policies that affect EV market uptake are directly linked to the vehicle, i.e. to vehicle regulation in a broader sense. Vehicle regulation encompasses a number of technical and non-technical aspects and constitutes one of the core areas for EV policy making. In the case of EVs, special attention has to be paid to:

- Regulation on $CO_2$ emissions from passenger vehicles and vans (Section 4.2.1).
- The measurement of emissions (Section 4.2.2).
- Technical type approval for EVs, including vehicle safety (Section 4.2.3).
- The Directive Relating to Consumer Information on Fuel Economy and the Directive to Promote Clean and Energy Efficient Vehicles (Section 4.2.4).

Note that the role of EVs in achieving the goals set in the Renewable Energy Directive and the Fuel Quality Directive with regards to renewable energy in transport and climate change mitigation in transport are discussed in the section on Energy regulation in Section 4.3.2.

### 4.2.1 Regulation on $CO_2$ Emissions from Passenger Vehicles and Vans

The EU seeks to reduce $CO_2$ emissions from passenger vehicles through mandatory minimum fuel efficiency standards. Regulation (EC) No 443/2009 sets emission performance standards ($CO_2$ emission limits) for manufacturers of new passenger cars. Recently, the European Parliament approved similar legislation for vans.

*Overview of Regulation on $CO_2$ Emissions from Passenger Vehicles and Vans*

Under the Regulation, an emission limit of 130 g/km[11] is applied to the average of all passenger cars registered in the EU in each calendar year, starting gradually in 2012. Car manufacturers have to meet this target, but may form a pool or group to meet their targets. The Regulation aims to provide a flexible approach that reduces $CO_2$ emissions and encourages innovation while considering market implications, manufacturers' competiveness and the direct and indirect costs for business. Key points of the Regulation include
(EC, 2010a):

- A limit value curve which is used to allow heavier cars higher emissions than lighter cars while maintaining the fleet average. Fleet average is defined at 130 grams per kilometre (g/km) for all cars registered in the EU.
- The phasing-in of the Regulation requires that 65% of each manufacturer's newly registered cars must comply on average with the limit value curve set by the legislation by 2012, 75% by 2013, 80% by 2014 and 100% by 2015 and onwards.
- Penalty payments for small excess emissions until 2018 will remain low, while fees will significantly rise in 2019.
- Long-term targets to reduce the required average to 95 g/km for the year 2020.
- Because certain innovative technologies for reducing $CO_2$ emissions are not included under the type approval test, manufacturers can be granted emission credits if they equip vehicles with innovative technologies, based on independently verified data.
- The regulation is based on end-of-pipe emissions, Electric Vehicles therefore count as zero-emission. Well-to-tank emissions for fossil fuel are relatively low (CONCAWE, 2007)[12]. In contrast to this, emissions for EVs are to 100% well-to-tank.

In addition the Regulation offers 'super credits' for low-emissions cars with less than 50 g $CO_2$/km. In 2012 and in 2013, these vehicles count for 3.5 cars, in 2014 for 2.5, in 2015 for 1.5 and from 2016 on simply as 1 vehicle.

---

[11] A further 10 g reduction will be achieved through additional measures.

[12] These well-to-tank (WTT) emissions are typically in the order of 15% for conventional fossil fuels, and higher for unconventional oil. Note that the Fuel Quality Directive is implemented to regulate WTT $CO_2$ emissions of the fuels.

**Super credits in the $CO_2$ strategy of car manufacturers**

It is not very straightforward to assess the commercial value of making use of super credits to car makers, as the potential avoided penalty payments are differentiated: the first gram costs € 5, the second gram € 15 and the third gram already € 25, the fourth and following gram being priced at € 95 each. This implies that for a manufacturer such as Porsche, being in 2006 103 gram away from its target (138 gram minus 25% for small manufacturers reduction), assuming no improvements in the fleet average, at approx. 40,000 vehicles sold, the penalties would amount to over € 380 million. For Porsche, under these assumptions, selling 1,000 cars that qualify for a super credit would lower the distance to target to 100 gram. Savings would thus be € 11.4 million or € 11,400 per car. This shadow value can be interpreted as the willingness to pay for the manufacturer in terms of accruing a deficit on EV sales.

Still, as Porsche is quite an extreme example and as manufacturers are closing down on their targets (T&E, 2010), it is much more likely that the shadow value of the super credits will be significantly smaller. The recent evaluation of carmaker progress shows that 6 out of the 14 large manufacturers were less than 10% from their $CO_2$ target already in 2009, with yearly progress rates (compared to 2008) between 1 and 10%, making it likely that many manufacturers will only pay small penalties for the first three gram. Taking into consideration the many other exemptions to the $CO_2$ targets, super credits will not be a decisive instrument in manufacturers' $CO_2$ strategy.

The Regulation aims to increase incentives for the car industry to invest in new technologies and to promote innovation in fuel efficient vehicles (EC, 2009).

A proposal for a similar regulation to cover light commercial vehicles (LCVs) – COM (2009)539 – was approved by the European Parliament in February 2011 with amendments and is likely to take effect in 2014. The $CO_2$ emission target for light commercial vehicles (vans) was set at 175 g/km by 2017 and 147 g/km by 2020. This regulation also contains super-credits, as each new light commercial vehicle with specific $CO_2$ emissions of less than 50 g $CO_2$/km shall be counted as 3.5 LCVs in 2014 and 2014, 2.5 in 2016, 1.5 in 2017 and 1 from 2018 onwards.

*Impacts of EVs*

Both zero counting and super credits can have significant impacts on the vehicle fleet, the competition of EV technology with other technologies and potentially also on GHG emissions.

First of all it gives an incentive to car manufacturers for selling more FEVs and also PHEVs and EREVs. This will allow car manufacturers to increase the share of conventional cars with relatively higher emissions than in the case without EVs. So, the average fuel efficiency of the ICEV fleet will reduce less than without EVs. The subset of all ICEVs in the vehicle sales will not meet the $CO_2$ emission target. This effect can be further accelerated by super credits which grant a higher weighting to low-emission vehicles and thus allow car makers to keep even more less-fuel efficient cars in their new car fleets while still achieving the targets. These effects were thoroughly investigated in the 'Green Power for Electric Cars' project (CE, 2010), which investigated the estimated effect of different shares of EVs and different weighting for EVs on total fleet fuel efficiency. This study found a significant effect even for low market penetrations which was augmented strongly under the presence of super credits for EVs.

The impact on overall GHG emissions, depends on the impact of EVs on the electricity production. Assuming that the emissions are capped under the ETS, the net impact of additional electricity demand from EVs is zero. Hence, the impact on the overall GHG emissions is zero. However this only holds under certain conditions, e.g. that the resulting impacts on electricity demand do not affect the number of future emission allowances under the ETS. To what extent this is to be expected is discussed in Section 4.3.2.

A third element regarding the possible interaction of EVs and the $CO_2$ and cars regulation is related to the competition of EV technology with other technologies. If electricity in transport is counted as emission-free, then obviously EVs benefit from an advantage compared to other vehicle technologies such as specific ICEVs needed for certain types of biofuels (e.g. biogas) or lightweight materials, which can lower tailpipe emissions but cannot eliminate them altogether and, hence, cannot compete with EVs in terms of tailpipe emissions. This advantage may lead to a situation where more EVs and fewer vehicles with other alternative technologies are used than that is optimal from a least-cost mitigation perspective.

A fourth, more indirect interaction between EVs and the $CO_2$ and cars regulation is related to the test cycle. Test cycle data are also used for other applications, such as labelling and tax differentiation. If zero counting is also applied for these applications, this will have additional effects.

*Discussion of various alternative approaches*
Given the fact that zero counting EVs entails significant risks for total fleet efficiency, but also risks with respect to fair competition between various technologies and possibly the overall GHG emissions, adjustments of the current approach need to be considered. We distinguish the following options for how to adapt the current tailpipe emissions system:
1. Maintain the current approach.
2. Develop specific energy efficiency limits for EV, while maintaining tailpipe emission regulation (either only for ICEVs or for all vehicles as in the current regulation).
3. Establishing well-to-wheel GHG emission standards for both ICEV and EV propulsion.
4. Replace the current $CO_2$ vehicle regulation by vehicle energy efficiency standards.

Below, we discuss the pros and cons of the various alternatives, particularly considering fairness, effectiveness and simplicity.

1. **Maintain the current system**
   This approach means that electricity in road transport are counted as emissions-free, assessing tailpipe emissions only. This would create an incentive to manufacture and sell EVs, mostly due to the so-called super credits.

   This approach is relatively simple, as no changes would be needed. The impacts on the overall GHG emissions depend on the interaction with the EU ETS. If all additional electricity demand from a shift to EVs would be carbon-neutral because of the ETS, GHG impacts are zero. However, there are some risks that this might not be the case (see Section 4.3.2). In addition and as stated before, this approach will lead to a situation where more EVs and fewer vehicles with other alternative technologies are used than that is optimal from a least-cost mitigation perspective.

Finally, the current approach does not give any incentives for electric energy efficiency improvements for EVs. However, one could argue that manufacturers already have strong incentives for optimising energy efficiency of EVs, because the range and cost of the battery are currently limiting factors for EVs competitiveness and both are linked to the battery capacity. With a higher energy efficiency, the battery capacity can be reduced (resulting in lower battery costs) or, when the battery capacity is kept constant, the range will be higher.

2. **Develop specific energy efficiency limits for EVs, while maintaining tailpipe emission regulation**

   This would constitute a hybrid approach, where $CO_2$ emission standards are complemented with energy efficiency standards for EVs. This way there would be a direct incentive to improve the efficiency of the electricity use of EVs.

   UNECE Regulation 101 enables the measurement of electrical energy consumption and range. Hence, a basis for testing FEVs and PHEVs is already available. However, improvement to the UNECE Regulation may be necessary to use it as a method for comparison.

   Establishing energy efficiency requirements for electric traction in terms of Wh/km would set incentives for manufacturers to develop energy efficient EVs. However, the ambition of Regulation 443/2009 is to mitigate climate change, not energy efficiency per se. While it is true that improving energy efficiency will lead to lower GHG emissions ceteris paribus, energy use does not link directly to GHG emissions, as different power generation technologies incur different levels of GHG emissions per unit of output. This is quite different for fossil fuel use, where one litre of same-grade gasoline will always result in the same quantity of GHG emissions. However, one could argue that the carbon content of the energy carrier is regulated by other types of regulation (e.g. the Fuel Quality Directive and Renewable Energy Directive, see Section 4.3.1).

   This approach would certainly be more complicated than the current one. There are two options: the existing $CO_2$ regulation could be limited to ICEVs or, as it is now, still include all EVs. The difficulty with both is the way PHEVs and EREVs should be treated. For these vehicles it seems impossible to define the energy efficiency separately from the ICE part. An alternative would be to apply the additional energy efficiency standards only to FEVs. However, this would still result in relatively strong stimulation of PHEV and EREV compared to other technologies for decreasing the $CO_2$ efficiency of cars. Therefore, the key problems with the current scheme, as discussed before, would not be solved.

3. **Establishing well-to-wheel GHG emission standards for both ICEV and EV propulsion.**
This approach would be a paradigm shift in EU vehicle emission monitoring. So far, tailpipe emissions have been at the centre of attention. However, EV emissions mostly[13] occur up-stream at the instance of power generation. Out of principles of equal treatment, if EV up-stream emissions are accounted for, then the same has to be performed for ICEVs, i.e. taking GHG emissions from exploration, refining and distribution into account as well.

For fossil fuels, this approach might prove to be feasible, though cumbersome: It would involve monitoring and reporting of all fossil fuel imports and fuel distribution. Fortunately, refining is already subject to the EU ETS and hence exhaustive monitoring and reporting material available.

For electricity, accounting for direct generation GHG emissions would also be possibly due to monitoring under EU ETS. However there are various fundamental choices to be made regarding the GHG intensity that could be attributed to the actual electricity consumption. First of all there are various options for the geographical scope: national or EU wide values. As the regulation is mainly aimed at car manufacturers, the EU average seems the most appropriate. A second choice is about the time period the data refer to. This could either be based on the recent past or on projections. As the regulation is aimed at cars that are sold and used in the future, using projections seems more appropriate. A third choice to be made is whether the value should reflect average or marginal GHG emissions from electricity production. In the case of electricity, the two differ significantly, particularly because of the impacts of the EU ETS. The answer to this third question is not very straightforward. Average data are more transparent and much easier to estimate, while marginal data might better reflect the true impact of additional electricity use.

Finally, one specific issue with this approach of moving to well to wheel emissions is that car manufacturers can not influence the carbon content of electricity. They could argue that the regulation should be as close as possible to what they can influence. However, the same is true for conventional fuels as diesel and petrol. The carbon content of these fuels depends fully on oil companies and for example on the blending of biofuels.

4. **Replace the current $CO_2$ vehicle regulation by vehicle energy efficiency standards.**
Another alternative would be to replace the current $CO_2$ regulation for cars by energy efficiency regulation. This way the regulation would fit better with the Renewable Energy Directive and Fuel Quality Directive, as any possible overlap could then be avoided. Also the 2011 White Paper on transport identifies the link between vehicle regulation and decarbonisation of energy carriers. The White Paper mentions the possibility of moving from $CO_2$-based vehicle standards towards energy-based standards (SEC(2011) 391 final; para 311).

The problem with this approach would be that the tank to wheel energy efficiency of ICEVs and EVs are hard to compare. The main energy losses

[13] Particulate emissions from tire rubber wear still occur and can still be a health hazard in terms of urban air quality, while GHG emissions are zero.

for electric driving is in the electricity production, while for ICE driving this is in the ICE. This could be an argument to base the regulation on well to wheel (WTW) energy efficiency, but this seems a quite complex approach, because the WTW energy efficiency from an EV running on water or wind power generated electricity can not be compared with that of a (bio) diesel powered car. Moreover, it would be a very fundamental change to replace the existing $CO_2$ based regulation by an energy based regulation where many elements of the legislation should be developed from scratch again.

*Recommendations for accounting for EV electricity use*
At the moment the Regulation uses tailpipe emissions as a basis to compare the environmental performance of vehicles. However, with increased production and use of alternative vehicle types such as EVs this becomes problematic because FEVs, EREVs and PHEVs when operating in electric mode, are counted as emission-free by the Regulation.

Zero counting and super credits may have a negative impact on total fleet energy efficiency (WTW), will increase overall emissions from road transport and might also increase overall GHG emissions, depending on the impacts on ETS.

In addition, counting electric propulsion as zero GHG emissions gives preferential treatment to a specific technology without factual justification. Subsidies and privileges should aim to be technology neutral and hence apply to certain performance levels (such as 50 g $CO_2$/km), not types of technologies regardless of their achievements.

Therefore, it will be necessary to include non-tailpipe emissions when evaluating EVs, i.e. the entire GHG emissions well-to-wheel should be assessed. However, this would also entail the need to take well-to-wheel emissions of all other propulsion forms into consideration.

However, for an interim time period, this can be a desired state if the overall aim of fostering EVs can be achieved. In view of avoiding distortions of the internal market, this preferential treatment might be debated.

In the long term, after 2020, however, it will become increasingly necessary to incorporate all well-to-wheel emissions in the assessment of $CO_2$ emissions from transport vehicles in order to achieve a transparent means to compare different technologies' performance values, especially regarding energy efficiency and GHG emissions. The key challenge for the development of a well-to-wheel emission regulation would be to develop GHG intensity for all energy carriers. Particularly for electricity this requires some further study, particularly because average and marginal emissions differ considerably.

### 4.2.2 Implications for emissions measurements
The $CO_2$ and Cars Regulation takes into account norm cycle emissions according to the New European Driving Cycle, as defined in Directive 93/116/EEC adapting to Technical Progress Council Directive 80/1268/EEC relating to the Fuel Consumption of Motor Vehicles. The norm cycle – as well as all other type approval methodologies, takes only tailpipe emissions into account. These standards are further detailed in Regulation 715/2007/EC which lays out requirements for testing vehicle emissions and amends the Directives 70/220/EEC and 2002/80/EC. In 2008 the Regulation was updated again, and is now Regulation 692/2008/EC on Euro 5 and Euro 6 type approval. It specifies six separate types of tests for exhaust emissions - including several

types of Hybrid Electric Vehicles - and emphasises the use of running emissions from a vehicle's exhaust (i.e. tailpipe emissions). The Regulation refers to UNECE Regulation 83 for many of its technical specifications, but also uses various exceptions to the Regulation (TRL, 2010).
Regulation 595/2009/EC (replacing 715/2007/EC) outlines that specific test procedures and requirements for type approval shall apply to vehicles regardless of fuel type (i.e. Hybrids and Electric Vehicles). Moreover, Regulation 692/2008/EC makes reference to two types of Hybrid Vehicles, 'externally chargeable' vehicles (i.e. Plug-in Hybrids) and 'not externally chargeable' vehicles, using the same wording as UNECE 83, focussing exclusively on the tailpipe emissions in non-electric drive, taking into consideration the electric drive range as emissions-free, Figure 41.
Annex X of Regulation 692/2008/EC outlines test procedures for emissions testing for both types of Hybrids, and cites Annex 14 of UNECE Regulation 83.

**Figure 41 UN ECE 83 methodology for computing emissions of Hybrid Electric Vehicles**

$$M_i = ( De \; A \; M1_i + Dav \; A \; M2_i ) \; / \; ( De + Dav )$$

Where:

| | | |
|---|---|---|
| $M_i$ | = | mass emission of the pollutant i in grams per kilometre. |
| $M1_i$ | = | average mass emission of the pollutant i in grams per kilometre with a fully charged electrical energy/power storage device calculated in paragraph 3.1.2.6. |
| $M2_i$ | = | average mass emission of the pollutant i in grams per kilometre with an electrical energy/power storage device in minimum state of charge (maximum discharge of capacity) calculated in paragraph 3.1.3.5. |
| De | = | vehicle electric range, according to the procedure described in Regulation No. 101, Annex 7, where the manufacturer must provide the means for performing the measurement with the vehicle running in pure electric mode. |
| Dav | = | 25 km (average distance between two battery recharges) |

While this methodology clearly takes into consideration the electric drive mode, the emissions data stem still exclusively from the ICEV combustion engines. Therefore, all regulations only address Hybrid Electric Vehicles, not FEVs.

It remains difficult to compare new technologies such as Hybrid Vehicles with ICEs. This is because parameters in the testing procedure such as DAV (average distance between two battery charges) are arbitrary and furthermore, the suggested mix of electric driving and combustion driving does not represent on-road driving conditions.

In addition, all regulations refer to tailpipe emissions only and do not take into account other forms of emissions, especially up-stream emissions from power generation.

In the case of FEVs there are no tailpipe emissions from the vehicle itself because only stored electricity is consumed. EV efficiency, electrical energy consumption, can only be measured in terms of watt hours per kilometre (Wh/km) not in l/km or g/km. Therefore the provisions in the Regulation 443/2009/EC do not cover FEVs at the moment (TRL, 2010). Hence, FEVs are considered zero-emission vehicles under current legislation, both in the EU and in the US.

This does not preclude that regulations exist to measure EV energy consumption: Regulation 692/2008/EC refers to Annex 7 of UNECE Regulation 101 for detailed methods and test cycles for measuring electrical energy consumption and range of pure Electric Vehicles. Annex 8 provides methods and test cycles for measuring Hybrid Electric Vehicles (TRL, 2010).

A mid-term review of Regulation 443/2009/EC is expected by the end of 2013. The review will look at the short-term outcomes of the Regulation to assess the modalities of reaching its 2020 target for emission standards and its long-term (2030) perspective.

### 4.2.3 The Framework Directive for Type-approval of Motor Vehicles

Framework Directive 2007/46/EC establishes the legislative framework for type-approval of motor vehicles and was extended to cover all road vehicles including alternative power train vehicles such as Full Electric and Hybrid Vehicles.

*Assessment of the Framework Directive for Type-approval of Motor Vehicles*

Presently there are no specific technical requirements in the legislation to deal with the specific characteristics and risks of Electric Vehicles and to ensure user protection from electric shock and other safety issues.

The UNECE Regulation No. 100 covers EV safety but as of October 2010 it is not yet applicable to EC type-approval of Electric Vehicles on a mandatory basis. Moreover, the Regulation only covers pure EVs, not PHEV and EREV. A UNECE working group has been established to revise the legislation.

*Recommendation for the Framework Directive for Type-approval of Motor Vehicles*

A harmonised approach for the approval requirements of Electric Vehicles is essential to ensure EV safety and their market entry. Directive 2007/46/EC must be updated to include relevant requirements for EVs such as the UNECE Regulation. A proposal is expected in early 2011 (EC, 2010).

Therefore no immediate additional action is necessary.

### 4.2.4 The Directive Relating to Consumer Information on Fuel Economy and the Directive to Promote Clean and Energy Efficient Vehicles

Additional policies which aim to promote clean and efficient transportation are: Directive Relating to Consumer Information on Fuel Economy (1999/94/EC) and the Directive to Promote Clean and Energy Efficient Vehicles (2009/33/EC). While the former aims at individual car sales, the latter promotes that energy and environmental impacts linked to the operation of vehicles over their whole lifetime are taken into account in all purchases of road transport vehicles, as covered by the public procurement Directives and the public service Regulation.

*Assessment of the Directive Relating to Consumer Information on Fuel Economy and the Directive to Promote Clean and Energy Efficient Vehicles*

Directive 1999/94/EC outlines a set of measures to provide consumers with information on passenger car fuel economy. The Directive specifies the use of a label, a showroom poster, a printed guide on fuel economy, as well as the

inclusion of $CO_2$ information in promotional material to inform consumers about vehicle fuel economy. The Directive covers all passenger vehicles regardless of fuel type. A revision of the Directive is expected in the near future, possibly including increased harmonisation of specific measures (e.g. the label) and/or extension of the scope, although no specific timeframe is outlined.
The Directive currently uses the measurement in accordance with Directive 80/1268/EEC, implying counting electric driving as emission free.

Directive 2009/33/EC aims to promote clean and energy-efficient road transport vehicles in the EU by stimulating the market for clean and energy-efficient vehicles. The Directive requires public authorities to include the environmental impact of vehicles into procurement decisions. Authorities are to consider the externalities linked to energy consumption, $CO_2$ emissions and other pollutant emissions during the entire operational lifetime of vehicles.

Electric Vehicles are specifically mentioned in the Directive, which requires that their energy consumption be measured in order to calculate the lifetime energy costs. Furthermore, in article 6.2, it refers to vehicle type approval testing for calculating $CO_2$ emissions, thus implying zero GHG emissions for Electric Vehicles.

*Recommendation for the Directive Relating to Consumer Information on Fuel Economy and the Directive to Promote Clean and Energy Efficient Vehicles*
Both these policies already take measures to promote clean and efficient vehicles. Therefore, they can be useful instruments – together with other policies – to promote a decarbonisation of road transport.

At the moment, electric driving is counted as having zero GHG emissions under both Directives. This will give preferential treatment to EVs under both Directives and might lead to:
- Higher overall GHG emissions from road transport.
- Possibly higher emissions from electricity generation (depending on ETS, see Section 4.3.2).
- A displacement of biofuels by EVs.
- A significant distortion of the internal market.

As both Directives refer to vehicle type approval rules, action needs to be taken in amending these norms.

## 4.3 Regulation of energy carriers

In this section we discuss the interaction between EVs and the energy regulation:
- The Renewable Energy Directive.
- The Fuel Quality Directive.
- The EU Emission Trading Scheme (ETS).

### 4.3.1 The Renewable Energy Directive and the Fuel Quality Directive
EVs are relevant to, or impact on, the Fuel Quality Directive (FQD), Directive 2009/30/EC, and the Renewable Energy Directive (RED), 2009/28/EC.

The Renewable Energy Directive sets a number of goals for fostering the share of renewable energy in the EU. Article 3 mandates a 10% share of renewable energy in the transport sector by 2020. In Subsection (c), the Directive sketches a methodology for calculating the share of renewable electricity consumed by Electric Vehicles, allowing for the application of either the EU average or the national average from two years prior to the year in question. Moreover, the Directive specifies multiplying the energy content from renewable sources by the factor 2.5. The Commission is supposed to present a methodology for calculating the share of renewable electricity in transport by the end of 2011[14].

The Fuel Quality Directive aims at a number of improvements in the environmental impact of diesel and petrol transport fuels. Moreover, it requires fuel suppliers to gradually reduce the life cycle GHG intensity of energy supplied from road transport. Article 7 (a) stipulates a reduction of 10% by the end of 2020 (of which 6% is obligatory). This reduction can be achieved via multiple elements, including a 2% reduction attributed to the use of Electric Vehicles in road transport. Accounting procedures under the FQD have to be in line with those under the RED. A first revision of the FQD is expected for the end of 2012.

Thus, EVs can contribute to reducing the carbon intensity of transport fuels as required under the FQD, and can help achieve the set target of 10% renewable energy sources in transport by 2020 formulated by the RED. However, both cases require a more detailed accounting methodology for EV electricity consumption.

*Assessment of the FQD and RED*

For the first review and reporting cycle of both the FQD and the RED, i.e. 2011-2012, there will be no significant numbers of EVs on the road in the EU. Therefore, any issues or inaccuracies related to EV energy accounting will have only very minor impacts on either achieving or missing the targets specified in the two Directives.

However, in the medium term, this aspect might become more urgent and pressing, especially since the FQD calls upon Member States to require fuel suppliers to reduce the GHG content of fuels. Hence, fuel suppliers could face unjust treatment in case the methodology is not developed fully by 2015 when the share of EVs might become more relevant in some Member States. Moreover, the 'Green Power for Electric Cars' project found evidence that EVs – under the current regulation – might crowd out biofuels as both the RED and the FQD allow EVs to fulfil the GHG reduction targets (CE, 2010). Also, the RED counts renewable electricity for EVs with a factor of 2.5, thus making EVs potentially a more competitive choice than biofuels for achieving the set goals. This effect is, however, at least partly compensated by the fact that the energy efficiency of Electric Vehicles is (much) higher than that of conventional vehicles, leading to less energy use per kilometre.

*Recommendations for the FQD and RED*

Our analysis shows the need for a transparent and practical methodology for calculating the use of electricity from renewable sources in the transport sector. As the Fuel Quality Directive refers directly to the Renewable Energies Directive, only one methodology needs to be put forward.

[14] By December 31st, 2011, the Commission shall present, if appropriate, a proposal permitting, subject to certain conditions, the whole amount of the electricity originating from renewable sources used to power all types of electric vehicles to be considered (EC, 2009c, Article 3(4)).

Different options for counting EV electricity use exist:
a On-board metering similar to the digital tachograph.
b Smart metering of EV charging outlets.
c Separate conventional metering of EV charging outlets.

Moreover, different options for determining the share of renewable electricity exist:
a Applying the European renewables average.
b Applying the national renewables average.
c Applying the share of renewables of the respective energy provider.
d Calculating the actual share of renewable electricity taking into consideration actual charging patterns and grid load.

More research will be necessary to determine exactly how to calculate this electricity use. Research on this issue is already under way and results are expected by the end of 2011.

Additionally, the RED-multiplier of 2.5 for renewable electricity used for EVs should be reviewed once the actual energy use per kilometre of these vehicles is known. It seems fair to compensate for the reduced energy use per kilometre, but overcompensation should be avoided to prevent an unfair advantage for EVs. Incentives for GHG emission reductions should be technology neutral in order to be as cost-efficient as possible.

### 4.3.2 Emissions Trading Scheme (ETS)

Directive 2003/87/EC establishes the European Emissions Trading Scheme, now operating in 30 countries and covering electricity generation, combustion plants, oil refineries and iron and steel works, as well as factories making cement, glass, lime, bricks, ceramics, pulp, paper and board. The scheme defines a cap for total GHG emissions and allocates national emission rights to each Member State. Installation have to match their actual emissions with emission allowance rights which they either receive for free, auction or buy on the market.

Hence, electricity used for Electric Vehicles is subject to the EU ETS and resulting GHG emissions are covered under the trading scheme. The total amount of allowances in the EU ETS is set until 2020. That being said, even though refineries are part of the ETS (and the price of fuels is therefore affected by the ETS), the fossil fuels that they produce for road transport are not subject to EU ETS. Thus, charging an Electric Vehicle with electricity from the grid will result in an additional demand for emission allowances to cover the GHG emissions from the consumed electricity, whereas the corresponding fossil fuel for fuelling ICEVs does not have to be matched with equivalent emission allowances[15].

[15] Electricity produced outside the grid – such as through roof-top solar panels fuelling directly the personal EV is not covered and does not affect the EU ETS balances.

*Assessment of the Emissions Trading Scheme*

Since the amount of electricity used for EVs is additional and has to be covered by capped emission allowances, the introduction of EVs can de facto lead to overall emission reductions – taking into consideration sectors within the EU ETS - either in the electricity sector or in any other sector within the EU ETS (WWF, 2009). This, of course only holds true under four conditions:

- Restricted use of CDM or JI credits.
- No increase in the overall cap due to electrification of the vehicle fleet.
- Electric Vehicles have to replace existing ICEVs and not be additional traffic.
- The sales of Electric Vehicles do not lead to a significant increase of $CO_2$ emissions of ICEs due to zero counting and super credits (CE, 2010).

Ensuring the latter point will be an important element of EV policies.

Introducing EVs basically comes down to a partial expansion of the EU ETS to road transport without increasing the cap. Assuming 1 million EVs with a specific yearly energy consumption of 20 kWh[16] per 100 km and yearly mileage of 10,000 km, net energy demand would be 2 . At the current EU average for power generation of 443 g $CO_2$/kWh, this results in emissions of 886,000 t $CO_2$. Actual allocations under EU ETS amount to approx. 2 billion tonnes of $CO_2$ (for 2008-2012). Thus, 1 million EVs would affect only 0.04% of European Union Allowance Units (EUA) and would therefore not cause significant disturbances in the EU ETS.

Larger numbers of EVs and a simultaneously decreasing cap might, however, change the picture, especially if the carbon price appreciates in the medium term and price elasticities become more significant. Then, EVs could become a significant burden for industries subject to EU ETS, such as cement, paper, glass, etc. This burden would be especially pronounced for industries which are qualified as being exposed to a high risk of carbon leakage[17]. Our analysis of the impact of EVs on the EU ETS shows that the total EV demand for allowances will be marginal up to 2025 under all three considered scenarios. Only in Scenario 3 the share can reach 2.4% of the total cap in 2030. In the more likely Scenario 1, shares of EV allowances in EU ETS would remain at 1.5%, see Table 7.

---

16 Actual electricity consumption of Electric Vehicles depends both on driving and charging patterns. For example, fast charging results in higher charging losses that can increase up to 25% of electricity consumed (FAZ, 2010), car heating can also significantly increase electricity use.

17 A sector or sub-sector is also deemed to be exposed to a significant risk of carbon leakage:
- If the sum of direct and indirect additional costs induced by the implementation of this directive would lead to a particularly high increase of production cost, calculated as a proportion of the Gross Value Added, of at least 30%. Or
- If the non-EU Trade intensity defined as the ratio between total of value of exports to non-EU + value of imports from non-EU and the total market size for the Community (annual turnover plus total imports) is above 30%.

**Table 7** **Impact of EV shares on EU ETS market (EV shares are total shares of FEV, PHEV and EREV in the EU passenger car fleet)**

| **Scenario 1** | **2010** | **2015** | **2020** | **2025** | **2030** |
|---|---|---|---|---|---|
| Electric vehicle share in the EU car fleet | 0% | 0% | 1% | 6% | 18% |
| Electricity (PJ/year) | 0 | 5 | 32 | 157 | 463 |
| Resulting $CO_2$ (in Mt) | 0 | 0.41 | 2.44 | 10.29 | 23.02 |
| Total EU ETS (in Mt)[18] | 1,860 | 1,969 | 1,804 | 1,653 | 1,514 |
| Share of EU ETS (%) | 0 | 0.02 | 0.13 | 0.62 | 1.52 |
| **Scenario 2** | **2010** | **2015** | **2020** | **2025** | **2030** |
| Electric vehicle share in the EU car fleet | 0% | 0% | 1% | 3% | 7% |
| Electricity (PJ/year) | 0 | 4 | 15 | 58 | 167 |
| Resulting $CO_2$ (in Mt) | 0 | 0.33 | 1.14 | 3.80 | 8.30 |
| Total EU ETS (in Mt) | 1,860 | 1,969 | 1,804 | 1,653 | 1,514 |
| Share of EU ETS (%) | 0 | 0.02 | 0.06 | 0.23 | 0.55 |

| **Scenario 3** | **2010** | **2015** | **2020** | **2025** | **2030** |
|---|---|---|---|---|---|
| Electric vehicle share in the EU car fleet | 0% | 0% | 2% | 12% | 33% |
| Electricity (PJ/year) | 0 | 6 | 48 | 263 | 730 |
| Resulting $CO_2$ (in Mt) | 0 | 0.49 | 3.65 | 17.24 | 36.30 |
| Total EU ETS (in Mt) | 1,860 | 1,969 | 1,804 | 1,653 | 1,514 |
| Share of EU ETS (%) | 0 | 0.03 | 0.20 | 1.04 | 2.40 |

Due to the economic downturn of 2008/2009, allowance prices will remain low for the entire trading period up to 2012. As EV shares will not be significant before 2025, their impact on EU ETS will be negligible until then.

From an environmental point of view, higher allowance prices do not present a call for action as this would create a stronger incentive to reduce GHG emissions. However, from an industry policy perspective, high allowance prices represent an additional burden on industry.

*Recommendation for the Emissions Trading Scheme*

In summary, the introduction of EVs translates into a partial extension of the EU ETS to road transport. Therefore, provided certain conditions are met, it also entails the potential of a de facto emissions reduction, albeit small-scale for the time being and depending on a number of conditions:

- Restricted use of CDM or JI credits.
- No increase in the overall cap due to electrification of the vehicle fleet.
- EVs have to replace existing ICEVs and not be additional traffic. And
- The sales of EVs do not lead to a significant increase of $CO_2$ emissions of ICEVs due to zero counting and super credits (CE, 2010).

If these conditions cannot be met, the introduction of EVs can lead to significant additional GHG emissions both from within the EU ETS and in the transport sector.

If they are met, it can be argued that electricity used for EV propulsion – albeit it having a factual GHG footprint – are virtually GHG emissions-free.

[18] Estimates based on projections of EU ETS cap development assuming the EU pursues a 20% emissions cut by 2020. This implies a yearly reduction of 1.74%, starting with 2.04 billion t $CO_2$ (EC, 2010h). Estimates on the GHG intensity of electricity generation are based on EC (2010i).

Nevertheless, if one assumes that the emissions allowances would have been banked or left unused in the absence of EVs, then EV use is not emission-free and the electricity use and its GHG impact has to be accounted for. However this seems unlikely.

In the case of more significant EV market uptake after 2030, it has to be considered that the increased scarcity of emission allowances might lead to a stronger price signal that could affect sectors subject to EU ETS such as cement, electricity or oil in the longer term, if EV shares become significant and the cap is not increased. In the near-term future, i.e. up to 2030, market shares of EVs remain sufficiently low to avoid negative impacts on the EU ETS: even for a market share of 12% of the fleet, i.e. approx. 25 million vehicles, the corresponding share of the ETS is still just 1%. Hence, no immediate action is necessary. After 2030, new alternatives for the EU ETS which consider the future presence of EVs and their electricity use might become necessary. In depth analysis leading to proposed updates to the ETS to account for potential changes brought on by EVs should be considered for after 2020, once more accurate predictions about future EV market uptake and electricity use can be made.

## 4.4 Fiscal policies

Transport is both a major household expenditure as well as a significant form of revenue for the EU and Member States. In times of constrained public budgets, it is essential for governments that tax revenues are maintained in a scenario of increased use of electricity by EVs. In addition to covering road infrastructure costs, revenues from road transport are increasingly expected to cover external costs such as environmental and health costs, in line with the polluter-pays principle, see the current revision of the Eurovignette Directive. On the other hand, fiscal measures are a potentially substantial influence to encourage consumers to buy EVs.

Our analysis has shown (see Section 3.9) that revenues from excise duty and VAT on fuel and electricity sales decrease in all three scenarios compared to the Reference Case without EVs. Under the fiscally least favourable scenario, revenues are € 20 billion below the Reference Case in 2020 and € 38 billion lower in 2030.

On the other hand, EVs have a higher average retail price and, thus, incur higher VAT revenues for most scenarios. However, these gains are considerably smaller than the losses due to the fuel switch. The highest gain is estimated for 2030 with some € 20 billion above the Reference Case.

This implies that we expect on average revenue losses. It has to be noted, though, that gains and losses are not distributed evenly across Member States.

When assuming that the goal is to maintain a constant revenue flow from the road sector, the following approaches seem possible: indirect and direct taxation. In particular, we will investigate the following revenue sources:
- Purchase and ownership taxation (direct); Section 4.4.1.
- Direct and indirect subsidies; also included in Section 4.4.1.
- Framework Directive for the taxation of energy products and electricity (indirect); Section 4.4.2.
- Road charging (direct); Section 4.4.3.

### 4.4.1 Fiscal policy for passenger cars – purchase and ownership taxation

Cars are a major expenditure in household budgets (around 15% according to the World Energy Council). Fiscal policies such as taxes or subsidies on car purchases, car ownership as well as motor fuels could therefore greatly influence the key drivers which affect vehicle purchase and vehicle ownership and hence promote more fuel efficient cars or EV uptake.

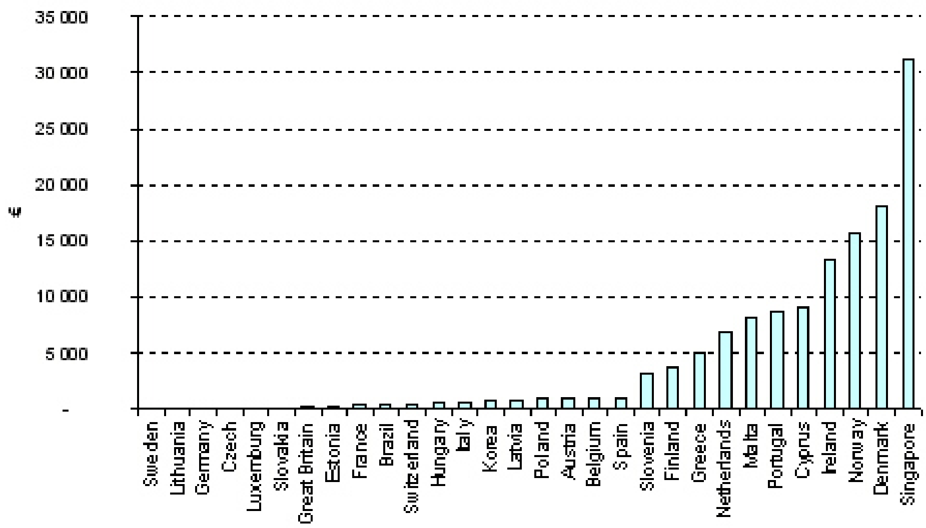
*Assessment of fiscal policies for passenger cars*

Different vehicle tax systems are used throughout the Member States. One option is to tax the purchase of vehicles, such as with a value added tax (VAT) system. It is generally the case in car producing countries (e.g. France, Germany, the UK, Italy and Sweden since 1997) to use only a VAT in combination with low registration fees. However, the VAT may vary greatly between countries (WEC, 2010). As EVs are more expensive on average than comparable ICEVs, this implies that at constant tax rates, their VAT is also higher.

*Purchase taxes*

To provide consumers with incentives to purchase more efficient cars with lower $CO_2$ emissions, some countries use specific taxes for car purchases. Vehicle purchase tax schemes may offer rebates for more efficient cars or higher tax rates for less efficient cars, being referred to as bonus-malus schemes. European countries which use specific green vehicle taxes include Austria (since 1992), Denmark (since 2000), France (for ‘powerful’ cars since 2006), the Netherlands (since 2006), Norway (since 1996), and the UK (for company cars since 2002). Similar green vehicle taxes are also planned for Spain and Portugal (WEC, 2010). See Figure 42 for a global overview of average car purchase tax and fee, excluding VAT.

**Figure 42 Average car purchase tax and fee, excluding VAT - Euro**




114Source: DIW, Trafico.; estimation based on a average car (Golf 1.4/TDI 2.0 resp. similar car).

Source: WEC, 2010.

However, some disadvantages of unintended effects must be noted. For example, high taxes may deter consumers from purchasing new cars which might lead to a general slowdown in the uptake of new technologies and with it the market penetration of more fuel efficient cars. Moreover, taxes on specific vehicle segments may focus on specific parts of the population (e.g. those who need larger and less efficient cars for work purposes, or those who can already afford to purchase newer or more expensive technologies).

*Circulation taxes*
An alternative option is the annual circulation tax (i.e. the ownership of the car). Assuming consumers will include this in their decision to buy a car, a circulation tax may also have the potential to influence purchasing decisions. Circulation taxes are already based on the power output or weight of a car in most countries, which therefore includes fuel consumption to some degree. Moreover, many countries already use annual circulation taxes which consider environmental or efficiency aspects. Annual circulation taxes which vary according to fuel consumption or $CO_2$ emissions are used in Denmark (since 1999), Germany (since 2009), France (since 2006 for company cars), Sweden (since 2006 for new cars) and the UK (since 2001) (WEC, 2010).

*Other fiscal incentives*
Other incentives can be introduced through $CO_2$ differentiated taxation of company vehicles, such as implemented successfully in the UK.[19] This is especially relevant as company purchases represent approximately 30% of new car sales in EU Member States[20], reaching even 50% for 18 Member States (Austria, Belgium, Czech Republic, Denmark, Finland, Germany, Greece, Hungary, Italy, Luxembourg, Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden and United Kingdom; EC, 2010g).

EU and Member State demand side measures and regulatory action are encouraged under the Green Cars Initiative to supplement EU financial support for energy efficient car technologies.

Already now, a growing number of national tax exemptions exist for EV purchases, which are, however, not coordinated or harmonised between Member States, Table 8. For example, in France, Ademe has offered buyers € 2,000 to 3,000 for the purchase of certain EVs until December 31st, 2010.

**Table 8** **Types of fiscal incentives in various Member States**

| Type of policy | Aimed at | Examples |
|---|---|---|
| Subsidy for EV purchase | Market uptake of the vehicles | Austria, Belgium, Cyprus, Germany, France, Italy, various regions in Spain, Sweden, UK (also for Plug-in Hybrids) |
| Discount on or exemption of vehicle registration tax | Market uptake of the vehicles | Tax exemption in Austria, the Netherlands, Denmark, Greece (also for Hybrids), Portugal, Romania; discount in Belgium, bonus in France, due to low $CO_2$ emissions |
| Discount on or exemption of vehicle circulation tax | Market uptake of the vehicles | Tax exemption in Austria, Czech Republic (EVs for business purposes only), the Netherlands, Ireland, Germany (5 first years after purchase), Greece |
| Reduction of VAT | Market uptake of the vehicles | Austria |

19 http://www.vcacarfueldata.org.uk/search/companyCarTaxSearch.asp.

20 http://www.markt-studie.de/168/d/2010/04/26/datamonitor-fleet-market-to-drive-new-car-sales/.

| Type of policy | Aimed at | Examples |
|---|---|---|
| Favourable fiscal treatment of leased cars | Market uptake of the vehicles | Netherlands, UK |
| Discount on or exemption of congestion charge | Market uptake of the vehicles | UK (London), Sweden (Stockholm) |
| $CO_2$ differential fuel and energy tax | Market uptake of the vehicles | |
| Free parking places for Electric Vehicles | Market uptake of the vehicles | Cities in Italy, the UK, Denmark, the Netherlands |
| Subsidies for the installation of charging points | Charging point availability | Cities in the Netherlands, UK, … |
| Subsidies for R&D (car manufacturers and research institutes) | Improving technology, reducing cost | The Netherlands, UK, … |

Source of the country examples: ACEA; http://www.acea.be/images/uploads/files/20100420_EV_tax_overview.pdf. AVERE and own data.

### *Rebound effects*

Funding, subsidies and non-financial incentives for EVs can create a rebound effect, where total passenger transport increases compared to the status quo. This effect is likely in cases where aggregate incentives reduce total cost of ownership (TCO) of EVs under the respective level for ICEVs. However, as consumers have subjective perception of costs and benefits – especially the lure of the free, heavy discounting, etc. – this might actually occur much earlier than at the equilibrium between TCO for EVs and TCO for ICEVs. This should be of particular concern as this would increase congestion and energy consumption in the transport sector and hence possibly also GHG emissions from transport.

Energy- or $CO_2$-based taxation schemes or road pricing can effectively prevent rebound effects.

Furthermore, policies aiming at EV sales – not use – will reinforce existing mobility patterns relying on vehicle ownership. New mobility models might include car sharing or integrated mobility solutions, where EV use would only be one option among many.

Road pricing schemes are most suited for influencing use patterns.

### *Recommendation for fiscal policies for passenger cars*

As seen in the assessment above, fiscal policies for car purchase and ownership are generally implemented at the Member State level, often with tax measures such as VAT or registration taxes. At the EU level, there is therefore not a lot of leverage for action.

However, guidance as well as clear signals given to the Member States on EVs and fiscal policies will help to shape EU-wide priorities for EVs, such as $CO_2$-differentiated vehicle taxation schemes, which can be harmonised in order to meet European climate targets. Furthermore, $CO_2$-based taxation schemes need to be updated regularly in order to take into consideration improvements in average vehicle energy efficiency. Otherwise, all vehicles will eventually be in the lowest tax class which will then entail revenue losses.

Direct subsidies to EV owners and manufacturers might also be considered both at the EU and the Member State level for the initial market introduction, i.e. for the next five to ten years. However, national subsidies should be coordinated through the EU in order to avoid distortions to the internal market. In addition, subsidies have the risk of over-stimulating EVs compared to competing technologies.

### 4.4.2 The Framework Directive for the Taxation of Energy Products and Electricity

Fuel taxation is currently a major income source to finance among others road infrastructure. Hence, it will be paramount to replace lost income from reduced sales of petrol and diesel through other forms of revenue.

*Assessment of the Framework Directive for the Taxation of Energy Products and Electricity*

In principle, two approaches to taxation exist: direct and indirect. Most taxes are indirect, such as the fuel tax which is included in the final sales price and paid for by mineral oil suppliers. The income tax and property taxes are direct taxes and are paid for directly from the tax subject to the collecting authority.

In fossil fuels, different fuel taxation and regulation exists. Aviation and shipping fuels, for example, are currently exempt from taxation and some Member States apply reduced rates to a number of other uses (e.g. use in electricity generation or for public transport) based on Directive 2003/96/EC. These fuels can be marked (colouring) and handled separately, reducing fraud risk. The Directive encourages more efficient use of energy to reduce dependence on energy imports and to limit greenhouse gas emissions. Therefore it also enables Member States to grant tax advantages to businesses which implement measures to reduce their emissions.

Electricity, however, is a completely homogeneous good that cannot be marked accordingly. Still, even now different users can have specific tariffs, either based on volumes and peak demand (mostly commercial users) or time and application. Households using electricity for heating purposes often have separate meters and can have access to lower fee night-time electricity.

In 2009, the revision of the Directive was expected. After some delay, a first orientation debate was held in June 2010, introducing a carbon tax for energy products, which could be in the order of 20 €/t $CO_2$ (ENDS, 2010). A final date for the proposal of a European carbon tax is not yet set. However, it should be noted that for any legal proposal related to EU tax matters unanimity should be obtained from all the 27 Member States.

*Recommendation for the Framework Directive for the Taxation of Energy Products and Electricity*

Separate metering for Electric Vehicles would enable differentiated taxation for different electricity types. This way, the considerable losses in fuel taxes can be recovered without affecting other electricity uses. This strategy should be followed from the early introduction of EVs on, enabling separate taxation once the market moves into maturity.

However, future vehicles may use any number of fuel or energy sources for propulsion (e.g. biofuels, hydrogen fuel cells), including combinations of sources.

Various options exist for recuperating lost revenue by adapting the Framework Directive for the Taxation of Energy Products and Electricity.

a One option would be to increase tax rates on electricity used in transport.
b Furthermore, it would be possible to increase taxation on both electricity used in transport and on fuels for ICEVs.
c Other options include a per-km charge or other forms of road charging such as a flat rate vignette which could also be environmentally differentiated. These options are discussed in Section 4.4.3.[21]

Strategy a) will reduce the cost advantage of EVs compared to ICEVs due to their lower per-km cost and, thus, hamper EV uptake.

Strategy b) would eliminate this distorting effect and would maintain the cost advantage of EVs due to their lower per km-costs compared to ICEVs while at the same time maintaining revenue equivalence. It is therefore the recommended course of action compared to alternative a).

Strategy c) does not pertain to the Framework Directive for the Taxation of Energy Products and Electricity and is discussed further in Section 4.4.3
The taxation of electricity for EVs can be done indirectly through the power supplier. Once a system to monitor EV electricity use is in place, a methodology to calculate taxes for electricity used by EVs can be developed. Due to cost considerations, enforcing a uniform plug format that is incompatible with any other use form would ensure a least cost monitoring and taxation of EV use through smart metering technology.
Action is required on this issue in the medium-term time horizon, when EVs become more prevalent and have a significant impact on public finances. It seems advisable to raise taxation levels under the Framework Directive for the Taxation of Energy Products and Electricity for both electricity and transport fuels.

This measure can be complemented or substituted by road charging instruments (Strategy c).

### 4.4.3 Charging for road use

By charging for road use it is possible to charge drivers according to when and where they drive. Generally, such policies are used to reduce the number of cars on the road to counter congestion, extended driving times and pollution, thus being in line with the polluter-pays principle. The possibility to charge users differently according to vehicle type is an option to support EV uptake.

Currently, legislation exists for road charging for heavy duty vehicles, Directive 1999/62/EC, modified by Directive 2006/38/EC – the Eurovignette Directive, putting restrictions to the costs that may be charged. A proposal for a revision is currently under negotiation (COM(2008)436). Within the current framework, various Member States introduced kilometre-based charges for road use of heavy goods vehicles. For passenger cars, there are no such restrictions for the introduction of road charging schemes. However apart from road tolls on certain motorways and a few congestion charging schemes, no large road charging schemes for passenger cars have been introduced so far, mainly because of a lack of public support and potential technical and organisational complexity and risks.

[21] Both approaches invariably hamper EV uptake as consumers intend to outweigh the higher initial purchasing costs with lower running costs. Adjusting these running costs to cover lost revenue will thus increase total cost of ownership and reduce market uptake.

*Assessment of charging for road use*
Generally, three alternatives for road charging are available: a corridor scheme, an area scheme and a national scheme. In the corridor scheme a toll is used to charge for a stretch of road, tunnel or bridge. The use of electronic toll booths makes this a simple and appealing option to charge drivers. The second alternative is to charge for a local road system. Such systems are used in, for example, London and Oslo. In London drivers are charged a flat fee of 8 GBP (about € 9) a day between 7:00 and 18:00 to enter the city. The final option is to charge for extended road networks with a national scheme. This approach then also charges those travelling longer distances. European countries such as Austria, Hungary and Switzerland require vignettes to use the motorway network for a certain period. In France and Italy, drivers pay according to number of kilometres driven on highways (WEC, 2010). In Germany, Switzerland, Austria and the Czech Republic heavy duty vehicles pay a toll depending on size and distance for using the motorway system (in Switzerland also on other roads).

Charging for road use is applied in many European countries. And although measures may have traditionally been used to earn revenue and counter construction and maintenance costs they also have a potential to be combined with Member State objectives for EV uptake.
A tax system based strictly on charging for road use would enable regulators to collect tax revenue without the need to distinguish between fuel types, and instead focus strictly on road use. However, this option would require a high initial investment, either to build road tolls or implement a national charging scheme, and moreover, would require a significant change for most Member State fuel taxation schemes. Nevertheless, this option to collect taxes, regardless of fuel type, is also beneficial considering that vehicle technologies are still advancing, and that the future may bring a rise in technologies that use hydrogen or other energy sources. Alternatively, it is also possible to implement environmentally differentiated road charging.

Road charging has some important benefits compared to energy taxation:
- Road charging is better in line with the user-pays and polluter-pays principles, because charge levels can be differentiated to vehicle type, road type, location and time of the day. This way, fee levels can be tuned with the cost imposed (congestion, pollution and noise) and so provide incentives to road users to reduce these costs, particularly at locations and times of the days where these costs are highest.
- Road charging can have additional benefits in reducing infrastructure and external costs and moreover optimising the use of available road capacity. Various studies show that this can result in important macro economic benefits (e.g. IMPACT study, CE, 2008).
- Road charging can guarantee tax revenues in case of a strong shift to Electric Vehicle use.
- Road charging can effectively contribute to reducing road usage and hence also road transport energy use and GHG emissions.

The main drawback of road charging is the difficulty of gaining public support. This is linked to loss aversion, privacy considerations and the fear for overpricing. Also, the implementation cost of differentiated charging schemes can be considerable. However, existing schemes for HGV suggest that large scale introduction of road pricing schemes is likely to be modest compared to the tax revenues. The latest kilometre charging scheme that was proposed for all road vehicles in the Netherlands aimed at costs below 5% of the revenues, which was quite ambitious. In case of a broad EU wide application of this type of schemes that charge all infrastructure and external costs, cost rates in a range of 5 to 10% of the revenues seem feasible. These costs have to be compared to the transaction costs of existing taxation schemes in order to come to a well-founded decision.

*Recommendation for charging for road use*
Road charging offers the potential to ensure that revenues from road transport will cover infrastructure expenditures even in times of decreasing revenues from fuel taxation due to EV market uptake. Moreover, they offer the opportunity to internalise external costs. In addition, user charges could be differentiated according to the specific emissions of the vehicle. Thus, road charging can implement true costs for driving and create significant incentives for a socially-optimal use of roads.

Given the fact that EV uptake will not become significant before 2025/2030, no immediate action is necessary in the field of road charging at this point. However, since the process to reach a European agreement, including the Parliament and the Council, will take a considerable amount of time – as can be observed on the occasion of the Eurovignette Directive – it might be necessary to begin the process at least 10 years before the desired implementation, i.e. before 2015.

## 4.5 Policies related to charging infrastructure

Policies to support the development of EV charging systems cover numerous aspects:
- Measures to support charging networks and making the grid EV-ready (Section 4.5.1).
- Making the grid EV-ready (Section 4.5.2).
- Technical standards and regulations (Section 4.5.3).
- Stimulating smart charging (Section 4.5.4).

### 4.5.1 Measures to support charging networks

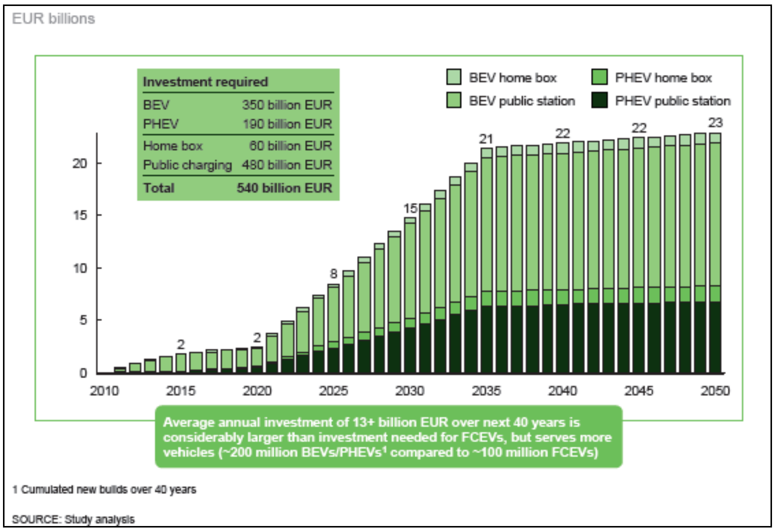
Without a dense network of charging stations, EV uptake is unlikely to accelerate.

*Need for building charging networks*
A major obstacle in Europe is that most car owners and especially prospective urban EV buyers do not own a garage but park their car at the curb. This requires a multitude of capital intensive public charging stations at costs of approximately € 1,500-2,000 for slow charging outlets and € 20,000-30,000 for fast charging (see Section 3.10.2, and ZERO, 2010). Given the immense investment needs and low electricity prices, no viable business concept has emerged so far.

Therefore there is a demand to support building charging infrastructure through a mix of instruments such as:
- Subsidies which could be given to individuals installing charging equipment.
- Regulation which could include requiring new parking lots or office buildings to be equipped with EV charging stations or requiring electricity providers to install a specific number of EV charging stations.
- Financial incentives could be given to prospective investors, e.g. tax credits, reduced-interest rate loans or credit guarantees.

Estimates in Section 3.10.2 of annual investments needed are in the € 20–100 billion range for 2030, (ZERO, 2010) estimate that investments to develop both home and public charging infrastructures could total € 540 billion by 2050.

**Figure 43** **Charging station investment costs of a large scale rollout of battery and Plug-in Hybrid Electric Vehicles in Europe**




Source: ZERO, 2010.

Increased support for public charging stations, leading to higher numbers of stations, would help to create a system which supports electric vehicle use, therefore fostering their increased uptake. More charging stations would also enable travelling long distances with Electric Vehicles, restricted by limited battery capacity. This would also render EVs a more appealing mode of transport and perhaps enhance their ability to compete with ICEVs.

Vehicle parking and infrastructure differences across Member States imply that support may be more necessary in some countries than in others.

*Recommendations for building charging networks*
Given limited public budgets, governments will not be able to cover the entire costs of setting up a charging system. Rather, it seems more feasible to envision a mix of measures where:
- Governments provide some funding for initial set-up (public investment).
- Governments require real estate developers and power providers to invest in charging infrastructure (private investment).
- Governments can provide assistance and incentives to alleviate the burden for private investors (public private partnership).

Initially, it will not be possible to hand down the costs of establishing the charging system to EV users as this would preclude any EV uptake.

In the medium term, however, assuming some market penetration, it will be possible to recover some of the initial investment as well as the running costs through instruments such as energy taxation and road pricing.

While most of these measures will need to be taken at the Member State level, the EU can facilitate the process by providing guidance and setting the framework, especially with regard to financing options.

### 4.5.2 Measures to support making the grid EV-ready

Measures which support a fully interoperable pan-European charging system and prepare electricity grids for EVs would help to foster EV uptake, as well as help to avoid potential grid issues caused by charging significant numbers of EVs. Support measures are likely to be necessary at the Member State as well as EU level to ensure electricity grids are ready EU wide, mostly after the 2030 horizon.

*Impact of EVs on the grid*

The transmission and distribution networks in most EU countries are already operating close to or beyond their rated capacity and some even frequently fail to meet supply due to demand which exceeds their design specifications (Dyke, 2009).

Thus, the expected growth of electric vehicle sales will have a significant impact on electric power distribution networks in Member States. Member States with insufficient distribution grids could face severe local stress on their power grids. Fast charging applications could change the picture and lead to bottlenecks in all Member States. However, challenges facing the European distribution network go beyond dealing with peak demand and additional loads, also affecting grid frequency and voltage. These constraints factually limit the total number of vehicles that the distribution grids can absorb.

Investments in distribution networks to support EVs, i.e. transformer stations etc., are likely to be substantial.

*Recommendations for making the grid EV-ready*

To ensure that local distribution grids become EV-ready, the European Commission can initiate best practice exchange, implement pilot and demonstrations projects under programs such as IEE and fund additional research through FP7 research funding.

### 4.5.3 Technical standards and regulations

Charging can be segmented into three categories: household connections, fast charging and battery swap systems.

A mandate for European standardisation was given to CEN/CENELEC/ETSI in June 2010, within the framework of Directive 98/34/EC, laying down a procedure for the provision of information in the field of technical standards and regulations. The Directive provides procedures for the provision of information in the field of technical standards and regulations. This work on standardisation is currently ongoing.

*Assessment of technical standards and regulations*

Common plug and charging standards, as well as protocols for data exchange, are essential to EVs and should be a priority area for policy making. Common standards and protocols would support the increased uptake of Electric Vehicles by enabling consumers to charge at any station with any plug type and by regulating the financial transactions linked to the charging process. Moreover, common standards help to avoid unnecessary trade barriers[22] and disincentives to enter the European market for manufacturers. Additionally, standards reduce the total number of charging stations needed to support Electric Vehicles by enabling all vehicles to be charged more easily.

[22] This may also be considered 'non-tariff' trade barriers under WTO rules.

The standard is expected to establish a charging interface which ensures interoperability and connectivity between the electricity supply point and the charger of Electric Vehicles. Additionally, smart charging and using electricity during 'off-peak hours' is also to be considered in standardisation.

Moreover, different technical requirements exist for different charging levels, i.e. slow charging (~10 kW) or fast charging (up to 500 kW).

Presently, three standards for connecting EVs to charging stations (power plug) compete for worldwide recognition: one from the American SAE, one from the European/international IEC and the Japanese CHAdeMO. Even though all players insist that they support a uniform standard, allowing any vehicle to charge at any station, no common standard has yet been agreed upon and the outcome of this race for an international standard is wide open. National governments are also involved – such as the German government who is supporting the IEC-based 'Mennekes' plug. A common international standard is not expected until 2017. A European standard is expected for 2012.

*Monitoring EV electricity use*

Common charging stations will improve the capacity of governments to create monitoring programmes because they will only need to focus on a limited number of charging stations when creating monitoring protocols.

Monitoring EV electricity consumption is relevant both for accounting for the use of renewable energy in transport, for measuring GHG emissions in relation to targets in transport and for general energy statistics (Section 4.3). Monitoring can best be done through data from smart metering supplied by electricity providers. Electricity consumption by Electric Vehicles can be monitored by separate meters if outlets are not compatible with standard electric power outlets. Metering at the charging station might be preferable to on-board monitoring as costs for the smart meter can be shared among user if it is not on-board. Furthermore, the vehicle weight can be further reduced by outsourcing the meter.

The European Commission intends to launch a public consultation exercise on counting electricity, and other energies, from renewable sources towards the 10% renewable energy target in transport in late 2010 or early 2011 and is preparing a possible amendment to the Renewable Energy Directive by late 2011. It is therefore essential that standard monitoring practices are developed which cover the different charging options and ensure that Electric Vehicles contribute to the target.

*Recommendation for technical standards and regulations*

As the European Standard is under way by 2012, there is no need for additional action at the moment at the European level. However, some cars and charging points are being sold now and in the coming years that are not compatible. Due to the very low numbers, this will not pose a significant obstacle.

Once standards are selected, methods to implement them are essential so that they are adopted throughout industry, including vehicle manufacturers, electricity providers and electricity distribution network operators. Moreover, global technological and market developments need to be monitored and relevant European standards need to be adjusted as necessary.

However, it is not essential to develop international standards for EVs, as is not the case in many other technologies (e.g. some regulations for ICEVs differ between countries such as the US and Japan and the EU). Nevertheless, international standards strengthen the capacity of manufacturers, from both the EU and third countries, to reach wider markets by removing non-tariff barriers to trade. This therefore also enhances market competition which may in turn help to spur innovation and development.

Monitoring standards for EV electricity consumption need to be developed quickly in order to assure that EVs can contribute to achieving RED and FQD goals.

### 4.5.4 Stimulating smart charging

Innovative and intelligent charging networks are essential to demand side electricity management and deliver a readily accessible monitoring option.

*Assessment of stimulating smart charging*

Controlled or smart charging will allow a much greater number of cars in the system without local overload.

Moreover, smart charging will allow load balancing both at sub-station and at the grid level, particularly with charging at peak wind supply times, thus easing the integration of large scale intermittent electricity sources such as off-shore wind energy. The total storage capacity of EVs is, however, quite limited and other forms of storage technology – such as pump storage or compressed air are more cost-effective. In the medium-term perspective, there is only a small likelihood of EVs operating as batteries for the electricity grid, i.e. feeding back energy at peak demand times.

Still, smart charging will allow EVs to penetrate the market with higher growth rates than the electricity generating capacity needs to grow, since it can make use of off-peak over-capacities. Nevertheless, under current legislation, EV owners would be able to charge whenever and wherever they want to, calling for a strong price incentive through dynamic tariffs.

Smart charging would require a concerted effort of EV manufacturers and electricity providers to invest in the necessary infrastructure. In addition, policy-makers need to second the process with a harmonised standard for data exchange between vehicles, charging points and the electricity grid.

*Recommendation for stimulating smart charging*

Priorities to cut power costs compete with needs to invest in smart grids and therefore impede their development. Distribution system operators of electricity have traditionally been in charge of network innovation, but they lack a strong incentive to invest in smart grids. Even though increased network efficiency will save money in the long term, smart grids imply more volatile revenues and hence financial risk for the mostly monopolistic power providers and grid operators.

According to Eurelectric, a new model for financing electricity distribution may be necessary to develop smart grids because current business practices do not provide adequate incentives to upgrade distribution networks. Eurelectric maintains that a revision to financing schemes for electricity distribution should be based on benefits of investments to consumers and the environment as well as guarantee a fair and long-term return on investment (Eurelectric, 2009).

The EU is already taking steps to move towards smart technologies and made recommendations for Member States to develop smart metering in October 2009. Member States are asked to develop common smart metering standards for stationary installations by the end of 2010, and a roll-out of meters is expected to be done by 2012. A smart charging standard for EVs could build upon this forthcoming standard.

At low EV penetration levels, smart charging is still optional. However, once a threshold of 5% EV penetration has been reached in any region, peak load pressure will make smart charging a necessity. Therefore, regulation could be developed to prescribe that electricity providers implement smart charging infrastructure once the 5% threshold has been reached in their distribution district.

## 4.6 Other policies

The EU is very active in creating a cleaner and healthier environment for all Europeans, including areas such as noise, air pollution, toxic waste, water pollution, etc. A more sustainable use of environmental resources implies recycling and reuse of materials. On the other hand, natural resources become increasingly scarce and resource access is becoming a constraint for EV manufacturing in Europe. A number of Directives and Regulations address these environmental concerns and touch upon issues related to Electric Vehicles, such as batteries. Far from being exhaustive, we will focus on the two most relevant legal acts:
- Raw Materials Initiative (Section 4.6.3).
- End-of-Life Vehicles Directive (Section 4.6.4).

This chapter starts with discussing two other relevant policy areas:
- Subsidies for pilot and demonstration projects (Section 4.6.1).
- Support for local policies (Section 4.6.2).

### 4.6.1 Subsidies for pilot and demonstration projects

Support from the European Commission and Member States through financing for pilot projects on electric mobility, especially for trans-national cooperation, could help to accelerate a European-wide uptake of EVs. This may help to develop common EU standards and also improve cross-border mobility. In this context, France and Germany started a cross-border EV pilot project in the Strasbourg-Stuttgart region. The project aims to develop a common approach to standardisation and ensure the interoperability of EVs and their charging infrastructure (BMWI, 2010).

*Assessment of subsidies for pilot and demonstration projects*

On an EU level, The European Green Cars Initiative (GCI) is the funding mechanism used to support clean and energy efficient vehicles. The GCI has two financial sources, the European Investment Bank (EIB) and the EU's Seventh Research Framework Programme (FP7), and provides € 5 billion in loans. The loans go to support research, development and innovation for cleaner and more efficient forms of transport. In particular, FP7 funds provide significant support to the electrification of road transport (EC, 2010e).

One FP7 project is 'Electric Vehicle communication to Infrastructure, Road services and Electricity Supply' (ELVIRE). ELVIRE is a pilot project which aims to use new technologies to reduce 'range anxiety' amongst EV drivers. The project demonstrates and tests an on-board communication system to connect EV drivers, EVs and charging infrastructures so that consumers have a reliable monitoring system when driving longer distances (ELVIRE, 2008).

The EIB manages two lending facilities which make loans available under the GCI. These are the European Clean Transport Facility (ECTF) and Risk-sharing Finance Facility (RSFF). The ECTF provides various funding opportunities to all transportation areas focused on reducing emissions and improving efficiency, and, in particular, supports automotive manufacturers and suppliers. The RSFF, a combined EIB and European Commission facility, improves financing for private companies and public institutions and includes green car technologies amongst its funding priorities.

*Recommendation for subsidies for pilot and demonstration projects*
The GCI demonstrates that funding opportunities for research and innovation into clean and energy efficient road technologies are available. Moreover, funding also exists for private companies and public institutions, as well as for the electrification of transport.

Nevertheless, consumer acceptance and thus market development for EVs, as with any new technology, is likely to increase through trial and experience. It is therefore important to provide continued support for demonstration projects for EVs and their supporting infrastructure, such as the German French partnership and the ELVIRE project, until the EV market matures further, i.e. 2025/2030. Funding levels can be gradually reduced, once 5-10% EV market penetration has been achieved. At the same time support for EV development and pilots should be balanced with support to the market introduction of competing technologies.

### 4.6.2 Support for local policies

An appropriate support framework for local stimulation policies is likely to speed up the market uptake of EVs. On the other hand, stimulating EVs should be a self-serving goal but also be seen in the context of reducing GHG emissions from road transport. Therefore stimulating policies have to be assessed regularly to prevent rebound effects.

*Assessment of support for local policies*
A supportive policy framework could contribute to creating business confidence and opportunities, enabling investment and production which benefit EVs and renewable energies. Moreover, policies which encourage consumers to use EVs may help to provide new acceptance or willingness to try EVs. It is most likely necessary that the EU should lead the introduction and consumer acceptance of Electric Vehicles while considering actions taken by the Member States, regions and municipalities.

A number of national and local policies are already implemented in some Member States, such as the UK and the Netherlands. At the national level, the UK uses several measures to create incentives for EV, such as tax exemptions and discounts. For example, EVs are exempt from the Vehicle Excise Duty, receive enhanced capital allowance (i.e. tax benefits for companies investing in climate technologies) and tax breaks for companies which use EVs as company cars (effective in 2011).

On the local level additional measures are also used in the UK to support EVs. For example, in London EVs are exempt from the city road charge, the ‘Congestion Charge’ (DfT, 2010).

Additionally, a local policy in the City of Westminster in the UK allows EVs to park in a number of city car parks and charge for free for up to four hours. The EV owners must first pay a yearly administrative fee, but then receive free parking and charging from the city (CW, 2010).

Stimulating policies incur costs. Under the current framework of public austerity measures, these policies cannot be maintained indefinitely and need to expire after a given time.

Moreover, the more EVs are on the roads and the higher their share in the new car market, the higher the costs of support policies.

*Recommendation for support for local policies*
Member State and local policies which support EVs can provide additional incentives to companies as well as consumers to select EVs. Policies which encourage companies to switch to EVs may help to foster the uptake of numerous EVs simultaneously, because of large commercial fleets.

Local policies such as exemptions from city road charges may also be extremely beneficial to the uptake of EVs. City drivers are already ideally placed to use EVs because of shorter driving periods, so local policies catered specifically to them offer significant potential to encourage EV use.

Additional local policies to encourage EV use may include various driving, parking or other vehicle related aspects. For example, free parking for EVs, or open access to car pool or bus lanes.

At the EU level, there is no specific action required to encourage local policies. However, similar to Member State fiscal policies, guidance as well as clear signals to Member States and local municipalities about EVs and local policies will help to shape EU-wide priorities for EVs.

So far, major potential applications for EV use remain more or less untapped. This includes the use of EVs in postal fleets, delivery services, public fleets such as parking enforcement and taxi cab services. These niche markets can be explicitly targeted by support policies both at European and national level.

### 4.6.3 The Raw Materials Initiative
The Raw Materials Initiative (COM(2008)699) aims at securing reliable and undistorted access to raw materials by means of access, recycling and resource efficiency. Although not having any binding character, the Initiative shows the increasing awareness of resource needs to assure the availability of novel technologies, ranging from solar panels, to permanent magnet motors, electronic components and lithium batteries.

*Assessment of the Raw Materials Initiative*
The European Commission’s Raw Materials Initiative, launched in 2008, is essential to ensure access to, recycling and recovery of indispensable materials, such as rare earth elements, e.g. lithium used in EV batteries. The Initiative recognises that such high-tech materials are crucial to the EU to develop and advance technologies as EVs. The European Commission is as of November 2010 preparing a Communication to report on the progress of its implementation and indicate the next steps (EC, 2010b). The implementation of the Initiative is critical to the long-term cost effectiveness, production potential and availability of EVs.

While measures aiming at increasing recycling and resource efficiency of raw materials are without doubt beneficial in many ways, albeit not always cost-efficient, measures aiming at ensuring access to resources in developing countries can have significant political implications, especially in a scenario of ever more intense competition between the EU, the US and BRIC countries for these raw materials.

The security impacts of raw material dependency should not be under-estimated, as can be seen in the example of the Gulf region, permanently at war for decades, with its conflicts fuelled by the oil dependency of the industrialised world. Currently, the Chinese government is pursuing restrictive export policies for lithium and rare earth minerals. A more in-depth assessment of resource scarcity can be found in the WP 2 report on EV and battery technology.

Another potential source of concern are individual national raw materials initiatives, such as the German case: in October 2010, the German government created a raw materials agency after launching a German raw materials initiative.[23] While national initiatives can be very helpful in accelerating EU action, they also incur the risk of growing national competition between EU Member States for scarce resources.

*Recommendation for the Raw Materials Initiative*
EVs rely on a number of scarce resources from lithium to rare earth minerals. Therefore, EV manufacturing in Europe links very directly to the Raw Materials Initiative.
Policies in the realm of raw material access have to take into consideration political implications and, especially, long-term security concerns. Fast growth in the EV manufacturing sector after 2025 could increase the pressure on resource access and lead to growing global tensions between the EU, China and the US.

It should be of paramount concern for the European Commission to harmonise national raw materials initiatives with the EU strategy in order to avoid harmful competition between Member States and in order to reap the maximum benefits from coordinated efforts to maintain resource access.

Action is needed in 2011 in order to prevent creating a negative precedent between EU Member States. At the global level, given the significant time lag before EV manufacturing becomes a dominant resource user, strategies have more time to be developed and conflicts can be resolved at an early stage.

Key elements of a European strategy to assure resource availability for EV production should be:
- Recycling of end-of-life EVs and parts.
- Increasing resource extraction efficiency through life-cycle management of resources and international cooperation. And
- Landfill mining, i.e. the reprocessing of resources from landfills.

### 4.6.4 The End-of-Life Vehicles Directive and the Batteries Directive
The End-of-Life Vehicles Directive (2000/53/EC) aims at making vehicle dismantling and recycling more environmentally friendly. It sets clear standards for the reuse, recycling and recovery of vehicles and their components.

The Batteries Directive (2006/66/EC) prohibits the use of certain hazardous substances in batteries and sets targets for separate collection and recycling of waste batteries.

[23] http://www.bmwi.de/English/Navigation/Press/press-releases,did=368098.html.

*Assessment of the End-of-Life Vehicles Directive and the Batteries Directive*

The End-of-Life Directive prescribes recycling rates of 95% after 2015 for all end-of-life vehicles. This reuse and recovery would include EVs and therefore also its components, most notably batteries. These contain high-tech materials such as rare earth, lithium and others. New lithium-based car batteries, however, are far less toxic than their lead-acid predecessors and far more difficult to recycle. In fact, recycling lithium-ion batteries is highly cost inefficient, as has been shown in the WP 2 report. A prescribe reuse rate of 95% would therefore potentially increase the costs for EV buyers and prevent a further spread of EV-technology or even a mass market altogether. Nevertheless, unconventional reuse forms such as using materials in construction or as road surface can open doors to more cost-effective recycling options in line with the legal requirements. These unconventional reuses would, however, not contribute to alleviating the resource pressure for materials such as lithium and rare earth minerals. Moreover, the Directive encourages manufacturers to consider the recyclability of vehicles during design and production (EC, 2000). At present the Directive focuses on ICEVs and the materials they use. Traditional car batteries are considered within the Directive, yet these differ from EV batteries regarding materials. Amendments to the Directive which include EV materials within their scope would therefore help to maintain resource efficiency and low costs for EVs.

The Batteries Directive requires a minimum rate of recycling: 65% for lead-acid batteries, 75% for nickel-cadmium batteries and 50% for other batteries. Battery manufacturers have to bear the costs of recycling. This would include EV batteries and hence possibly add to the total costs of EVs and harm a quick market penetration of EVs.

In the longer term, rising resource costs might make battery recycling cost effective even for lithium batteries or their successors. In the meantime, this aspect might incur a cost burden to the sale and operation of EVs in Europe. However, incorporating recyclability as a design feature early in the development process of batteries and vehicles might allow significant cost reductions. Furthermore, economies of scale and learning will arise with growing production volumes, reducing recycling costs even more.

*Recommendation for the End-of-Life Vehicles Directive and the Batteries Directive*

Given the lack of information on costs and benefits of recycling and reuse of rare earth minerals and lithium, further research will be needed to explore viable options, including unconventional reuse and design to recycle.

A potential outcome of this research could be to adapt or supplement the recycling requirements taking account of technical or scientific progress, in order to help EV market penetration. However, in view of raw materials access and resource efficiency, but also the aspiration of sustainable transport, EV components should be recycled with priority. It has to be considered, given the additional cost burden of EV users, whether further financial support, i.e. subsidies, can be applied specifically for EV battery recycling for a limited time frame.

Action will be required especially in view of the 2015 goal line in the End-of-Life Vehicles Directive.

# 5 Conclusions and recommendations

## 5.1 Impact analysis

This impact analysis is based on an assessment of three scenarios, which describe three different electric vehicle futures:

- Scenario 1: A 'most realistic' scenario, which is based on current best estimates of cost and performance development of EVs and conventional cars, and current government incentives and fiscal policies. This scenario leads to about 3.3 million Electric Vehicles in the EU in 2020, but sales increase rapidly afterwards, to more than 50 million EVs on the EU roads in 2030. Most of these EVs are Plug-in Hybrids (about 60% of all EVs), the remainder are Full Electric Vehicles and EREVs. Smart charging will become standard after 2020, to avoid grid overload problems due to EV charging and to steer the time of charging away from peak demand periods.
- Scenario 2: A scenario where Electric Vehicles will gain some market share, but remain a relatively small part of the car fleet. Here, ICEVs remain the prominent technology also in the longer term – with strongly improved fuel efficiency. This scenario leads to about 2 million EVs in 2020 throughout the EU, increasing to 20 million in 2030. PHEVs again take the largest share, about two third, in EV sales. As the sales remain limited, it is assumed that smart charging is not applied on a significant scale.
- Scenario 3: This scenario assumes a technological breakthrough in battery technology in the next decade, leading to fast cost reductions and thus market uptake after 2020. In this scenario, EVs become competitive with ICEVs, both financially as well as regarding performance. This scenario leads to 5.5 million EVs in 2020, and 93 million in 2030: the sales of EVs is expected to exceed those of ICEVs from about 2025 onwards. Again, about two thirds of EV Smart charging will be adopted from 2020 onwards, for the same reason as in Scenario 1.

These three scenario are intended to 'cover the playing field', based on current knowledge and expectations regarding future policies and technological developments.

### 5.1.1 Impact on fuel and electricity demand and production

Clearly, the higher the market penetration of EVs, the higher the impact on both petrol and diesel use, and on electricity demand. Petrol and diesel use was found to reduce by about 12-20% in 2030, in Scenarios 1 and 3 respectively (compared to the Reference Scenario). Scenario 2 illustrates that petrol and diesel use can also be reduced by improvements of ICEV fuel efficiency[24]. In these scenarios, electricity demand of EVs was found to range from 180 to 740 PJ, in 2030 (and about 10-50 PJ in 2020).

[24] The assessment and comparison of cost and benefits of both improved ICE efficiency and of EV market uptake was not part of this study, but has been carried by Ricardo and TNO in the 'Vehicle Emission' study for the Commission.

Based on the results of the market uptake modelling, and assumptions regarding the distribution of the additional electricity demand over the days, the impact on power production was calculated using the IPM model. Results illustrate the impact of increasing electricity demand but also of smart charging, which leads to a somewhat different fuel mix for the additional power generation: managed charging in Scenarios 1 and 3 mainly leads to more wind and gas capacity, and some additional coal, the unmanaged charging in Scenario 2 will mainly lead to an increase in gas of coal capacity.

### 5.1.2 Impact on emissions, noise and materials use

Looking at the net effect on emissions of the reduced diesel and petrol on the one hand, and the increase electricity demand on the other hand, we can conclude that an EV market uptake will lead to reductions in $CO_2$ emissions, but an increase in $NO_x$ emissions – all compared to the Reference Case without EVs. The EV Scenarios 1 and 3 achieve reductions of 21-53 Mton $CO_2$ in 2030 (4-10% of passenger car emissions). Scenario 2 leads to 116 Mton $CO_2$ reduction, mainly due to the more fuel efficient ICEVs. Note that part of the remaining $CO_2$ emissions will automatically fall under the EU ETS, and will therefore have to be compensated elsewhere within the ETS. If we assume that all GHG emissions from additional electricity demand are zero because of the ETS, the $CO_2$ reduction of passenger car emissions is 15% (Scenario 1) to 27% (Scenario 3) in 2030, compared to the Reference Scenario.

The net effect on $NO_x$ emission in the EU is less positive: emissions of additional power production are higher than emission reductions due to the lower use of petrol and diesel. The respective scenarios lead to additional emissions of about 150, 50 and 240 kton $NO_x$ in 2030. The lower PM emissions outweigh the higher $NO_x$ emissions. The air pollution costs in 2030 are estimated to decrease by about 2% in Scenario 1, 10% in Scenario 2 and 5% in Scenario 3.

Regarding noise emissions, it is concluded that the impact of EVs on overall, average transport noise levels seem negligible at least until 2020, but might become significant after 2025 in Scenarios 1 and 3. Local effects may occur earlier, if higher EV shares are achieved in certain cities, districts or regions.

The impact of EV market uptake on demand of certain materials, namely lithium and some specific rare earth metals, is a significant demand increase after 2020. Technical availability (global reserves) does not seem to pose a restriction to these developments, but production needs to increase significantly after 2020 if these scenarios come true.

### 5.1.3 Economic impact

The uptake of electric vehicles will have a variety of economic impacts on various actors, including the car industry and their suppliers, consumers and governments. A number of these economic impacts could be assessed, such as the impact on fuel and electricity taxes, on VAT revenues from cars sales – all assuming that current tax levels remain the same. In Scenarios 1 and 3, the effect of the market uptake of EVs on energy tax revenues can be clearly seen to start to become significant after 2020, when the sales of EVs start to increase. This results in a revenue loss of about € 2 billion in 2020, which increases to € 25 to 40 billion in 2030. In Scenario 2, fuel tax revenues decrease right from the start – compared to the reference – as the fuel efficiency of the ICEVs is assumed to reduce faster than in the other scenarios. This reduces revenues from fuel taxes in the EU-27, by about € 20 billion in 2020 and € 38 billion in 2030.

On the other hand, Increased EV sales can be expected to increase government revenues, due to the higher catalogue price of the EVs when compared to ICEVs of the same size. The increases found are in the range of € 0-10 billion in 2020 and € 3-20 billion in 2030. The higher the EV share and the higher the additional cost, the greater the revenue increase.

As the number of EV increases, the number of charging points will have to increase as well. The investment costs of these were estimated as well, and range from € 2-10 billion till 2020 to € 30-150 billion till 2030, again depending on the number of EVs in the fleet and thus charging points required. The uncertainty of this estimate is quite large, as the technology and the cost are still in development.

Other economic impacts, for example on car manufacturers or impacts on vehicle taxation revenues throughout the EU, could not be assessed within the scope of this project.

### 5.1.4 Impact on primary energy use and imports

A shift to electro-mobility resulting in a shift from petrol and diesel use (oil) to electricity use (gas and coal) will change the use and import of fossil fuels in the following ways:

- The impact on the overall use of fossil fuels (in terms of primary energy content) will be very limited. Oil consumption will decrease but that effect will be compensated for a large part by an increase in gas and coal. Just on the long term and with a high share of electricity from renewable sources, the reduction in fossil fuel use can become significant.
- The overall effects on import of fossil fuels is uncertain. Based on current import rates, the overall import might decrease because for oil the imported share is considerably higher than for gas and coal.
- It is impossible to predict how the dependency on various regions in the world would change, without further, detailed study. Changes are likely to be small.
- At the long run (after 2030) when electricity mix further develops towards renewable energy sources and petrol and diesel use decreases stronger, the dependency on oil imports is likely to decrease with further uptake of EVs.

### 5.1.5 Potentially drastic changes

Clearly, especially Scenario 3 represents quite a drastic change to the passenger car fleet in the coming two decades. It would mean very significant changes to car and drive train production, and very significant efforts in battery production (and recycling) and battery materials mining would be required. Large scale charging infrastructure would need to be made available to consumers, and many parts of society would have to get used to the new technology – car owners, the car service industry, rescue workers but also other traffic participants, as they, for example, have to get used to the lower noise levels. In the other scenarios, developments are somewhat slower, allowing all stakeholders more time to adopt.

## 5.2 Policy implications

The introduction of EVs is linked to various EU policy areas in particular on energy and climate, including policies aimed at clean and energy efficient vehicles.

For the short term, at least the next five years, the EV technology is clearly not yet mature and governments could certainly support innovation. In this phase it is important to be aware of other possibly competing technologies. In the case of EV, particularly competition with other types of energy efficient vehicles should be considered, such as ICEVs and hybrid electric vehicles. In addition competition with other alternative energy carriers should be fair non-biased, e.g. competition with ($2^{nd}$ generation) biofuels. A simultaneous support of the various innovations stimulates innovation and may help to avoid unfair competition.

Once the share of EVs becomes significant, government policy framework should adapt. Maintaining support for EV for too long results in over-simulation and market distortion. Therefore, the coming years a consistent overall fiscal and regulatory framework should be developed, covering EVs and all competing technologies consistently. The key policy conclusions and recommendations in this chapter could serve as a starting point for this and are summarised in the next subsections.

### 5.2.1 Vehicle regulation

Existing $CO_2$ regulation for passenger cars and light commercial vehicles (under development) use tailpipe emissions as a basis to compare the environmental performance of vehicles. They count emissions from electricity production as zero, leading to relatively strong stimulation of EVs. This effect is amplified by the so called super credits.

Zero counting and super credits can have a positive effect regarding stimulation of EVs research and production, but they also have a negative impact on total fleet efficiency (well to wheel). If EV sales increase, they can increase overall emissions from road transport and possibly conflict with EU climate change mitigation targets. In addition zero counting EVs entails significant risks with respect to fair competition between various technologies and possibly the overall GHG emissions. Therefore, adjustments of the current approach need to be considered, at least for period after 2020.

The most appropriate and feasible solution seems to extend the current vehicle regulation to a system that covers the well-to-wheel GHG emissions for both ICEV and EV propulsion[25]. It is true that upstream emissions cannot be influenced by car manufacturers but the same is true for conventional fuels. The key challenge for the development of a well-to-wheel emission regulation would be to develop GHG intensity data for all energy carriers. Particularly for electricity this requires some further in-depth study of the various options, particularly because average and marginal emissions differ considerably.

### 5.2.2 EV impact on the electricity sector

EVs can contribute to reducing the carbon intensity of transport fuels as required under the FQD, and can help achieve the set target of 10% renewable energy sources in transport by 2020 formulated by the RED. Both require a more detailed accounting methodology for EV electricity consumption. As the Fuel Quality Directive refers directly to the Renewable Energies Directive, only one methodology needs to be put forward.

[25] Alternative approaches like moving to well-to-wheel energy efficiency standards, as mentioned in the White Paper on Transport, might also be considered, but seems for various reasons less favourable, see Section 4.2.1.

Different options for counting EV electricity use exist as well as different options for determining the share of renewable electricity. More research will be necessary to determine exactly how to calculate this electricity use. Research in this issue is already under way and is expected by the end of 2011.

Additionally, the RED-multiplier of 2.5 for renewable electricity used for EVs should be reviewed once the actual energy use per kilometre of these vehicles is known. It seems fair to compensate for the reduced energy use per kilometre, but overcompensation should be avoided to prevent an unfair advantage for EVs.

Another policy with which EVs might interfere is the EU ETS. The introduction of EVs translates into a partial extension of the EU ETS to road transport. Therefore, it also entails the potential of a de facto emissions reduction, albeit small-scale for the time being and depending on a number of conditions:

- Restricted use of CDM or JI credits.
- No increase in the overall cap due to electrification of the vehicle fleet.
- Electric Vehicles have to replace existing ICEVs and not be additional traffic. And
- The sales of EVs do not lead to a significant increase of $CO_2$ emissions of ICEVs due to zero counting and super credits.

If these are met, it can be argued that electricity used for EV propulsion – albeit it having a factual GHG footprint – are virtually GHG emissions free. If some of these conditions are not met, EVs can lead to additional GHG emissions.

In the near-term future, i.e. up to 2030, market shares of EVs remain sufficiently low to avoid negative impacts on the EU ETS. After 2030, new alternatives for the EU ETS which consider the future presence of EVs and their electricity use might become necessary. In depth analysis leading to proposed updates to the ETS to account for potential changes brought on by EVs should be considered for after 2030, once more accurate predictions about future EV market uptake and electricity use can be made.

### 5.2.3 Fiscal policy

Member states can provide incentives to stimulate EV sales by differentiating circulation taxes or purchase taxes. In this field the EU can give guidance in order to shape EU-wide priorities for EVs and harmonise national schemes. Direct subsidies to EV owners and manufacturers might also be considered both at the EU and the Member State level for the initial market introduction. However, national subsidies should be coordinated through the EU in order to avoid distortions to the internal market. In addition, subsidies have the risk of over-stimulating EVs compared to competing technologies.

Another issue is that without policy intervention a shift to EVs will lad to a substantial lower revenues from car and energy taxation. The impacts vary significantly over the various member states and are on average only partly compensated by higher VAT revenues from car sales. There are various ways how this could be compensated.

Separate metering for Electric Vehicles would enable differentiated taxation for different electricity types. This way, the considerable losses in fuel taxes can be recovered without affecting other electricity uses. This strategy should be followed from the early introduction of EVs on, enabling separate taxation once the market moves into maturity.

Action is required on EV electricity taxation in the medium-term time horizon, when EVs become more prevalent and have a significant impact on public finances. It seems advisable to raise taxation levels under the Framework Directive for the Taxation of Energy Products and Electricity for both electricity and transport fuels in order to avoid distortion. This measure can be complemented or substituted by road charging instruments.

Road charging offers the potential to ensure that revenues from road transport will cover infrastructure expenditures even in times of decreasing revenues from fuel taxation due to EV market uptake. Moreover, they offer the opportunity to internalise external costs. In addition, user charges could be differentiated according to the specific emissions of the vehicle. Thus, road charging can implement true costs for driving and create significant incentives for a socially-optimal use of roads.

### 5.2.4 Charging infrastructure and support measures

Given limited public budgets, governments will not be able to cover the entire costs of setting up a charging system. Rather, it seems more feasible to envision a mix of measures where:

- Governments provide some funding for initial set-up (public investment).
- Governments require real estate developers and power providers to invest in charging infrastructure (private investment).
- Governments can provide assistance and incentives to alleviate the burden for private investors (public private partnership).

To ensure that local distribution grids become EV-ready, the European Commission can initiate best practice exchange, implement pilot and demonstrations projects under programs such as IEE and fund additional research through FP7 research funding. Funding levels can be gradually reduced, once 5-10% EV market penetration has been achieved.

Common plug and charging standards, as well as protocols for data exchange, are essential to EVs and should be a priority area for policy making. Monitoring standards for EV electricity consumption need to be developed quickly in order to assure that EVs can contribute to achieving RED and FQD goals.
At low EV penetration levels, smart charging is still optional. However, once a threshold of 5% EV penetration has been reached in any region, peak load pressure will make smart charging a necessity. Therefore, regulation could be developed to prescribe that electricity providers implement smart charging infrastructure once the 5% threshold has been reached in their distribution district.

Major potential applications for EV use remain more or less untapped. This includes the use of EVs in postal fleets, delivery services, public fleets such as parking enforcement and taxi cab services. These niche markets can be explicitly targeted by support policies both at European and national level.

### 5.3 Recommendations for further study

This study identified a number of topics and issues that would require further research before more definite conclusions can be drawn:

- Assessment of costs and benefits of EVs, compared to other GHG reduction options in transport. This study did not address the question why and to what extent EVs should be promoted, compared to alternatives.
- Further assessment and elaboration on potential benefits of smart charging. Including a an assessment of other options for grid stabilisation and power storage, and a comparison of costs and benefits.
- Standardisation of smart charging. Identification of requirements from both the electricity sector, battery technology and users, design of potential technical standards that could meet or facilitate these needs.
- Further assessment and elaboration of conversion of current $CO_2$ vehicle regulation to a WTW approach. Various options are discussed in Section 4.2, these should be further assessed and the best option then needs to be develop further. Particularly the development of an appropriate GHG intensity of electricity requires further study, reflecting either marginal or average emissions.
- Monitoring of EV electricity use. This is an important issue from both monitoring and policy point of view which needs to be addressed in the future.
- Development of potential alternative methodologies to incorporate EVs in the Renewable Energy Directive (RED) and the Fuel Quality Directive (FQD). Both regulations include electricity used for transport, but still quite crudely. This may be improved in the future, to provide a stronger incentive for renewable or low carbon electricity sources and to prevent the implementation of less cost effective options. Monitoring of electricity use in transport is an important precondition for this development.
- Harmonisation of EV incentives and policies in the EU. There may be benefits to align specific parts of EV policies that are implemented on a national or regional level, in order to prevent competition between member states and to improve the overall efficiency of these policies by offering a larger, harmonised market to the car industry.
- Cost-benefit analysis of battery recycling options. If EVs enter the market on a large scale, large number of batteries will be produced, which will potentially take up significant volumes of lithium and rare earth elements (REE). Reducing cost of recycling of lithium-ion batteries for cars, and an assessment of the possibilities to recover the lithium and REEs for reuse in new batteries is therefore an issue that should be further assessed.
- This report focussed on passenger cars, as these are expected to have the most significant impacts and policy implications in the short to medium term. However, in the future attention should also be given to the potential related to other types of electric transport, e.g. electric bicycles, scooters, vans, buses and heavy duty vehicles.

# References

**BMWI, 2010**
Pressemitteilung : German-French working group on electric mobility issues its report
S.l. : German Federal Ministry of Economics and Technology(BMWI), 2010
http://www.bmwi.de/English/Navigation/Press/press-releases,did=333820.html

**CE, 2008**
H.P. van Essen, B.H. Boon, A. Schroten, M. Otten (CE Delft); M. Maibach and C. Schreyer (INFRAS); C. Doll (Fraunhofer Gesellschaft - ISI); P. Jochem (IWW); M. Bak and B. Pawlowska (University of Gdansk)
Internalisation measures and policies for the external cost of transport
Produced within the study Internalisation Measures and Policies for all external cost of Transport (IMPACT) – Deliverable 3
Delft : CE Delft, 2008

**CE, 2010**
Bettina Kampman, Cor Leguijt, Dorien Bennink, Lonneke Wielders, Xander Rijkee, Ab de Buck, Willem Braat
Green Power for Electric Cars: Development of policy recommendations to harvest the potential of electric vehicles
Delft : CE Delft, 2010

**CONCAWE, 2006**
Well-to-wheels analysis of future automotive fuels and powertrains in the European context : WELL-to-TANK Report version 2b
Brussels : European Commission, 2006

**COUNCIL, 1996**
Community strategy on climate change – Council conclusions.
In : 1939th Council Meeting Environment, Document Nr. 8518/96.
Brussels : European Union Council, 1996
http://ue.eu.int/ueDocs/cms_Data/docs/pressData/en/envir/011a0006.htm

**CW, 2010**
Electric Vehicle Policy, Westminster City Council Car Parks
London : City of Westminster (CW), 2010
http://www.westminster.gov.uk/services/transportandstreets/parking/masterpark/electric/

**DfT, 2010**
Policy, guidance and research, Low carbon and electric vehicles
London : UK Department of Transport (Dft), 2010
http://www.dft.gov.uk/pgr/scienceresearch/technology/lowcarbonelecvehicles/
Last accessed 30 November 2010

**DYKE et al., 2009**
K. Dyke, N. Schofield and M. Barnes
Analysis of Electric Vehicles on Utility Networks,
In: World Electric Vehicle Journal Vol. 3.(2009); p. 1-9
http://www.evs24.org/wevajournal/php/download.php?f=vol3/WEVJ3-5750489.pdf

**EC, 1998**
Directive 98/34/EC of the European Parliament and of the Council of 22 June 1998 laying down a procedure for the provision of information in the field of technical standards and regulations
Brussels : European Commission, 1998
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1998:204:0037:0048:en:PDF

**EC, 1999**
Directive 1999/94/EC of the European Parliament and of the Council of 13 December 1999 relating to the availability of consumer information on fuel economy and $CO_2$ emissions in respect of the marketing of new passenger cars
Brussels : European Commission, 1998
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31999L0094:EN:NOT

**EC, 2000**
European Commission (2000): Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles
Brussels : European Commission, 2000
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32000L0053:EN:NOT

**EC, 2003**
Directive 2009/33/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of clean and energy-efficient road transport vehicles
Brussels : European Commission, 2003
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32009L0033:EN:NOT

**EC, 2003a**
Council Directive 2003/96/EC of 27 October 2003 Restructuring the Community Framework for the Taxation of Energy Products and Electricity
Brussels : European Commission, 2003
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:283:0051:0070:EN:PDF

**EC, 2007**
Directive 2007/46/EC of the European Parliament and of the Council of 5 September 2007 establishing a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles
Brussels : European Commission, 2007
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32007L0046:en:NOT

**EC, 2008**
Communication from the Commission, Action Plan for the Deployment of Intelligent Transport Systems in Europe on 16.12.2008 (COM(2008) 886 final)
Brussels : European Commission, 2008
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2008:0886:FIN:EN:PDF

**EC, 2009a**
Commission Regulation (EC) No 443/2009 of the European Parliament and of the Council of 23 April 2009, setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce $CO_2$ emissions from light-duty vehicles
In : Official Journal of the European Union, L 140 (5.6.2009); p. 1-15
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0001:0015:EN:PDF

**EC, 2009b**
Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC
In : Official Journal of the European Union, L 140 (5.6.2009); p. 16-62
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF

**EC, 2009c**
Directive 2009/30/EV of the European Parliament and of the Council of 23 April 2009 amending Directive 98/70/EC as regards the specification of petrol, diesel and gas-oil and introducing a mechanism to monitor and reduce greenhouse gas emissions and amending Council Directive 1999/32/EC as regards the specification of fuel used by inland waterway vessels and repealing Directive 93/12/EEC
Official Journal of the European Union, L 140 (5.6.2009); p. 88-113
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0088:0113:EN:PDF

**EC, 2010**
Roadmap on Regulations and Standards for the Electrification of Cars
Brussels : Euopean Commission (EC), DG Enterprise, 2010
http://ec.europa.eu/enterprise/sectors/automotive/files/pagesbackground/competitiveness/roadmap-electric-cars_en.pdf

**EC, 2010a**
Website of the European Commission, Directorate-General Climate Action
Reducing $CO_2$ emissions from light-duty vehicles
http://ec.europa.eu/environment/air/transport/co2/co2_home.htm
Last accessed 23.11.2010

**EC, 2010b**
Website of the European Commission, Directorate-General Enterprise and Industry
Raw materials, Public consultation on the Raw Materials Initiative
http://ec.europa.eu/enterprise/policies/raw-materials/public-consultation/index_en.htm
Last accessed 23.11.2010

**EC, 2010c**
Communication from the Commission to the European Parliament, the Council and the European Economic and Social Committee of 28 April 2010 -
A European strategy on clean and energy efficient vehicles (COM(2010)186 final)
Brussels : European Commission, 2010
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52010DC0186:EN:NOT

**EC, 2010d**
Website of the European Commission, Directorate-General Research & Innovation – Transport
Green Cars Initiative
http://ec.europa.eu/research/transport/info/green_cars_initiative_en.html
Last accessed 26.11.2010

**EC, 2010e**
Website of the European Commission, Directorate-General Research & Innovation – Transport
Steering EU funds towards green cars
http://ec.europa.eu/research/transport/info/article_9093_en.html
Last accessed 27.11.2010

**EC, 2010f**
Website of the European Commission, Directorate-General Research & Innovation – Transport
Banking on innovation
http://ec.europa.eu/research/transport/info/article_9092_en.html

**EC, 2010g**
European Commission (EC
Taxation papers: Company Car Taxation
Luxembourg: Publications Office of the European Union, 2010
http://ec.europa.eu/taxation_customs/resources/documents/taxation/gen_info/economic_analysis/tax_papers/taxation_paper_22_en.pdf

**EC, 2010h**
Emissions trading: Questions and Answers concerning the second Commission Decision on the EU ETS cap for 2013, Memo/10/513
Brussels : European Commission, 2010
http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/10/513&format=HTML

**EC, 2010i**
EU energy trends to 2030 - UPDATE 2009
Brussels : European Commission, Directorate-General for Energy, 2010
http://ec.europa.eu/clima/documentation/docs/trends_to_2030_update_2009_en.pdf

**ECF, 2010**
Roadmap 2050 – a practical guide to a prosperous, low-carbon Europe
S.l. : European Climate Foundation (ECF), 2010

**ELVIRE, 2008**
ELVIRE, Electric Vehicle communication to Infrastructure, Road services and Electricity Supply, Fact sheet
http://www.elvire-project.org/home/liblocal/docs/Fact%20Sheet.pdf

**ENDS, 2010**
Still no EU agreement on $CO_2$ targets for vans
In : ENDS Europe DAILY, Tuesday 30 November 2010

**Eurelectric, 2009**
DSO Regulation: Current financing model must be revised to embrace new market facilitation role and environmental agenda
Brussels : Eurelectric, 2009
http://www.eurelectric.org/PublicDoc.asp?ID=60925

**FAZ, 2010**
Boris Schmidt
Schöner stromern im Smart
In : Frankfurter Allgemeine Sonntagszeitung (FAZ), 20.06.2010, V8

**JEAN, 2010**
Philippe Jean, Philippe
European strategy on clean and energy efficient vehicles : Where are we and what are the next steps? presentation
Tokyo : EU-Japan Centre for Industrial Cooperation Seminar, 26 October 2010
http://documents.eu-japan.eu/seminars/japan/green_cars/presentation_jean.pdf

**T&E, 2010**
How clean are Europe's cars? : An analysis of carmaker progress towards EZ $CO_2$ targets in 2009
Brussels : Transport & Environment (T&E), 2010

**TRL, 2010**
C. Visvikis, P. Morgan, P. Boulter, B. Hardy, B. Robinson, M. Edwards, M. Dodd and M. Pitcher
Electric vehicles: Review of type-approval legislation and potential risks, Final report
S.l. : Transport Research Laboratory (TRL), 2010
http://ec.europa.eu/enterprise/sectors/automotive/files/projects/report_electric_vehicles_en.pdf

**WEC, 2010**
Website World Energy Council (WEC)
Energy Efficiency Policies Around the World: Review and Evaluation
http://www.worldenergy.org/publications/energy_efficiency_policies_around_the_world_review_and_evaluation/3_evaluation_of_energy_efficiency_policies_and_measures/1194.asp
Last accessed 24 November 2010

**ZERO, 2010**
A portfolio of power-trains for Europe a fact-based analysis: The role of Battery Electric Vehicles, Plug-in Hybrids and Fuel Cell Electric Vehicles
S.l. : Zeroemissionvehicles, 2010

# Annex A Assumptions and input data for the scenarios

## A.1 Data needed for the calculations

The calculations of total cost of ownership of various vehicle types, resulting market uptake and impacts require quite a large amount of input data and assumptions. As explained in Chapter 2, data were defined for three different scenarios, using the approach to first define different storylines that represent a number of possible future developments, and then converting these storylines into concrete input data for the calculations. The data used in these three scenarios are provided in this Annex.

As the basis of the market uptake calculations is a cost comparison between the various vehicle types, we start with the data needed for total cost of ownership (TCO) calculations:

- Vehicle purchase cost: catalogue price, vehicle registration tax, VAT, in some cases minus EV purchase subsidies.
- Vehicle registration tax.
- Vehicle lifetime or residual value after x years.
- In case the batteries of Electric Vehicles have lower lifetime than the rest of the car (i.e. will need to be replaced after some years): battery cost and lifetime.
- Kilometres per vehicle, per year.
- Average real-life fuel use and/or electricity use per kilometre.
- This depends on urban or non urban use of the car.
- Electricity price.
- Fuel price.
- Annual insurance and maintenance cost.

Note that in these scenarios, we have set the residual value of the vehicles to zero, as we are using the vehicle lifetime to calculate annual depreciation cost of the vehicles. Furthermore, the lifetime of the electric vehicles was set equal to that of the assumed battery lifetime that was derived in Deliverable 2 of this project. As battery lifetimes are expected to increase quite rapidly to 10+ years, it would not be expected that batteries are replaced in vehicles older than 10 years.

A number of other, non-financial performance data are also relevant for the market uptake. Especially range (real life), and perhaps also acceleration (or general driving performance), will also play a role in the choice of consumers to buy a specific vehicle type. To some car buyers, the 'green or 'new technology' characteristics may also play a role: they may prefer an EV because of these factors.

As will be explained in Annex D.5, the EV market uptake model differentiates between different user groups (urban and non-urban, and innovators and laggards). However, the input parameters given here were assumed equal for all user groups, i.e. average kilometres, fuel use and cost etc. was not varied between urban and non-urban consumers and innovators and laggards. The main reason for this choice was lack of reliable (i.e. large scale) real life data on EV drivers – it was thus deemed best to use relatively simple but transparent assumptions.

The uncertainty regarding the future development of these parameters is quite significant, as earlier reports show (WP 1 and WP 2). In addition, the variation between individual vehicles and owners can be expected to be large. This makes generic and representative calculations quite difficult. This is the main reason for the scenario approach adopted here: the scenarios are intended to cover the future playing field and to provide insight in the main issues that may arise and in impacts that could occur, and to get some feeling for costs, sensitivities and trends.

As discussed in Deliverable 4, we first derived a set of ‘most realistic’ input data, based on the outcome of the earlier work phases of this project. These input data were used in the Deliverable 4 to calculate the expected TCO developments, the impact of government incentives, etc., and are used as input data set for Scenario 1 in this report. The other scenarios derived here are then based on variations of certain key input parameters of this base set.

## A.2 Input data Scenario 1

Cost data used for Scenario 1 can be found in Table 9, other vehicle and user data are depicted in Table 10.

Regarding the development of fuel efficiency of ICEs, we assume here that the improvement between 2010 and 2020 is somewhat less strong than the $CO_2$ and cars regulation requires: emissions would reduce to approximately 105 g/km in 2020. The reasoning behind this is that the 'real life' emission reduction of cars is generally seen to be less strong than the reductions during type approval. Also, EVs will contribute to the target.

An important aspect of vehicle cost calculations and comparisons are the fiscal policies related to vehicle purchase and ownership (i.e. levels of registration and circulation taxes, fiscal incentives for EVs and VAT). A comparison of tax levels in EU Member States reveals very large differences between countries, both regarding tax level and tax structure. As it was not feasible to model cost and EU market uptake separately for each Member State, it was decided to distribute the countries into three groups: countries with high incentives for both FEVs and PHEVs, countries with high incentives for FEV but medium/low incentives for PHEV and countries with limited/no incentives for EVs. The country grouping and the level of taxes used in the modelling was based on calculations of current tax levels for specific small, medium and large vehicles.

The assumptions used for vehicle taxes in these three policy categories, and the groups of counties are given Table 8 and Table 9. These cost are expressed as €/year per vehicle, were one-off taxes or subsidies are depreciated over the lifetime of the vehicles. Note that the main aim was to mimic the level of incentives as realistically as possible in a limited number of groups (in order to model market uptake of EVs as realistically as possible), but the actual tax levels in the various countries might differ quite significantly in reality.

Table 9 Scenario 1: Cost-related input data

| | Type | Size | Fuel | 2010 | 2015 | 2020 | 2025 | 2030 | Based on |
|---|---|---|---|---|---|---|---|---|---|
| **Catalogue price (€), excl. taxes** | ICEV | Small | Petrol | 9,000 | 9,450 | 9,923 | 10,419 | 10,940 | Assumptions, based on EU car prices report 2010 and 5% increase/5 years) |
| | ICEV | Medium | Petrol | 13,000 | 13,650 | 14,333 | 15,049 | 15,802 | “ |
| | ICEV | Large | Petrol | 19,000 | 19,950 | 20,948 | 21,995 | 23,095 | “ |
| | ICEV | Small | Diesel | 9,000 | 9,450 | 9,923 | 10,419 | 10,940 | “ |
| | ICEV | Medium | Diesel | 13,000 | 13,650 | 14,333 | 15,049 | 15,802 | “ |
| | ICEV | Large | Diesel | 19,000 | 19,950 | 20,948 | 21,995 | 23,095 | “ |
| | PHEV | Small | Petrol | 22,000 | 20,900 | 19,855 | 18,862 | 17,919 | Own estimates 2010, -5% every 5 years |
| | PHEV | Medium | Petrol | 26,000 | 24,700 | 23,465 | 22,292 | 21,177 | “ |
| | PHEV | Large | Petrol | 38,000 | 36,100 | 34,295 | 32,580 | 30,951 | “ |
| | PHEV | Small | Diesel | 22,000 | 20,900 | 19,855 | 18,862 | 17,919 | “ |
| | PHEV | Medium | Diesel | 26,000 | 24,700 | 23,465 | 22,292 | 21,177 | “ |
| | PHEV | Large | Diesel | 38,000 | 36,100 | 34,295 | 32,580 | 30,951 | “ |
| | EREV | Small | Petrol | 26,000 | 24,700 | 23,465 | 22,292 | 21,177 | “ |
| | EREV | Medium | Petrol | 35,000 | 33,250 | 31,588 | 30,008 | 28,508 | “ |
| | EREV | Large | Petrol | 50,000 | 47,500 | 45,125 | 42,869 | 40,725 | “ |
| | EREV | Small | Diesel | 26,000 | 24,700 | 23,465 | 22,292 | 21,177 | “ |
| | EREV | Medium | Diesel | 35,000 | 33,250 | 31,588 | 30,008 | 28,508 | “ |
| | EREV | Large | Diesel | 50,000 | 47,500 | 45,125 | 42,869 | 40,725 | “ |
| | FEV | Small | Electra | 28,000 | 26,600 | 25,270 | 24,007 | 22,806 | “ |
| | FEV | Medium | Electra | 35,000 | 33,250 | 31,588 | 30,008 | 28,508 | “ |
| | FEV | Large | Electra | 50,000 | 47,500 | 45,125 | 42,869 | 40,725 | “ |
| **Residual value (€)** | All vehicles | | | 0 | 0 | 0 | 0 | 0 | Assumed to be zero at end of lifetime |
| **Fuel price petrol (€/l)** | | | | 1.35 | 1.52 | 1.70 | 1.87 | 2.05 | 2010: EU oil bulletin, July 2010, EU average incl. taxes 2015-2030: following oil price trend as in ‘EU Energy Trends to 2030’ |
| **Fuel price diesel (€/l)** | | | | 1.18 | 1.33 | 1.49 | 1.64 | 1.79 | “ |
| **Electricity price (€/kWh)** | | | | 0.16 | 0.18 | 0.20 | 0.22 | 0.24 | 2010: Eurostat data 2015-2030: following price trend as in ‘EU Energy Trends to 2030’ (Figure 19) |
| **Maintenance costs (€/year)** | ICEV | Small | | 457 | 505 | 557 | 615 | 679 | CE Delft estimate, based on current ICEV maintenance cost |
| | ICEV | Medium | | 914 | 1009 | 1114 | 1230 | 1358 | “ |
| | ICEV | Large | | 1396 | 1541 | 1702 | 1879 | 2074 | “ |
| | PHEV | Small | | 457 | 505 | 557 | 615 | 679 | “ |
| | PHEV | Medium | | 914 | 1009 | 1114 | 1230 | 1358 | “ |
| | PHEV | Large | | 1396 | 1541 | 1702 | 1879 | 2074 | “ |
| | EREV | Small | | 209 | 231 | 255 | 281 | 311 | “ |
| | EREV | Medium | | 418 | 462 | 510 | 563 | 621 | “ |
| | EREV | Large | | 628 | 693 | 766 | 845 | 933 | “ |
| | FEV | Small | | 209 | 231 | 255 | 281 | 311 | “ |
| | FEV | Medium | | 418 | 462 | 510 | 563 | 621 | “ |

| | Type | Size | Fuel | 2010 | 2015 | 2020 | 2025 | 2030 | Based on |
|---|---|---|---|---|---|---|---|---|---|
| | FEV | Large | | 628 | 693 | 766 | 845 | 933 | “ |
| **Insurance costs (€/year)** | ICEV | Small | | 620 | 685 | 756 | 834 | 921 | CE Delft estimate, based on current ICEV insurance cost |
| | ICEV | Medium | | 1,240 | 1,369 | 1,512 | 1,669 | 1,843 | “ |
| | ICEV | Large | | 1,958 | 2,162 | 2,387 | 2,635 | 2,909 | “ |
| | PHEV | Small | | 975 | 1,076 | 1,189 | 1,312 | 1,449 | “ |
| | PHEV | Medium | | 1,949 | 2,152 | 2,376 | 2,623 | 2,896 | “ |
| | PHEV | Large | | 2,924 | 3,228 | 3,564 | 3,935 | 4,345 | “ |
| | EREV | Small | | 975 | 1,076 | 1,189 | 1,312 | 1,449 | “ |
| | EREV | Medium | | 1,949 | 2,152 | 2,376 | 2,623 | 2,896 | “ |
| | EREV | Large | | 2,924 | 3,228 | 3,564 | 3,935 | 4,345 | “ |
| | FEV | Small | | 975 | 1,076 | 1,189 | 1,312 | 1,449 | “ |
| | FEV | Medium | | 1,949 | 2,152 | 2,376 | 2,623 | 2,896 | “ |
| | FEV | Large | | 2,924 | 3,228 | 3,564 | 3,935 | 4,345 | “ |

**Table 10 Scenario 1: Other input data**

| | Type | Size | Fuel | 2010 | 2015 | 2020 | 2025 | 2030 | Based on |
|---|---|---|---|---|---|---|---|---|---|
| **Vehicle lifetime (years)** | ICEV | | | 14 | 14 | 14 | 14 | 14 | Own estimate |
| | PHEV | | | 12 | 13 | 14 | 14 | 14 | Own estimate, based on WP 2 |
| | EREV | | | 10 | 11 | 12 | 13 | 14 | Own estimate, based on WP 2 |
| | FEV | | | 10 | 11 | 12 | 13 | 14 | Own estimate, based on WP 2 |
| **Vehicle kilometers (km/year)** | ICEV, PHEV, EREV | Small | Petrol | 8,245 | 8,050 | 7,854 | 7,926 | 7,998 | TREMOVE |
| | ICEV, PHEV, EREV | Medium | Petrol | 10,525 | 10,487 | 10,449 | 10,589 | 10,728 | TREMOVE |
| | ICEV, PHEV, EREV | Large | Petrol | 12,204 | 12,116 | 12,027 | 12,186 | 12,344 | TREMOVE |
| | ICEV, PHEV, EREV | Small | Diesel | 20,623 | 19,835 | 19,047 | 19,253 | 19,458 | TREMOVE |
| | ICEV, PHEV, EREV | Medium | Diesel | 20,749 | 20,120 | 19,491 | 19,549 | 19,607 | TREMOVE |
| | ICEV, PHEV, EREV | Large | Diesel | 22,484 | 22,006 | 21,528 | 21,630 | 21,731 | TREMOVE |
| | FEV | Small | Electra | 8,245 | 8,050 | 7,854 | 7,926 | 7,998 | Equal to comparable petrol ICEV |
| | FEV | Medium | Electra | 10,525 | 10,487 | 10,449 | 10,589 | 10,728 | “ |
| | FEV | Large | Electra | 12,204 | 12,116 | 12,027 | 12,186 | 12,344 | “ |

| | Type | Size | Fuel | 2010 | 2015 | 2020 | 2025 | 2030 | Based on |
|---|---|---|---|---|---|---|---|---|---|
| **Fuel use (litre/100 km)** | ICEV | Small | Petrol | 8.0 | 7.5 | 6.1 | 5.8 | 5.5 | 2010: Tremove data<br>2010-2020: somewhat less improvement than prescribed by the $CO_2$ and cars regulation (see text)<br>2020-2030: -5% every 5 years |
| | ICEV | Medium | Petrol | 9.6 | 8.9 | 7.3 | 6.9 | 6.6 | " |
| | ICEV | Large | Petrol | 12.0 | 11.2 | 9.2 | 8.7 | 8.3 | " |
| | ICEV | Small | Diesel | 5.1 | 4.8 | 3.9 | 3.7 | 3.5 | " |
| | ICEV | Medium | Diesel | 6.7 | 6.2 | 5.1 | 4.9 | 4.6 | " |
| | ICEV | Large | Diesel | 9.2 | 8.6 | 7.0 | 6.7 | 6.3 | " |
| | PHEV | Small | Petrol | 3.2 | 3.0 | 2.4 | 1.7 | 1.7 | 2010-2020: 0.4 * fuel use ICEV<br>2025-2030: 0.3 * fuel use ICEV |
| | PHEV | Medium | Petrol | 3.8 | 3.6 | 2.9 | 2.1 | 2.0 | " |
| | PHEV | Large | Petrol | 4.8 | 4.5 | 3.7 | 2.6 | 2.5 | " |
| | PHEV | Small | Diesel | 2.1 | 1.9 | 1.6 | 1.1 | 1.1 | " |
| | PHEV | Medium | Diesel | 2.7 | 2.5 | 2.0 | 1.5 | 1.4 | " |
| | PHEV | Large | Diesel | 3.7 | 3.4 | 2.8 | 2.0 | 1.9 | " |
| | EREV | Small | Petrol | 2.4 | 2.2 | 1.8 | 1.2 | 1.1 | 2010-2020: 0.3 * fuel use ICEV<br>2025-2030: 0.2 * fuel use ICEV |
| | EREV | Medium | Petrol | 2.9 | 2.7 | 2.2 | 1.4 | 1.3 | " |
| | EREV | Large | Petrol | 3.6 | 3.4 | 2.8 | 1.7 | 1.7 | " |
| | EREV | Small | Diesel | 1.5 | 1.4 | 1.2 | 0.7 | 0.7 | " |
| | EREV | Medium | Diesel | 2.0 | 1.9 | 1.5 | 1.0 | 0.9 | " |
| | EREV | Large | Diesel | 2.8 | 2.6 | 2.1 | 1.3 | 1.3 | " |
| | FEV | All | | 0 | 0 | 0 | 0 | 0 | No fuel use |
| **Electricity use (kWh/100 km)** | ICEV | All | | 0 | 0 | 0 | 0 | 0 | No electricity use |
| | PHEV | Small | | 15.0 | 14.3 | 13.5 | 15.0 | 14.3 | 2010-2020: 0.6 * electricity use FEV<br>2025-2030: 0.7 * electricity use FEV |
| | PHEV | Medium | | 17.4 | 16.5 | 15.7 | 17.4 | 16.5 | " |
| | PHEV | Large | | 19.8 | 18.8 | 17.9 | 19.8 | 18.8 | " |
| | EREV | Small | | 17.5 | 16.6 | 15.8 | 17.1 | 16.3 | 2010-2020: 0.7 * electricity use FEV<br>2025-2030: 0.8 * electricity use FEV |
| | EREV | Medium | | 20.3 | 19.3 | 18.3 | 19.9 | 18.9 | " |
| | EREV | Large | | 23.1 | 21.9 | 20.8 | 22.6 | 21.5 | " |
| | FEV | Small | | 25.0 | 23.8 | 22.6 | 21.4 | 20.4 | Own estimate, 5% improvement every 5 years |
| | FEV | Medium | | 29.0 | 27.6 | 26.2 | 24.9 | 23.6 | " |
| | FEV | Large | | 33.0 | 31.4 | 29.8 | 28.3 | 26.9 | " |

| | Type | Size | Fuel | 2010 | 2015 | 2020 | 2025 | 2030 | Based on |
|---|---|---|---|---|---|---|---|---|---|
| **Range (km)** | ICEV | All | | 600 | 600 | 600 | 600 | 600 | 2010-2020: own estimate<br>2020-2030: Ricardo/TNO |
| | PHEV | All | | 450 | 500 | 550 | 600 | 600 | " |
| | EREV | All | | 450 | 450 | 450 | 450 | 450 | " |
| | FEV | Small | | 120 | 120 | 150 | 200 | 250 | " |
| | FEV | Medium | | 150 | 150 | 175 | 238 | 300 | " |
| | FEV | Large | | 175 | 175 | 200 | 275 | 350 | " |
| **'Green Image'** | ICEV | | | 7 | 6 | 6 | 6 | 6 | Own assumption |
| | PHEV | | | 9 | 9 | 8 | 8 | 8 | " |
| | EREV | | | 8 | 9 | 9 | 9 | 9 | " |
| | FEV | | | 8 | 10 | 10 | 10 | 10 | " |

**Table 11 Scenario 1: annual cost of fiscal policy related to vehicle purchase and ownership (€/year per vehicle, positive = cost, negative = subsidy)**

| | | | High: High FEV and PHEV incentives | | | | | Medium: High FEV, medium/low PHEV incentives | | | | | Low: Low EV incentives | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2010 | 2015 | 2020 | 2025 | 2030 | 2010 | 2015 | 2020 | 2025 | 2030 | 2010 | 2015 | 2020 | 2025 | 2030 |
| ICEV | Small | Petrol | 184 | 188 | 192 | 196 | 201 | 82 | 82 | 83 | 84 | 84 | 96 | 99 | 102 | 106 | 110 |
| ICEV | Medium | Petrol | 347 | 357 | 368 | 379 | 391 | 238 | 239 | 241 | 243 | 244 | 177 | 183 | 189 | 195 | 201 |
| ICEV | Large | Petrol | 736 | 764 | 793 | 823 | 855 | 1.020 | 1.030 | 1.039 | 1.049 | 1.060 | 651 | 666 | 681 | 698 | 715 |
| ICEV | Small | Diesel | 184 | 188 | 192 | 196 | 201 | 82 | 82 | 83 | 84 | 84 | 96 | 99 | 102 | 106 | 110 |
| ICEV | Medium | Diesel | 347 | 357 | 368 | 379 | 391 | 238 | 239 | 241 | 243 | 244 | 177 | 183 | 189 | 195 | 201 |
| ICEV | Large | Diesel | 736 | 764 | 793 | 823 | 855 | 1.020 | 1.030 | 1.039 | 1.049 | 1.060 | 651 | 666 | 681 | 698 | 715 |
| PHEV | Small | Petrol | -222 | -197 | -176 | -159 | -144 | 50 | 50 | 50 | 50 | 50 | 58 | 54 | 51 | 49 | 47 |
| PHEV | Medium | Petrol | -138 | -121 | -108 | -96 | -86 | 222 | 218 | 214 | 211 | 209 | 96 | 92 | 88 | 85 | 83 |
| PHEV | Large | Petrol | 260 | 235 | 215 | 198 | 183 | 821 | 803 | 788 | 775 | 764 | 546 | 521 | 501 | 484 | 469 |
| PHEV | Small | Diesel | -222 | -197 | -176 | -159 | -144 | 50 | 50 | 50 | 50 | 50 | 58 | 54 | 51 | 49 | 47 |
| PHEV | Medium | Diesel | -138 | -121 | -108 | -96 | -86 | 222 | 218 | 214 | 211 | 209 | 96 | 92 | 88 | 85 | 83 |
| PHEV | Large | Diesel | 260 | 235 | 215 | 198 | 183 | 821 | 803 | 788 | 775 | 764 | 546 | 521 | 501 | 484 | 469 |
| EREV | Small | Petrol | -263 | -234 | -210 | -189 | -172 | 50 | 50 | 50 | 50 | 50 | 64 | 60 | 56 | 53 | 51 |
| EREV | Medium | Petrol | -192 | -169 | -151 | -135 | -121 | 235 | 230 | 225 | 221 | 218 | 109 | 104 | 99 | 95 | 92 |
| EREV | Large | Petrol | 331 | 299 | 273 | 250 | 231 | 875 | 851 | 831 | 814 | 799 | 617 | 585 | 559 | 536 | 517 |
| EREV | Small | Diesel | -263 | -234 | -210 | -189 | -172 | 50 | 50 | 50 | 50 | 50 | 64 | 60 | 56 | 53 | 51 |
| EREV | Medium | Diesel | -192 | -169 | -151 | -135 | -121 | 235 | 230 | 225 | 221 | 218 | 109 | 104 | 99 | 95 | 92 |
| EREV | Large | Diesel | 331 | 299 | 273 | 250 | 231 | 875 | 851 | 831 | 814 | 799 | 617 | 585 | 559 | 536 | 517 |
| FEV | Small | Electra | -409 | -365 | -327 | -296 | -269 | -492 | -434 | -386 | -345 | -310 | 22 | 22 | 22 | 22 | 22 |
| FEV | Medium | Electra | -400 | -356 | -318 | -287 | -260 | -476 | -409 | -353 | -306 | -265 | 106 | 101 | 96 | 92 | 89 |
| FEV | Large | Electra | -116 | -100 | -87 | -75 | -66 | 153 | 201 | 241 | 275 | 304 | 539 | 515 | 495 | 478 | 463 |

**Table 12 Scenario 1: EV fiscal policy category per EU Member State**

| | Policy category |
|---|---|
| Austria | Low |
| Belgium | Medium |
| Bulgaria | Low |
| Cyprus | Low |
| Czech Republic | Low |
| Germany | Low |
| Denmark | Medium |
| Estonia | Low |
| Spain | High |
| Finland | Low |
| France | High |
| Greece | High |
| Hungary | Low |
| Ireland | Low |
| Italy | Low |
| Lithuania | Low |
| Luxemburg | Low |
| Latvia | Low |
| Malta | Low |
| Netherlands | High |
| Poland | Low |
| Portugal | High |
| Romania | Low |
| Sweden | Medium |
| Slovenia | Low |
| Slovakia | Low |
| United Kingdom | High |

## A.3 Input data Scenario 2

Cost data used for Scenario 2 can be found in Table 13. Compared to Scenario 1, different assumptions were used for the catalogue prices of the various vehicles: ICEV costs were assumed to increase less fast than in Scenario 1, and EV cost were assumed to reduce less fast.

Other vehicle and user data are depicted in Table 14. There, we assume that the performance of EVs (fuel efficiency, electric range, etc.) develop less or remain constant between 2010-2030. ICEV fuel efficiency, on the other hand, develops faster than in the first scenario, and is assumed to be exactly in line with the $CO_2$ and cars regulation. This means that the real life emissions of new ICEs follow the reduction prescribed in the regulation, whereas in Scenario 1 (and 3), it is assumed that they remain somewhat higher.

The assumptions used for vehicle taxes (incl. subsidies and VAT, expressed in €/year per vehicle) are the same as in Scenario 1, but it is assumed that the countries that currently have high incentives, switch to medium incentives in 2015 and to low in 2020. Medium incentive countries move towards low incentive levels from 2020 onwards.

**Table 13 Scenario 2: Cost-related input data**

| | Type | Size | Fuel | 2010 | 2015 | 2020 | 2025 | 2030 | Based on |
|---|---|---|---|---|---|---|---|---|---|
| **Catalogue price (€), excl. taxes** | ICEV | Small | Petrol | 9,000 | 9,225 | 9,456 | 9,692 | 9,934 | Assumptions, based on EU car prices report 2010 and 2.5% increase/ 5 years) |
| | ICEV | Medium | Petrol | 13,000 | 13,325 | 13,658 | 14,000 | 14,350 | " |
| | ICEV | Large | Petrol | 19,000 | 19,475 | 19,962 | 20,461 | 20,972 | " |
| | ICEV | Small | Diesel | 9,000 | 9,225 | 9,456 | 9,692 | 9,934 | " |
| | ICEV | Medium | Diesel | 13,000 | 13,325 | 13,658 | 14,000 | 14,350 | " |
| | ICEV | Large | Diesel | 19,000 | 19,475 | 19,962 | 20,461 | 20,972 | " |
| | PHEV | Small | Petrol | 22,000 | 21,450 | 20,914 | 20,391 | 19,881 | Own estimates 2010, -2.5% every 5 years |
| | PHEV | Medium | Petrol | 26,000 | 25,350 | 24,716 | 24,098 | 23,496 | " |
| | PHEV | Large | Petrol | 38,000 | 37,050 | 36,124 | 35,221 | 34,340 | " |
| | PHEV | Small | Diesel | 22,000 | 21,450 | 20,914 | 20,391 | 19,881 | " |
| | PHEV | Medium | Diesel | 26,000 | 25,350 | 24,716 | 24,098 | 23,496 | " |
| | PHEV | Large | Diesel | 38,000 | 37,050 | 36,124 | 35,221 | 34,340 | " |
| | EREV | Small | Petrol | 26,000 | 25,740 | 25,483 | 25,228 | 24,975 | " |
| | EREV | Medium | Petrol | 35,000 | 34,650 | 34,304 | 33,960 | 33,621 | " |
| | EREV | Large | Petrol | 50,000 | 49,500 | 49,005 | 48,515 | 48,030 | " |
| | EREV | Small | Diesel | 26,000 | 25,740 | 25,483 | 25,228 | 24,975 | " |
| | EREV | Medium | Diesel | 35,000 | 34,650 | 34,304 | 33,960 | 33,621 | " |
| | EREV | Large | Diesel | 50,000 | 49,500 | 49,005 | 48,515 | 48,030 | " |
| | FEV | Small | Electra | 28,000 | 27,300 | 26,618 | 25,952 | 25,303 | " |
| | FEV | Medium | Electra | 35,000 | 34,125 | 33,272 | 32,440 | 31,629 | " |
| | FEV | Large | Electra | 50,000 | 48,750 | 47,531 | 46,343 | 45,184 | " |
| **Residual value (€)** | All vehicles | | | 0 | 0 | 0 | 0 | 0 | Assumed to be zero at end of lifetime |
| **Fuel price petrol (€/l)** | | | | 1.35 | 1.52 | 1.70 | 1.87 | 2.05 | 2010: EU oil bulletin, July 2010, EU average incl. taxes. 2015-2030: following oil price trend as in 'EU Energy Trends to 2030' |
| **Fuel price diesel (€/l)** | | | | 1.18 | 1.33 | 1.49 | 1.64 | 1.79 | " |
| **Electricty price (€/kWh)** | | | | 0.16 | 0.18 | 0.20 | 0.22 | 0.24 | 2010: Eurostat data. 2015-2030: following price trend as in 'EU Energy Trends to 2030' (Figure 16) |

| | Type | Size | Fuel | 2010 | 2015 | 2020 | 2025 | 2030 | Based on |
|---|---|---|---|---|---|---|---|---|---|
| **Maintenance costs (€/year)** | ICEV | Small | | 457 | 505 | 557 | 615 | 679 | CE Delft estimate, based on current ICEV maintenance cost |
| | ICEV | Medium | | 914 | 1009 | 1114 | 1230 | 1358 | “ |
| | ICEV | Large | | 1396 | 1541 | 1702 | 1879 | 2074 | “ |
| | PHEV | Small | | 457 | 505 | 557 | 615 | 679 | “ |
| | PHEV | Medium | | 914 | 1009 | 1114 | 1230 | 1358 | “ |
| | PHEV | Large | | 1396 | 1541 | 1702 | 1879 | 2074 | “ |
| | EREV | Small | | 209 | 231 | 255 | 281 | 311 | “ |
| | EREV | Medium | | 418 | 462 | 510 | 563 | 621 | “ |
| | EREV | Large | | 628 | 693 | 766 | 845 | 933 | “ |
| | FEV | Small | | 209 | 231 | 255 | 281 | 311 | “ |
| | FEV | Medium | | 418 | 462 | 510 | 563 | 621 | “ |
| | FEV | Large | | 628 | 693 | 766 | 845 | 933 | “ |
| **Insurance costs (€/year)** | ICEV | Small | | 620 | 685 | 756 | 834 | 921 | CE Delft estimate, based on current ICEV insurance cost |
| | ICEV | Medium | | 1.240 | 1.369 | 1.512 | 1.669 | 1.843 | “ |
| | ICEV | Large | | 1.958 | 2.162 | 2.387 | 2.635 | 2.909 | “ |
| | PHEV | Small | | 975 | 1.076 | 1.189 | 1.312 | 1.449 | “ |
| | PHEV | Medium | | 1.949 | 2.152 | 2.376 | 2.623 | 2.896 | “ |
| | PHEV | Large | | 2.924 | 3.228 | 3.564 | 3.935 | 4.345 | “ |
| | EREV | Small | | 975 | 1.076 | 1.189 | 1.312 | 1.449 | “ |
| | EREV | Medium | | 1.949 | 2.152 | 2.376 | 2.623 | 2.896 | “ |
| | EREV | large | | 2.924 | 3.228 | 3.564 | 3.935 | 4.345 | “ |
| | FEV | Small | | 975 | 1.076 | 1.189 | 1.312 | 1.449 | “ |
| | FEV | Medium | | 1.949 | 2.152 | 2.376 | 2.623 | 2.896 | “ |
| | FEV | Large | | 2.924 | 3.228 | 3.564 | 3.935 | 4.345 | “ |

Table 14 Scenario 2: Other input data

| | Type | Size | Fuel | 2010 | 2015 | 2020 | 2025 | 2030 | Based on |
|---|---|---|---|---|---|---|---|---|---|
| **Vehicle lifetime (years)** | ICEV | | | 14 | 14 | 14 | 14 | 14 | Own estimate |
| | PHEV | | | 12 | 12 | 12 | 12 | 12 | Assumption |
| | EREV | | | 10 | 10 | 10 | 10 | 10 | Assumption |
| | FEV | | | 10 | 10 | 10 | 10 | 10 | Assumption |
| **Vehicle kilometers (km/year)** | ICEV, PHEV, EREV | Small | Petrol | 8.245 | 8.050 | 7.854 | 7.926 | 7.998 | TREMOVE |
| | ICEV, PHEV, EREV | Medium | Petrol | 10.525 | 10.487 | 10.449 | 10.589 | 10.728 | TREMOVE |
| | ICEV, PHEV, EREV | Large | Petrol | 12.204 | 12.116 | 12.027 | 12.186 | 12.344 | TREMOVE |
| | ICEV, PHEV, EREV | Small | Diesel | 20.623 | 19.835 | 19.047 | 19.253 | 19.458 | TREMOVE |
| | ICEV, PHEV, EREV | Medium | Diesel | 20.749 | 20.120 | 19.491 | 19.549 | 19.607 | TREMOVE |
| | ICEV, PHEV, EREV | Large | Diesel | 22.484 | 22.006 | 21.528 | 21.630 | 21.731 | TREMOVE |
| | FEV | Small | Electra | 8.245 | 8.050 | 7.854 | 7.926 | 7.998 | Equal to comparable petrol ICEV |
| | FEV | Medium | Electra | 10.525 | 10.487 | 10.449 | 10.589 | 10.728 | “ |
| | FEV | Large | Electra | 12.204 | 12.116 | 12.027 | 12.186 | 12.344 | “ |
| **Fuel use (litre/100 km)** | ICEV | Small | Petrol | 8.0 | 7.2 | 5.4 | 4.9 | 4.4 | 2010: Tremove data 2010-2020 in line with $CO_2$ and cars regulation 2020-2030: - 10% every 5 years |
| | ICEV | Medium | Petrol | 9.6 | 8.6 | 6.5 | 5.8 | 5.2 | “ |
| | ICEV | Large | Petrol | 12.0 | 10.8 | 8.1 | 7.3 | 6.6 | “ |
| | ICEV | Small | Diesel | 5.1 | 4.6 | 3.5 | 3.1 | 2.8 | “ |
| | ICEV | Medium | Diesel | 6.7 | 6.0 | 4.5 | 4.1 | 3.7 | “ |
| | ICEV | Large | Diesel | 9.2 | 8.3 | 6.2 | 5.6 | 5.0 | “ |
| | PHEV | Small | Petrol | 3.2 | 2.9 | 2.2 | 1.9 | 1.8 | Assumption: 0,4 * fuel use _ ICEV |
| | PHEV | Medium | Petrol | 3.8 | 3.4 | 2.6 | 2.3 | 2.1 | “ |
| | PHEV | Large | Petrol | 4.8 | 4.3 | 3.2 | 2.9 | 2.6 | “ |
| | PHEV | Small | Diesel | 2.1 | 1.8 | 1.4 | 1.2 | 1.1 | “ |
| | PHEV | Medium | Diesel | 2.7 | 2.4 | 1.8 | 1.6 | 1.5 | “ |
| | PHEV | Large | Diesel | 3.7 | 3.3 | 2.5 | 2.2 | 2.0 | “ |
| | EREV | Small | Petrol | 2.4 | 2.2 | 1.6 | 1.5 | 1.3 | Assumption: 0,3 * fuel use _ ICEV |
| | EREV | Medium | Petrol | 2.9 | 2.6 | 1.9 | 1.7 | 1.6 | “ |
| | EREV | Large | Petrol | 3.6 | 3.2 | 2.4 | 2.2 | 2.0 | “ |
| | EREV | Small | Diesel | 1.5 | 1.4 | 1.0 | 0.9 | 0.8 | “ |
| | EREV | Medium | Diesel | 2.0 | 1.8 | 1.4 | 1.2 | 1.1 | “ |
| | EREV | Large | Diesel | 2.8 | 2.5 | 1.9 | 1.7 | 1.5 | “ |
| | FEV | All | | 0 | 0 | 0 | 0 | 0 | No fuel use |

| | Type | Size | Fuel | 2010 | 2015 | 2020 | 2025 | 2030 | Based on |
|---|---|---|---|---|---|---|---|---|---|
| **Electricity use (kWh/100 km)** | ICEV | All | | 0 | 0 | 0 | 0 | 0 | No electricity use |
| | PHEV | Small | | 15.0 | 14.6 | 14.3 | 13.9 | 13.6 | Assumption: 0,6 * electricity use_EV |
| | PHEV | Medium | | 17.4 | 17.0 | 16.5 | 16.1 | 15.7 | Assumption: 0,6 * electricity use_EV |
| | PHEV | Large | | 19.8 | 19.3 | 18.8 | 18.4 | 17.9 | Assumption: 0,6 * electricity use_EV |
| | EREV | Small | | 17.5 | 17.1 | 16.6 | 16.2 | 15.8 | Assumption: 0,7 * electricity use_EV |
| | EREV | Medium | | 20.3 | 19.8 | 19.3 | 18.8 | 18.3 | Assumption: 0,7 * electricity use_EV |
| | EREV | Large | | 23.1 | 22.5 | 22.0 | 21.4 | 20.9 | Assumption: 0,7 * electricity use_EV |
| | FEV | Small | | 25.0 | 24.4 | 23.8 | 23.2 | 22.6 | Own estimate, 2,5% improvement every 5 years |
| | FEV | Medium | | 29.0 | 28.3 | 27.6 | 26.9 | 26.2 | Own estimate, 2,5% improvement every 5 years |
| | FEV | Large | | 33.0 | 32.2 | 31.4 | 30.6 | 29.8 | Own estimate, 2,5% improvement every 5 years |
| **Range (km)** | ICEV | All | | 600 | 600 | 600 | 600 | 600 | 2010-2020: own estimate 2020-2030: Ricardo/TNO |
| | PHEV | All | | 450 | 450 | 450 | 450 | 450 | “ |
| | EREV | All | | 450 | 450 | 450 | 450 | 450 | “ |
| | FEV | Small | | 120 | 120 | 150 | 200 | 200 | “ |
| | FEV | Medium | | 150 | 150 | 175 | 238 | 250 | “ |
| | FEV | Large | | 175 | 175 | 200 | 250 | 250 | “ |
| **‘Green Image’** | ICEV | | | 7 | 6 | 6 | 6 | 6 | Own assumption |
| | PHEV | | | 9 | 9 | 8 | 8 | 8 | “ |
| | EREV | | | 8 | 9 | 9 | 9 | 9 | “ |
| | FEV | | | 8 | 10 | 10 | 10 | 10 | “ |

## A.4 Input data Scenario 3

Cost data used for Scenario 3 can be found in Table 15. ICEV prices are assumed to rise more rapidly than in Scenario 1 (due to efforts that need to be taken to meet the future fuel efficiency regulations), whereas EV prices are assumed to reduce rapidly after 2015.

Other vehicle and user data are depicted in Table 16. Both the lifetime of EVs and the range of FEVs improve somewhat faster than in Scenario 1.
Other data, including assumptions for fuel efficiency of ICEs, are the same as in Scenario 1.
Regarding fiscal vehicle policies, all countries with currently high incentives are assumed to switch to medium incentives from 2020 onwards, all medium incentive countries will become low from 2020 onwards. The policies assumed under high, medium and low are the same as in Scenario 1.

**Table 15 Scenario 3: Cost-related input data**

| | Type | Size | Fuel | 2010 | 2015 | 2020 | 2025 | 2030 | Based on |
|---|---|---|---|---|---|---|---|---|---|
| **Catalogue price (€), excl. taxes** | ICEV | Small | Petrol | 9,000 | 9,900 | 10,890 | 11,979 | 13,177 | Assumptions, based on EU car prices report 2010 and 10% increase/5 years) |
| | ICEV | Medium | Petrol | 13,000 | 14,300 | 15,730 | 17,303 | 19,033 | “ |
| | ICEV | Large | Petrol | 19,000 | 20,900 | 22,990 | 25,289 | 27,818 | “ |
| | ICEV | Small | Diesel | 9,000 | 9,900 | 10,890 | 11,979 | 13,177 | “ |
| | ICEV | Medium | Diesel | 13,000 | 14,300 | 15,730 | 17,303 | 19,033 | “ |
| | ICEV | Large | Diesel | 19,000 | 20,900 | 22,990 | 25,289 | 27,818 | “ |
| | PHEV | Small | Petrol | 22,000 | 20,900 | 17,765 | 15,100 | 12,835 | Own estimates 2010, -5% in 2015, thereafter -15% every 5 years |
| | PHEV | Medium | Petrol | 26,000 | 24,700 | 20,995 | 17,846 | 15,169 | “ |
| | PHEV | Large | Petrol | 38,000 | 36,100 | 30,685 | 26,082 | 22,170 | “ |
| | PHEV | Small | Diesel | 22,000 | 20,900 | 17,765 | 15,100 | 12,835 | “ |
| | PHEV | Medium | Diesel | 26,000 | 24,700 | 20,995 | 17,846 | 15,169 | “ |
| | PHEV | Large | Diesel | 38,000 | 36,100 | 30,685 | 26,082 | 22,170 | “ |
| | EREV | Small | Petrol | 26,000 | 24,700 | 20,995 | 17,846 | 15,169 | “ |
| | EREV | Medium | Petrol | 35,000 | 33,250 | 28,263 | 24,023 | 20,420 | “ |
| | EREV | Large | Petrol | 50,000 | 47,500 | 40,375 | 34,319 | 29,171 | “ |
| | EREV | Small | Diesel | 26,000 | 24,700 | 20,995 | 17,846 | 15,169 | “ |
| | EREV | Medium | Diesel | 35,000 | 33,250 | 28,263 | 24,023 | 20,420 | “ |
| | EREV | Large | Diesel | 50,000 | 47,500 | 40,375 | 34,319 | 29,171 | “ |
| | FEV | Small | Electra | 28,000 | 26,600 | 22,610 | 19,219 | 16,336 | “ |
| | FEV | Medium | Electra | 35,000 | 33,250 | 29,925 | 26,933 | 24,239 | “ |
| | FEV | Large | Electra | 50,000 | 47,500 | 42,750 | 38,475 | 34,628 | “ |
| **Residual value (€)** | All vehicles | | | 0 | 0 | 0 | 0 | 0 | Assumed to be zero at end of lifetime |
| **Fuel price petrol (€/l)** | | | | 1.35 | 1.52 | 1.70 | 1.87 | 2.05 | 2010: EU oil bulletin, July 2010, EU average incl. taxes. 2015-2030: following oil price trend as in ‘EU Energy Trends to 2030’ |
| **Fuel price diesel (€/l)** | | | | 1.18 | 1.33 | 1.49 | 1.64 | 1.79 | “ |

| | Type | Size | Fuel | 2010 | 2015 | 2020 | 2025 | 2030 | Based on |
|---|---|---|---|---|---|---|---|---|---|
| **Electricty price (€/kWh)** | | | | 0.16 | 0.18 | 0.20 | 0.22 | 0.24 | 2010: Eurostat data. 2015-2030: following price trend as in 'EU Energy Trends to 2030' (fig. 16) |
| **Maintenance costs (€/year)** | ICEV | Small | | 457 | 505 | 557 | 615 | 679 | CE Delft estimate, based on current ICEV maintenance cost |
| | ICEV | Medium | | 914 | 1,009 | 1,114 | 1,230 | 1,358 | " |
| | ICEV | Large | | 1,396 | 1,541 | 1,702 | 1,879 | 2,074 | " |
| | PHEV | Small | | 457 | 505 | 557 | 615 | 679 | " |
| | PHEV | Medium | | 914 | 1,009 | 1,114 | 1,230 | 1,358 | " |
| | PHEV | Large | | 1,396 | 1,541 | 1,702 | 1,879 | 2,074 | " |
| | EREV | Small | | 209 | 231 | 255 | 281 | 311 | " |
| | EREV | Medium | | 418 | 462 | 510 | 563 | 621 | " |
| | EREV | Large | | 628 | 693 | 766 | 845 | 933 | " |
| | FEV | Small | | 209 | 231 | 255 | 281 | 311 | " |
| | FEV | Medium | | 418 | 462 | 510 | 563 | 621 | " |
| | FEV | Large | | 628 | 693 | 766 | 845 | 933 | " |
| **Insurance costs (€/year)** | ICEV | Small | | 620 | 685 | 756 | 834 | 921 | CE Delft estimate, based on current ICEV insurance cost |
| | ICEV | Medium | | 1,240 | 1,369 | 1,512 | 1,669 | 1,843 | " |
| | ICEV | Large | | 1,958 | 2,162 | 2,387 | 2,635 | 2,909 | " |
| | PHEV | Small | | 975 | 1,076 | 1,189 | 1,312 | 1,449 | " |
| | PHEV | Medium | | 1,949 | 2,152 | 2,376 | 2,623 | 2,896 | " |
| | PHEV | Large | | 2,924 | 3,228 | 3,564 | 3,935 | 4,345 | " |
| | EREV | Small | | 975 | 1,076 | 1,189 | 1,312 | 1,449 | " |
| | EREV | Medium | | 1,949 | 2,152 | 2,376 | 2,623 | 2,896 | " |
| | EREV | Large | | 2,924 | 3,228 | 3,564 | 3,935 | 4,345 | " |
| | FEV | Small | | 975 | 1,076 | 1,189 | 1,312 | 1,449 | " |
| | FEV | Medium | | 1,949 | 2,152 | 2,376 | 2,623 | 2,896 | " |
| | FEV | Large | | 2,924 | 3,228 | 3,564 | 3,935 | 4,345 | " |

**Table 16 Scenario 3: Other input data**

| | Type | Size | Fuel | 2010 | 2015 | 2020 | 2025 | 2030 | Based on |
|---|---|---|---|---|---|---|---|---|---|
| **Vehicle lifetime (years)** | ICEV | | | 14 | 14 | 14 | 14 | 14 | Own estimate |
| | PHEV | | | 10 | 11 | 13 | 14 | 14 | Own estimate |
| | EREV | | | 10 | 11 | 13 | 14 | 14 | Own estimate |
| | FEV | | | 10 | 11 | 13 | 14 | 14 | Own estimate |
| **Vehicle kilometers (km/year)** | ICEV, PHEV, EREV | Small | Petrol | 8,245 | 8,050 | 7,854 | 7,926 | 7,998 | TREMOVE |
| | ICEV, PHEV, EREV | Medium | Petrol | 10,525 | 10,487 | 10,449 | 10,589 | 10,728 | TREMOVE |
| | ICEV, PHEV, EREV | Large | Petrol | 12,204 | 12,116 | 12,027 | 12,186 | 12,344 | TREMOVE |
| | ICEV, PHEV, EREV | Small | Diesel | 20,623 | 19,835 | 19,047 | 19,253 | 19,458 | TREMOVE |

| | Type | Size | Fuel | 2010 | 2015 | 2020 | 2025 | 2030 | Based on |
|---|---|---|---|---|---|---|---|---|---|
| | ICEV, PHEV, EREV | Medium | Diesel | 20,749 | 20,120 | 19,491 | 19,549 | 19,607 | TREMOVE |
| | ICEV, PHEV, EREV | Large | Diesel | 22,484 | 22,006 | 21,528 | 21,630 | 21,731 | TREMOVE |
| | FEV | Small | Electra | 8,245 | 8,050 | 7,854 | 7,926 | 7,998 | Equal to comparable petrol ICEV |
| | FEV | Medium | Electra | 10,525 | 10,487 | 10,449 | 10,589 | 10,728 | " |
| | FEV | Large | Electra | 12,204 | 12,116 | 12,027 | 12,186 | 12,344 | " |
| **Fuel use (litre/100 km)** | ICEV | Small | Petrol | 8.0 | 7.5 | 6.1 | 5.8 | 5.5 | 2010: Tremove data 2010-2020: roughly in line with $CO_2$ and cars regulation[26] 2020-2030: -5% every 5 years |
| | ICEV | Medium | Petrol | 9.6 | 8.9 | 7.3 | 6.9 | 6.6 | " |
| | ICEV | Large | Petrol | 12.0 | 11.2 | 9.2 | 8.7 | 8.3 | " |
| | ICEV | Small | Diesel | 5.1 | 4.8 | 3.9 | 3.7 | 3.5 | " |
| | ICEV | Medium | Diesel | 6.7 | 6.2 | 5.1 | 4.9 | 4.6 | " |
| | ICEV | Large | Diesel | 9.2 | 8.6 | 7.0 | 6.7 | 6.3 | " |
| | PHEV | Small | Petrol | 3.2 | 3.0 | 2.4 | 1.7 | 1.7 | 2010-2020: 0.4 * fuel use ICE 2025-2030: 0.3 * fuel use ICEV |
| | PHEV | Medium | Petrol | 3.8 | 3.6 | 2.9 | 2.1 | 2.0 | " |
| | PHEV | Large | Petrol | 4.8 | 4.5 | 3.7 | 2.6 | 2.5 | " |
| | PHEV | Small | Diesel | 2.1 | 1.9 | 1.6 | 1.1 | 1.1 | " |
| | PHEV | Medium | Diesel | 2.7 | 2.5 | 2.0 | 1.5 | 1.4 | " |
| | PHEV | Large | Diesel | 3.7 | 3.4 | 2.8 | 2.0 | 1.9 | " |
| | EREV | Small | Petrol | 2.4 | 2.2 | 1.8 | 1.2 | 1.1 | 2010-2020: 0.3 * fuel use ICEV 2025-2030: 0.2 * fuel use ICEV |
| | EREV | Medium | Petrol | 2.9 | 2.7 | 2.2 | 1.4 | 1.3 | " |
| | EREV | Large | Petrol | 3.6 | 3.4 | 2.8 | 1.7 | 1.7 | " |
| | EREV | Small | Diesel | 1.5 | 1.4 | 1.2 | 0.7 | 0.7 | " |
| | EREV | Medium | Diesel | 2.0 | 1.9 | 1.5 | 1.0 | 0.9 | " |
| | EREV | Large | Diesel | 2.8 | 2.6 | 2.1 | 1.3 | 1.3 | " |
| | FEV | All | | 0 | 0 | 0 | 0 | 0 | No fuel use |
| **Electricity use (kWh/100 km)** | ICEV | All | | 0 | 0 | 0 | 0 | 0 | No electricity use |
| | PHEV | Small | | 15.0 | 14.3 | 13.5 | 15.0 | 14.3 | 2010-2020: 0,6 * electricity use FEV 2025-2030: 0,7 * electricity use FEV |
| | PHEV | Medium | | 17.4 | 16.5 | 15.7 | 17.4 | 16.5 | " |
| | PHEV | Large | | 19.8 | 18.8 | 17.9 | 19.8 | 18.8 | " |
| | EREV | Small | | 17.5 | 16.6 | 15.8 | 17.1 | 16.3 | 2010-2020: 0,7 * electricity use FEV |

26 This fuel efficiency improvement assumed here for 2020 is somewhat less strong than the $CO_2$ and cars regulation requires (emissions would reduce to appr. 105 gr/km in 2020). The reasoning behind this is that the 'real life' emission reduction of cars is generally seen to be less strong than the reductions during type approval. Also, EVs will contribute to the target.

| | Type | Size | Fuel | 2010 | 2015 | 2020 | 2025 | 2030 | Based on |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 2025-2030: 0,8 * electricity use FEV |
| | EREV | Medium | | 20.3 | 19.3 | 18.3 | 19.9 | 18.9 | “ |
| | EREV | Large | | 23.1 | 21.9 | 20.8 | 22.6 | 21.5 | “ |
| | FEV | Small | | 25.0 | 23.8 | 22.6 | 21.4 | 20.4 | Own estimate, 5% improvement every 5 years |
| | FEV | Medium | | 29.0 | 27.6 | 26.2 | 24.9 | 23.6 | Own estimate, 5% improvement every 5 years |
| | FEV | Large | | 33.0 | 31.4 | 29.8 | 28.3 | 26.9 | Own estimate, 5% improvement every 5 years |
| **Range (km)** | ICEV | All | | 600 | 600 | 600 | 600 | 600 | 2010-2020: own estimate 2020-2030: Ricardo/TNO |
| | PHEV | All | | 450 | 500 | 550 | 600 | 600 | “ |
| | EREV | All | | 450 | 450 | 450 | 450 | 450 | “ |
| | FEV | Small | | 120 | 120 | 200 | 250 | 300 | “ |
| | FEV | Medium | | 150 | 150 | 250 | 300 | 350 | “ |
| | FEV | Large | | 175 | 175 | 250 | 300 | 350 | “ |
| **‘Green Image’** | ICEV | | | 7 | 6 | 6 | 6 | 6 | Own assumption |
| | PHEV | | | 9 | 9 | 8 | 8 | 8 | “ |
| | EREV | | | 8 | 9 | 9 | 9 | 9 | “ |
| | FEV | | | 8 | 10 | 10 | 10 | 10 | “ |

# Annex B Impacts on electricity production – regional results

## B.1 Scenario 1

The aggregated impact of the EV scenarios on the EU electricity production capacity and generation are shown in Section 3.5.2. In the following, more detailed results are provided for the various regions within the EU.

### B.1.1 North-West Mainland Block capacity and generation mix

Growth in renewable capacity is nearly identical between Scenario 1 and the Reference Case. Scenario 1 shows a slightly higher growth in 2025 and 2030 in comparison with the Reference Case. Renewable capacity grows from 33% of the mix in 2010 to 72% in 2030 in Scenario 1, while growing to 71% in the Reference Case. Figure 44 shows differences in the capacity mix in this region for Scenario 1.

**Figure 44 Differences in the North-West Mainland Block capacity mix forecast between Scenario 1 and the Reference Case**

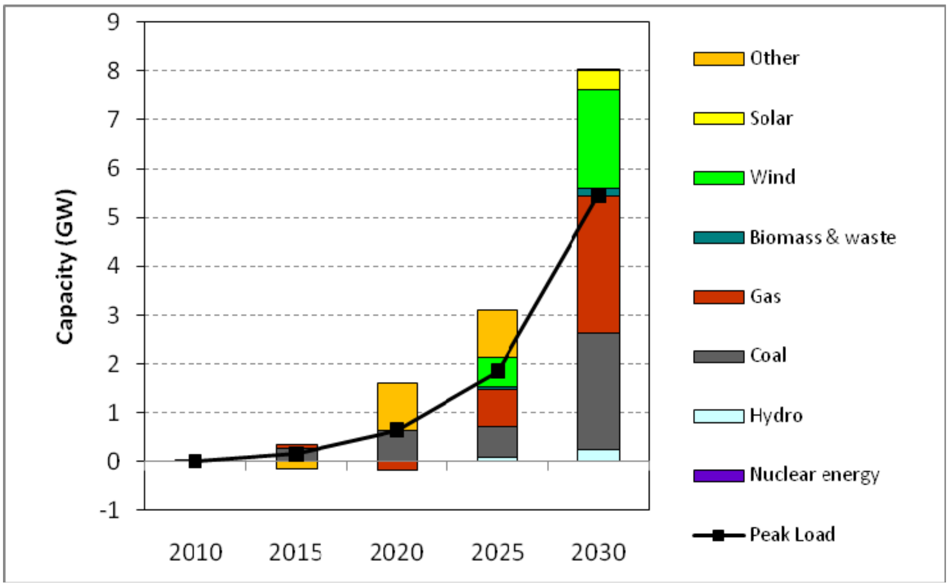
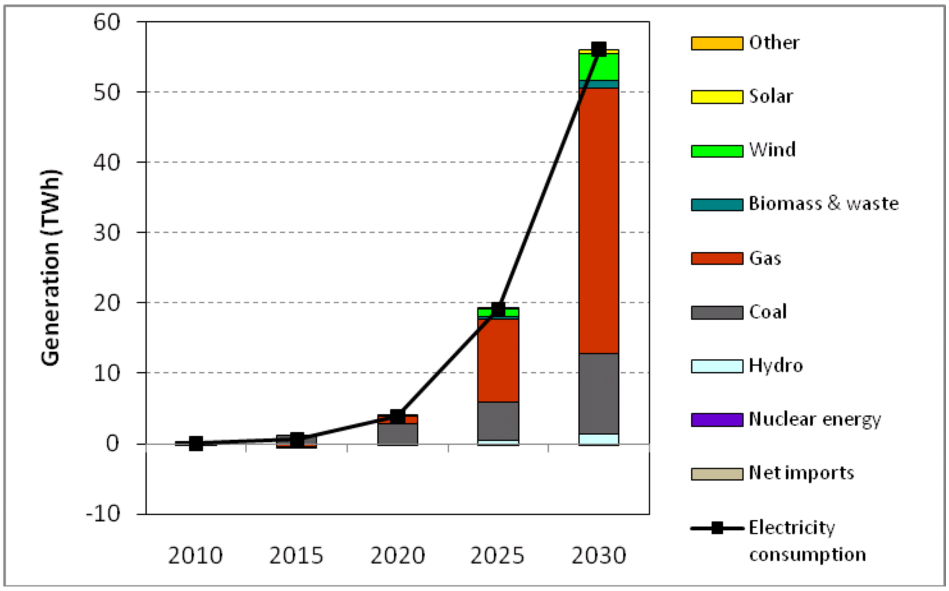



Figure 45 shows differences in Scenario 1 with the Reference Case for the generation mix forecast for the North-West Mainland Block. By 2030 EU generation is 3% higher in sensitivty 1 than in the Reference Case. Most of this difference is made up by increased gas and coal generation, 38 and 11 s higher generation in sensitivty 1, respectivly.

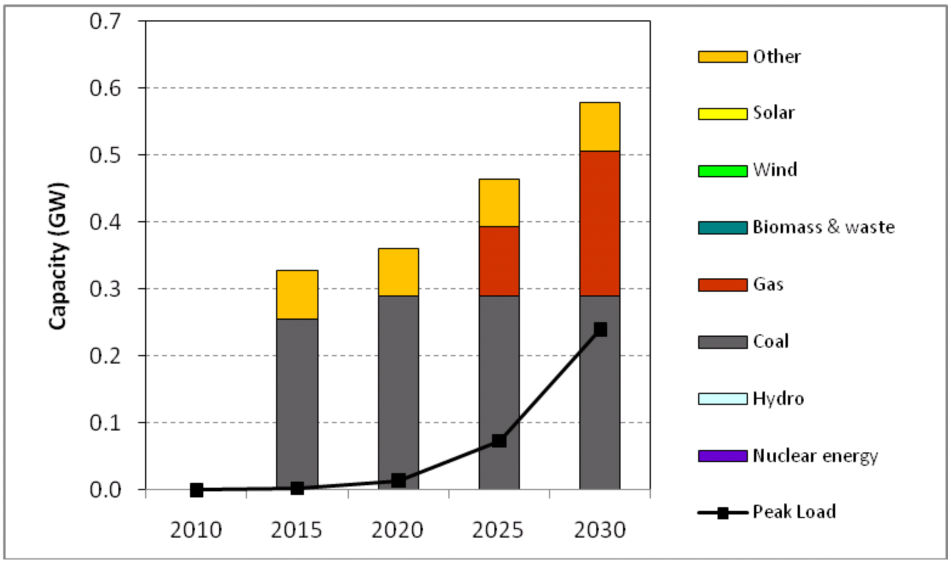
Figure 45 **Differences in the North-West Mainland Block generation mix forecast between Scenario 1 and the Reference Case**




## B.1.2 North-East Block capacity and generation mix

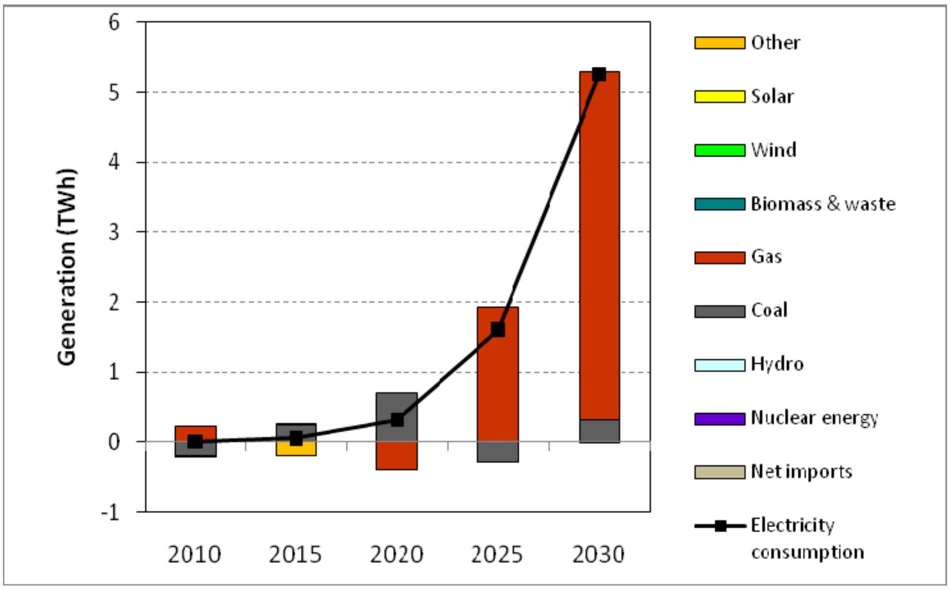
Figure 46 shows differences in the capacity mix for Scenario 1 in the North-East Block. The capacity mix between Scenario 1 and the Reference Case are almost identical. The capacity in this region is predominantly coal.

Figure 46 **Differences in the North-East Block capacity mix forecast between Scenario 1 and the Reference Case**




The generation mix is also very similar to the Reference Case. However, there is nearly 5 s of more gas generation by 2030. Coal also generates slightly more in Scenario 1. Figure 47 shows differences in the generation mix for the North-East Block.

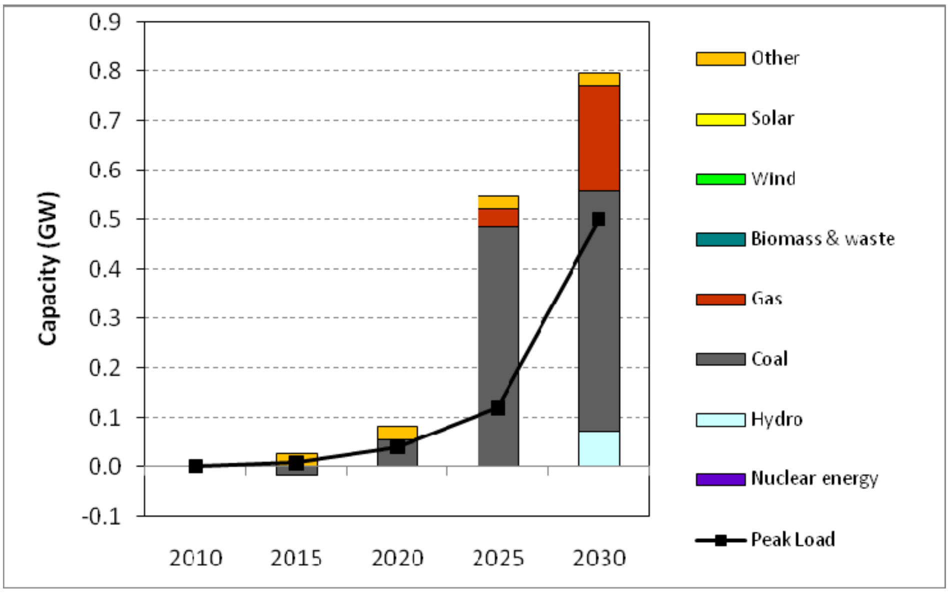
**Figure 47** Differences in the North-East Block generation mix forecast between Scenario 1 and the Reference Case




### B.1.3 South-East Block capacity and generation mix

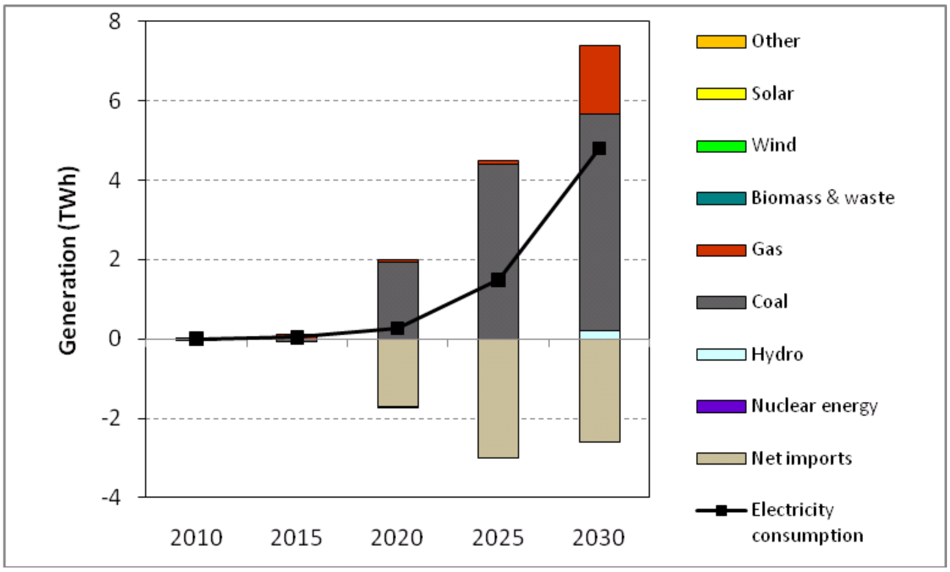
The capacity mix in this region is dominated by coal and hydro in the first ten years of the forecast, consisting of more than 60% of the total capacity in the region. Wind displaces significant portions of coal capacity in the later years. Figure 48 shows differences in the capacity mix forecast in the South-East Block for Scenario 1.

**Figure 48** Differences in the South-East Block capacity mix forecast between Scenario 1 and the Reference Case




The generation mix in this region is similar to the Reference Case. The main difference is in the coal and gas generation. By 2030, there is approximatly than 5 s more coal generation. Gas generation is higher by almost 2 s. Figure 49 shows differences in Scenario 1 with the Reference Case for the South-East Block generation mix.

Figure 49 **Differences in the South-East Block generation mix between Scenario 1 and the Reference Case**




## B.1.4 Centre-South Block capacity and generation mix

In the Centre-South Block the capacity differences are in economic retirements and gas. There are about 3 s of fewer retirements in Scenario 1 than in the Reference Case. Gas capacity is higher by nearly that amount. Figure 50 shows capacity mix differences for the Centre-South Block in the forecast.

Figure 50 **Differences in the Centre-South Block capacity mix forecast between Scenario 1 and the Reference Case**

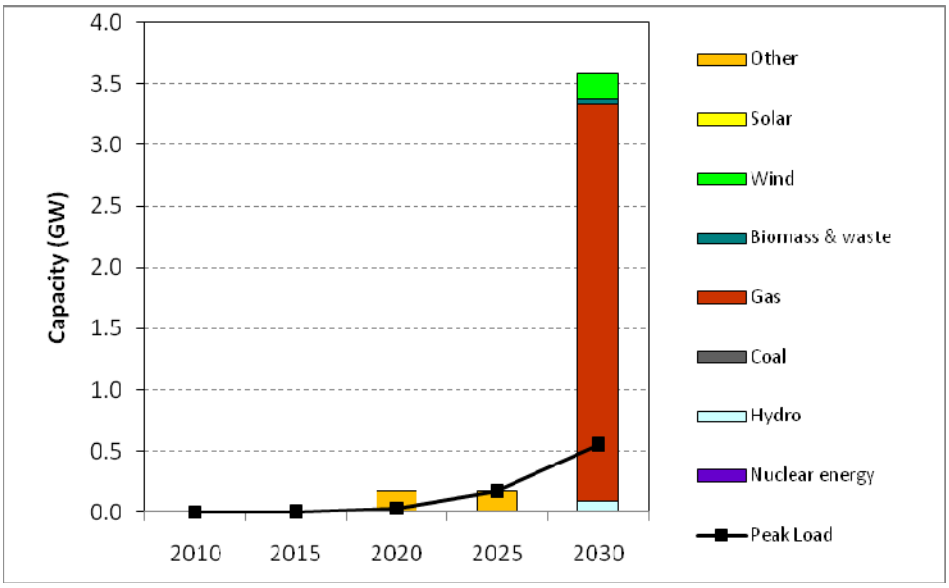
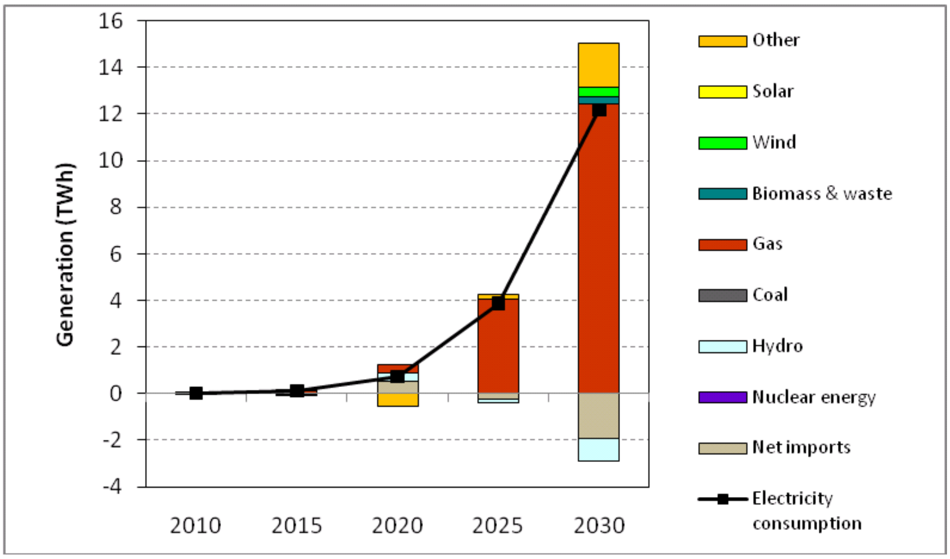



Figure 51 shows differences in Scenario 1 with the Reference Case for the generation mix forecast for the Centre-South Block. Generation in this region is mostly gas. Gas generation in Scenario 1 has 12 s greater gas generation in 2030. By 2030, there is a significant increase in nuclear generation. This is also found in the Reference Case.

**Figure 51** **Differences in the Centre-South Block generation mix forecast between Scenario 1 and the Reference Case**




## B.1.5 South-West Block capacity and generation mix

In 2030, most fuel types have small capacity differences in Scenario 1 than in the Reference Case. Figure 52 shows differences in Scenario 1 with the Reference Case for the capacity mix forecast in the South-West Block.
The largest differences are in economic retirements and gas capacity. In Scenario 1, about 1 GW of gas retires more than in the Reference Case.

**Figure 52** **Differences in the South-West Block capacity mix forecast between Scenario 1 and the Reference Case**

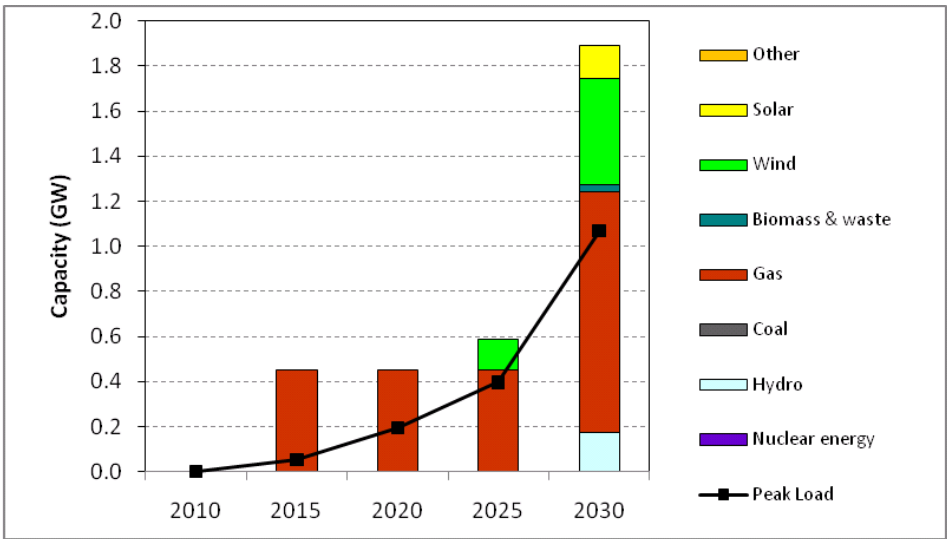
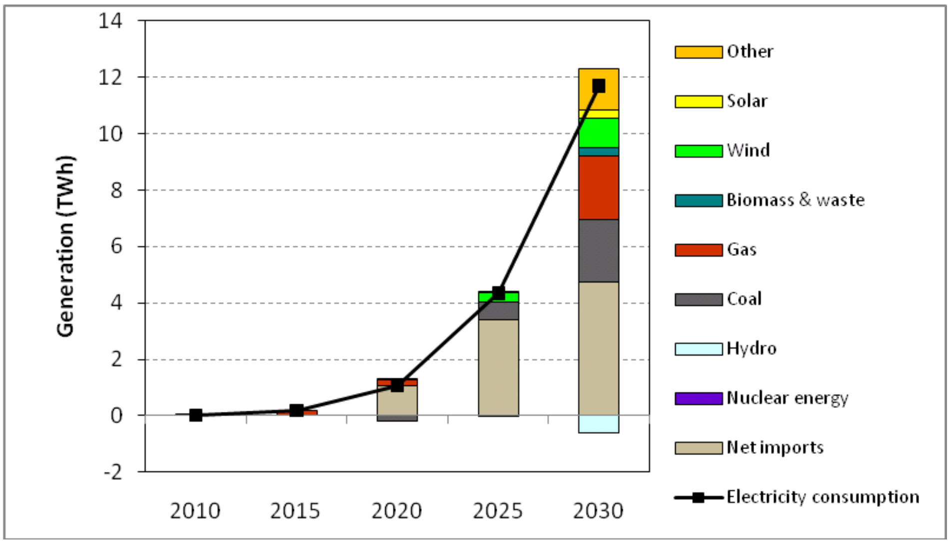



Figure 53 shows differences in Scenario 1 with the Reference Case for the generation mix forecast in the South-West Block. In 2030, there is more generation across all fuel types except hydro and nuclear. Hydro generation is lower in sensitivty 1 by half a GW. Imports are similar in the Reference Case and sensitivty 1 through 2020. In 2025 and 2030, sensitivty 1 imports about 4 TWh more generation.

**Figure 53** **Differences in the South-West Block generation mix forecast between Scenario 1 and the Reference Case**




### B.1.6 Nordel-Baltics Block capacity and generation mix

Figure 54 shows differences in Scenario 1 with the Reference Case for the capacity mix forecast in the Nordel-Baltics Block. The capacity mix in this region is similar to the Reference Case, dominated by hydro capacity. Wind capacity is a quickly growing segment of the capacity mix. By 2020, wind capacity is already 24% of the mix.

**Figure 54** **Differences in the Nordel-Baltics Block capacity mix forecast between Scenario 1 and the Reference Case**

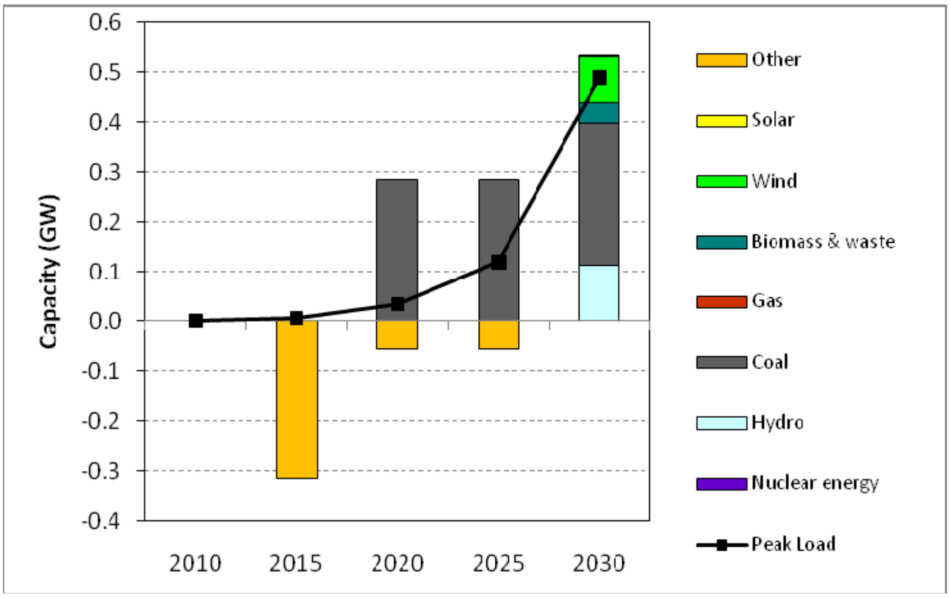
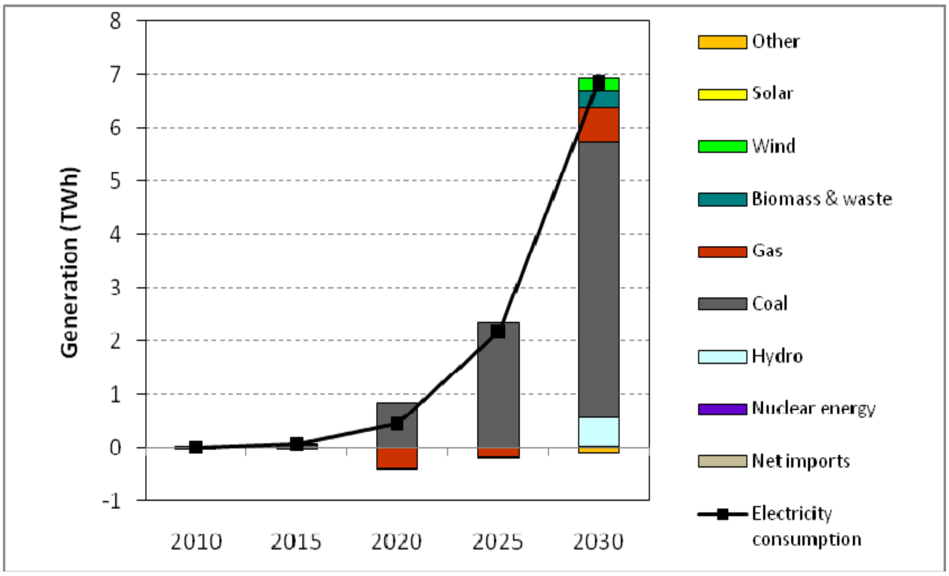



Figure 55 shows differences in Scenario 1 with the Reference Case for the Nordel-Baltics Block generation mix forecast. In this region coal does not retire as much by 2030 in sensitivty 1. In 2030, there is still 5 TWhs more coal geneartion in Scenario 1.

**Figure 55 Differences in the Nordel-Baltics Block generation mix forecast between Scenario 1 and the Reference Case**




## B.1.7 UK-Ireland Block capacity and generation mix

Figure 56 shows differences in Scenario 1 with the Reference Case for the UK-Ireland Block capacity mix forecast. In Scenario 1, wind grows 1 GW more by 2030. Wind is the fastest growing segment and also grows into the largest portion of the regions mix by 2030. Wind is more than 50% of the capacity mix by 2030. Solar also grows quickly to 8 GW by 2030, however; initially it is a very small part of the mix. Biomass doubles by 2030.

**Figure 56 Differences in the UK-Ireland Block capacity mix forecast between Scenario 1 and the Reference Case**

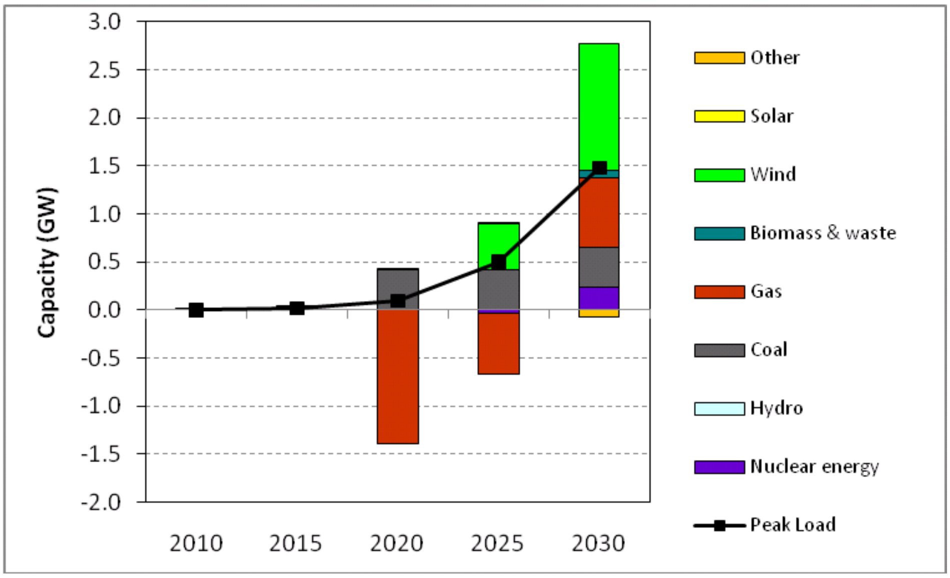
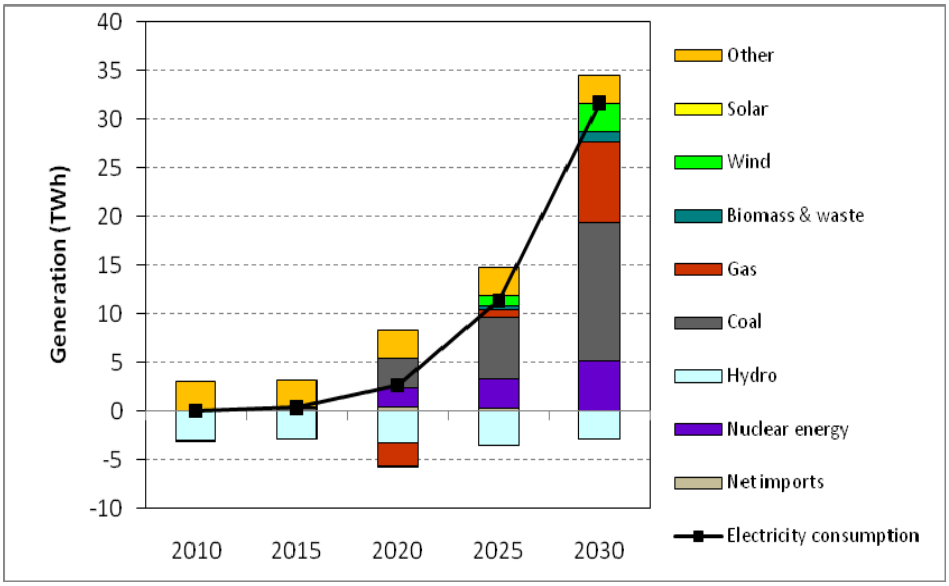



Figure 57 shows differences in Scenario 1 with the Reference Case for the UK-Ireland Block generation mix forecast (TWh). Some of the more significant differences between the Reference Case and Scenario 1 are found in this region. By 2030, coal generates 14 TWh more electricity from coal sources. Between 2 and 8 TWhs of more electricity is generated between each of nuclear, wind, other and gas sources in 2030. Only hydro sources generate less in this region. By 2030, there is approximatly 3 TWhs less hydro generation.

**Figure 57 Differences in the UK-Ireland Block generation mix forecast between Scenario 1 and the Reference Case**




## B.2 Scenario 2

The detailed regional impacts on electricity capacity and generation can be found below.

### B.2.1 North-West Mainland Block capacity and generation mix

Figure 58 shows differences from Scenario 2 and the Reference Case in the capacity mix forecast for the North-West Mainland Block. In this region capacity from renewable sources is nearly the same throughout the modeling horizon. Wind resources increase the most from 38 GW in 2010 to 163 GW in 2030. Gas and Coal are higher in 2030 in Scenario 2 than in the Reference Case by 1 and 2 GW, respectively.

**Figure 58** **Differences in the North-West Mainland Block capacity mix forecast between Scenario 2 and the Reference Case**

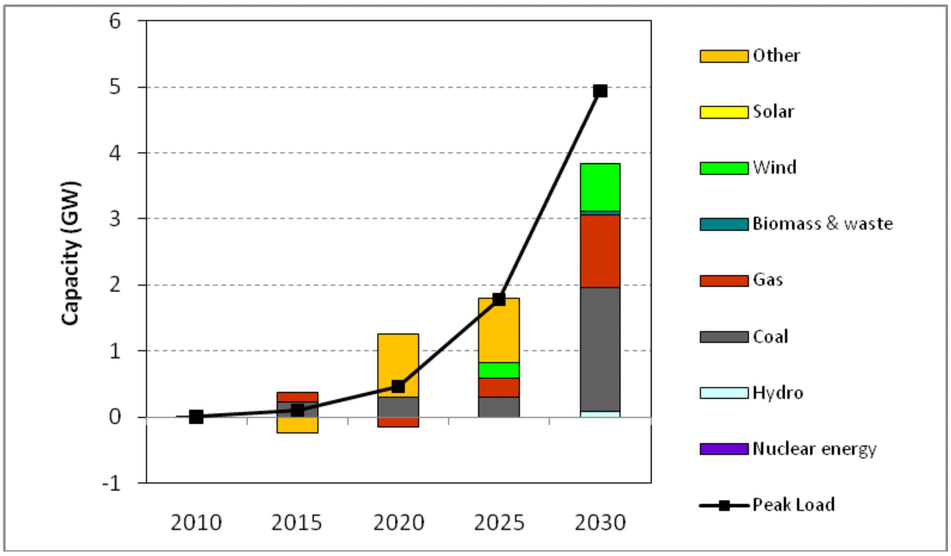
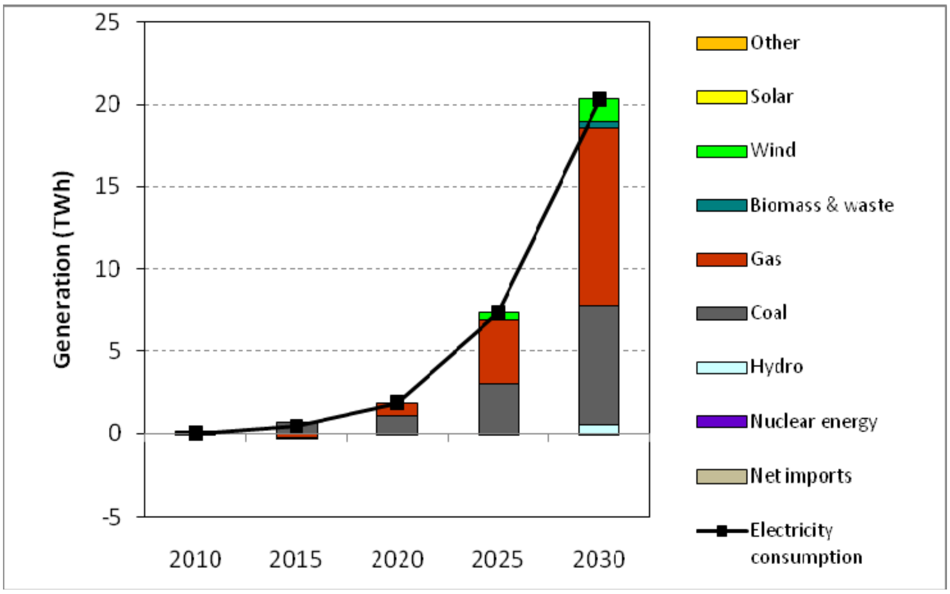



Figure 59 shows differences from Scenario 2 and the Reference Case in the generation mix forecast for the North-West Mainland Block. Generation in this region is higher in 2030 in sensitivty 2 than in the Reference Case overall and across most fuel types. In 2030, generation is the same for nuclear and solar, but lower for other in sensistivity 2 than in the Reference Case. Nuclear generation share decreases over the modeling horizon from 45% to 28% by 2030.

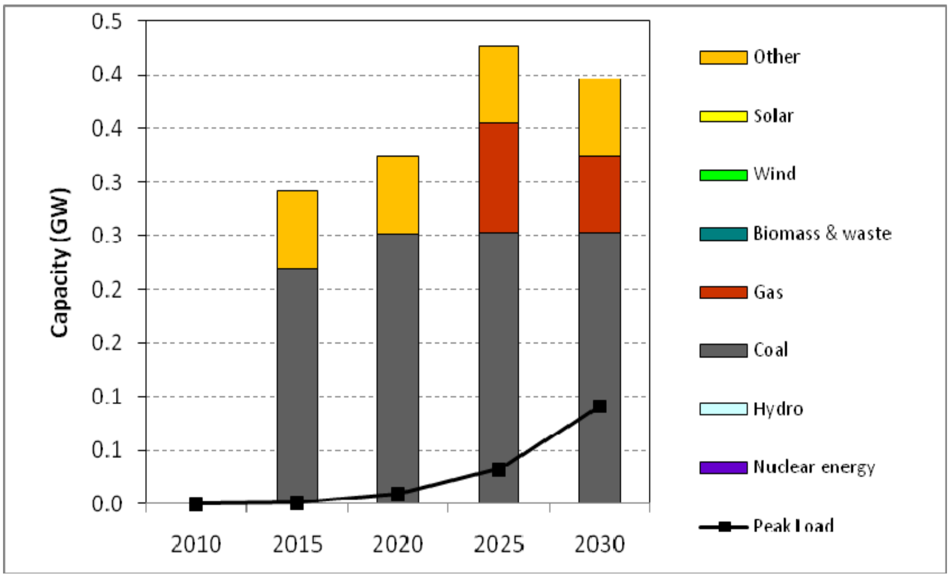
**Figure 59** **Differences in the North-West Mainland Block generation mix forecast between Scenario 2 and the Reference Case**



### B.2.2 North-East Block capacity and generation mix

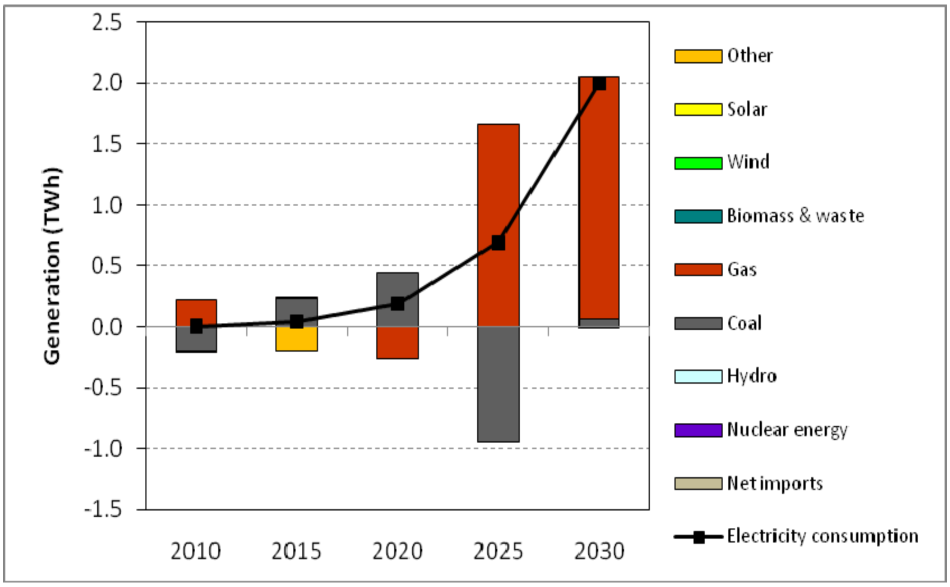
Figure 60 shows differences from Scenario 2 and the Reference Case in the capacity mix forecast for the North-East Block. In comparison with the Reference Case, Scenario 2 capacity in the North-East Block remains mostly the same. There slightly higher capacity in Scenario 2 by 2030 for coal, gas and other fuel types.

**Figure 60 Differences in the North-East Block capacity mix forecast between Scenario 2 and the Reference Case**




Similar to capacity, generation is mostly the same between Scenario 2 and the Reference Case. By 2030, generation is higher for gas in Scenario 2 than in the Reference Case by 2 TWhs. The majority of generation in this region comes from coal. Figure 61 shows differences from Scenario 2 and the Reference Case in the generation mix forecast for the North-East Block.

**Figure 61 Differences in the Norh-Eastern Block generation mix forecast between Scenario 2 and the Reference Case**



### B.2.3 South-East Block capacity and generation mix

Figure 62 shows differences from Scenario 2 and the Reference Case in the capacity mix forecast for the South-East Block. Capacity in this region is very similar between Scenario 2 and the Reference Case. There are slight higher capacities in 2030 for coal, gas and other fuel types.

**Figure 62 Differences in the South-East Block capacity mix forecast between Scenario 2 and the Reference Case**

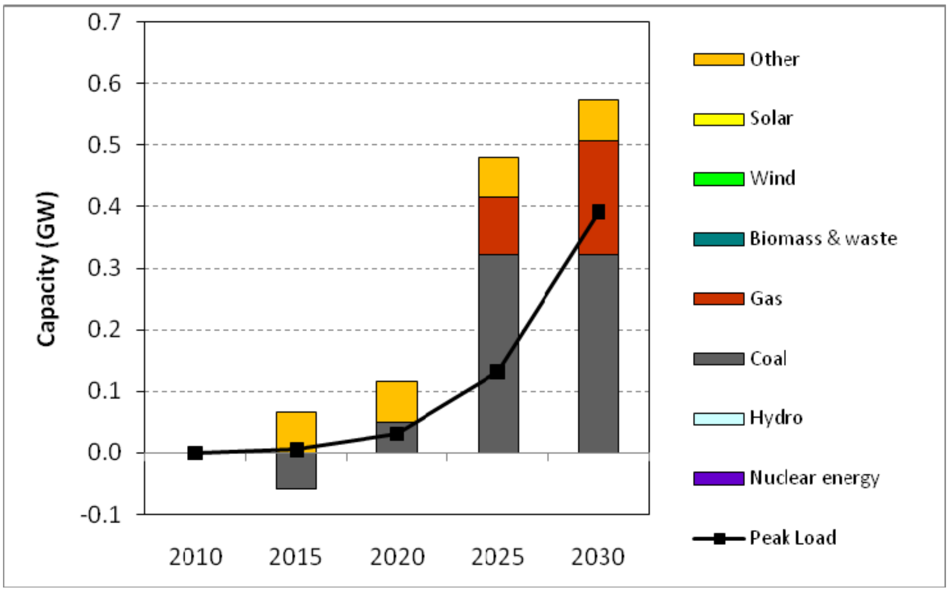
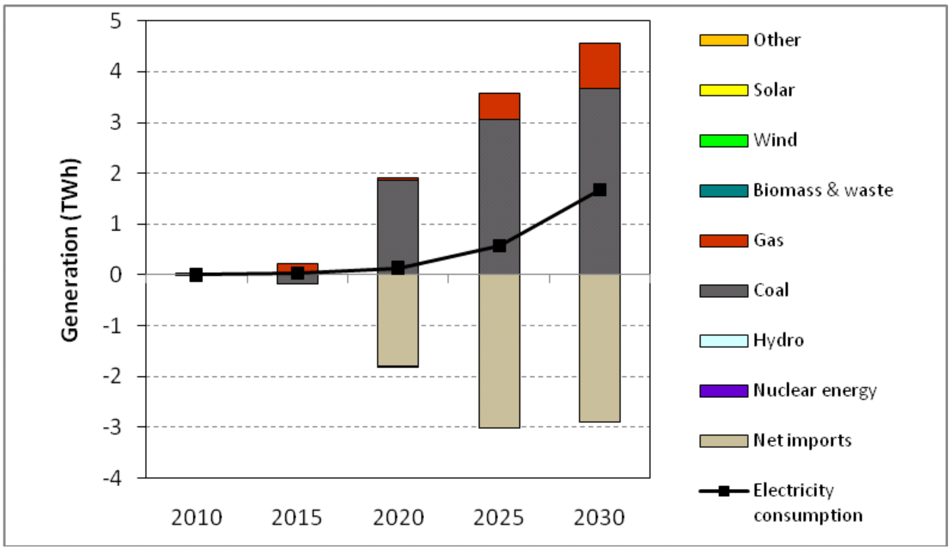



Figure 63 shows differences from Scenario 2 and the Reference Case in the generation mix forecasat for the South-East Block. Generation between Scenario 2 and the Reference Case for this region is very similar. By 2030, coal and gas have higher generation than in the Reference Case by 4 and 1 TWhs, respectivly. Nuclear and wind have the most growth in this region. Together their share grow from 19% in 2010 to 37% share of generation in 2030.

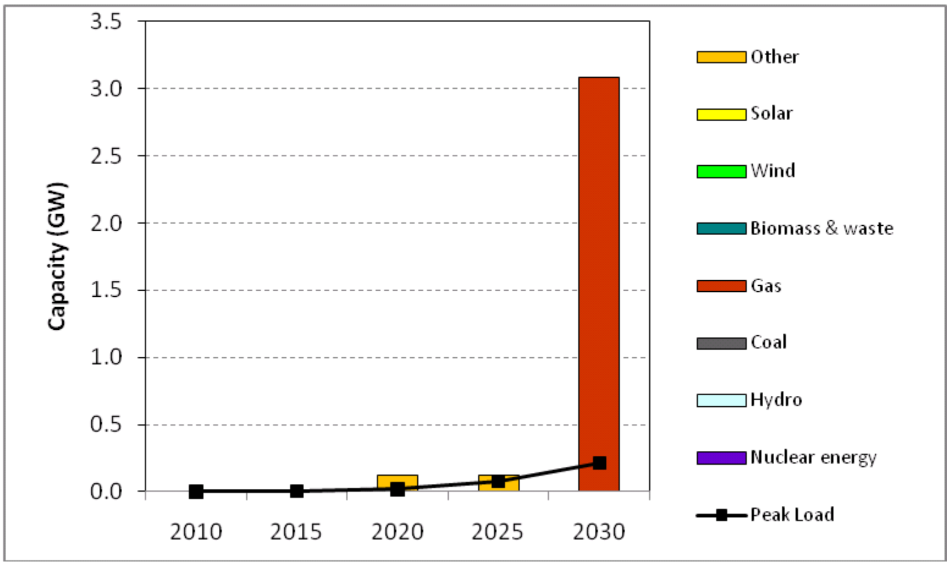
**Figure 63 Differences in the South-East Block generation mix forecast between Scenario 2 and the Reference Case**



### B.2.4 Centre-South Block capacity and generation mix

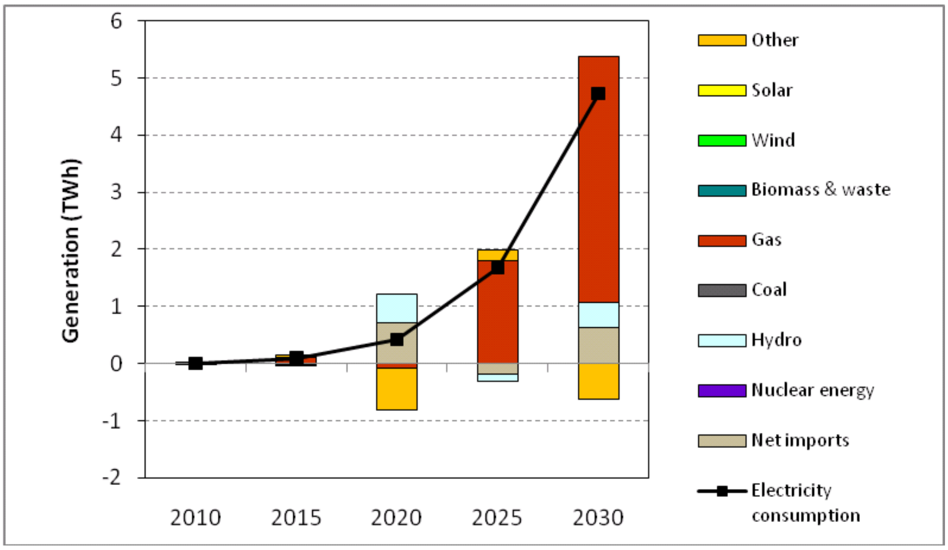
Capacity in this region is very similar between Scenario 2 and the Reference Case. Only gas is higher in Scenario 2 than in the Reference Case by 2030. Gas has 3 GW more capacity available in Scenario 2. Figure 64 shows differences from Scenario 2 and the Reference Case in the capacity mix forecast for the Centre-South Block.

**Figure 64 Differences in the Centre-South Block capacity mix forecast between Scenario 2 and the Reference Case**




Some of the generation differences in this region between Scenario 2 and the Reference Case are found in gas, hydro and other fuel types. Gas and hydro have higher generation in Scenario 2 than in the Reference Case while other fuels have lower by 2030. Nuclear generation increases significantly over the modeling horizon in this region. Nuclear increases from 6 TWh to 106 TWh in 2030. As a share, nuclear does not increase very much because capacity in the region grows by nearly 30%. Figure 65 shows differences from Scenario 2 and the Reference Case in the generation mix forecast for the Centre-South block.

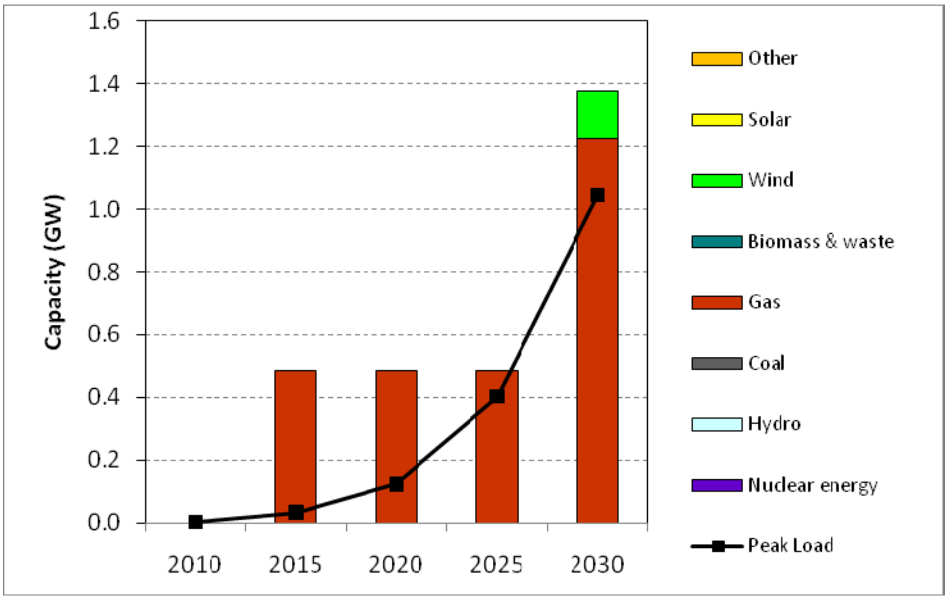
**Figure 65 Differences in the Centre-South Block generation mix forecast between Scenario 2 and the Reference Case**




## B.2.5 South-West Block capacity and generation mix

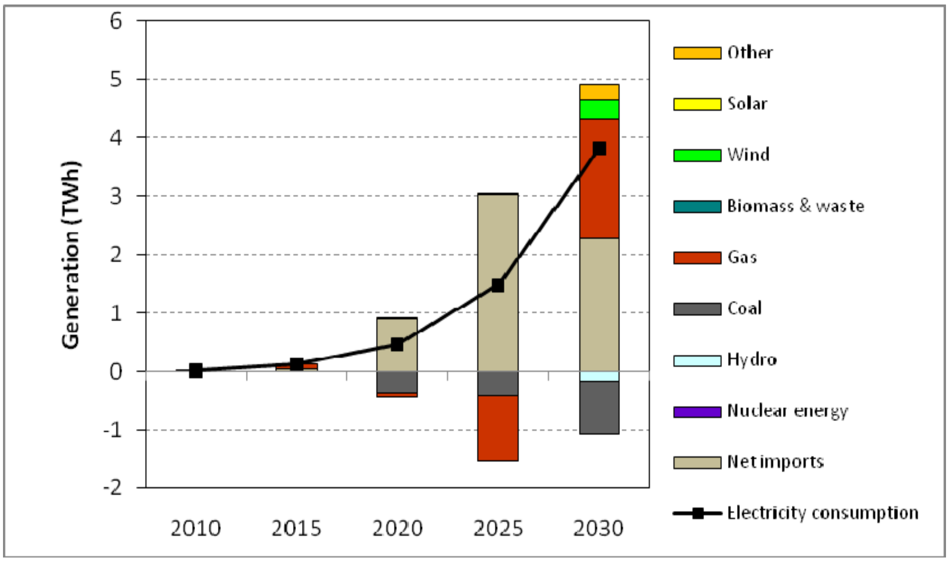
Figure 66 shows differences from Scenario 2 and the Reference Case in the capacity mix forecast for the South-West Block. The capacity mix for this region is different in Scenario 2 than in the Reference Case for only gas and hydro fuel types by 2030. Gas has 1 GW more capacity and hydro has 152 MW more capacity by 2030. Wind becomes the dominant capacity type by 2030 with nearly 40% share of total capacity in the region.

**Figure 66 Differences in the South-West Block capacity mix forecast between Scenario 2 and the Reference Case**




Generation in this region higher in this region for gas wind and other fuel types in Scenario 2 than the Reference Case. There is slightly less generation in coal and hydro. Figure 67 shows differences from Scenario 2 and the Reference Case in the South-West Block generation mix forecast.

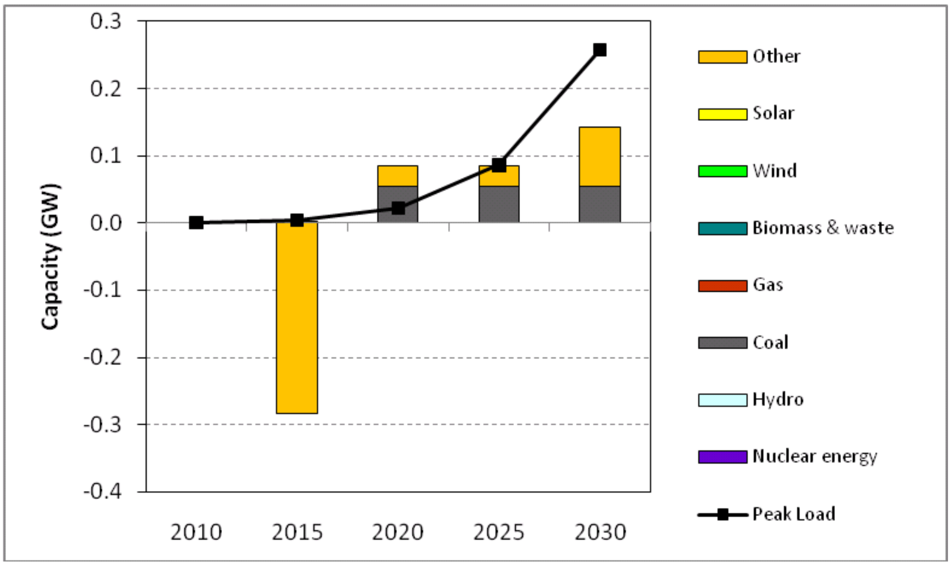
Figure 67 Differences in the South-West Block generation mix forecast between Scenario 2 and the Reference Case




## B.2.6 Nordel-Baltics Block capacity and generation mix

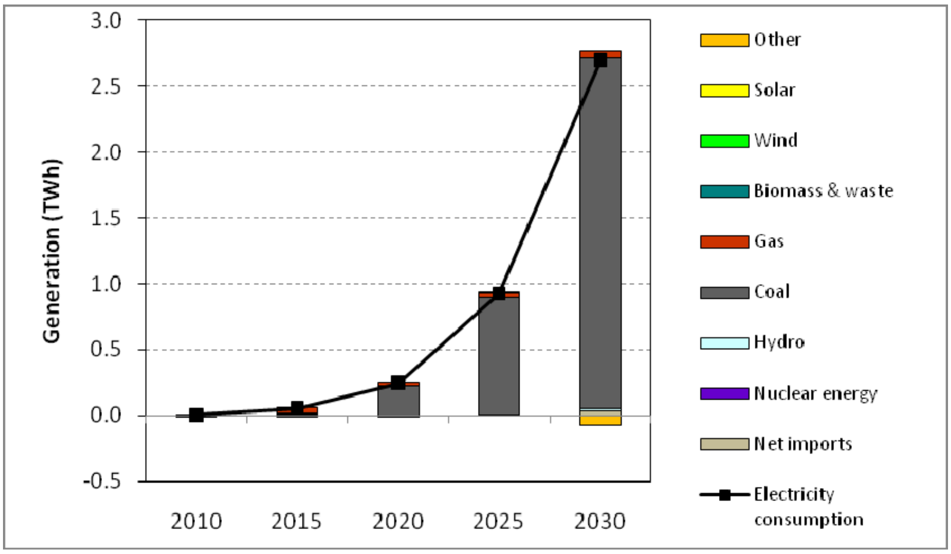
The capacity mix is very similar in this region between Scenario 2 and the Reference Case. Coal and other fuel types have slightly higher capacity by 2030. Renewable capacity increases as a share of total capacity in this region from 44% in 2010 to 69% in 2030. Figure 68 shows differences from Scenario 2 and the Reference Case in the capacity mix forecast for the Nordel-Baltics Block.

Figure 68 Differences in the Nordel-Baltics Block capacity mix forecast between Scenario 2 and the Reference Case




Generation in this region is similar across most fuels except for coal by 2030. Coal is 3 TWh larger in Scenario 2 than in the Reference Case. Renewable gerneation as a share of the generation mix increases from 42% to 53% in 2030. Figure 69 shows differences from Scenario 2 and the Reference Case in the Nordel-Baltics Block generation mix forecast.

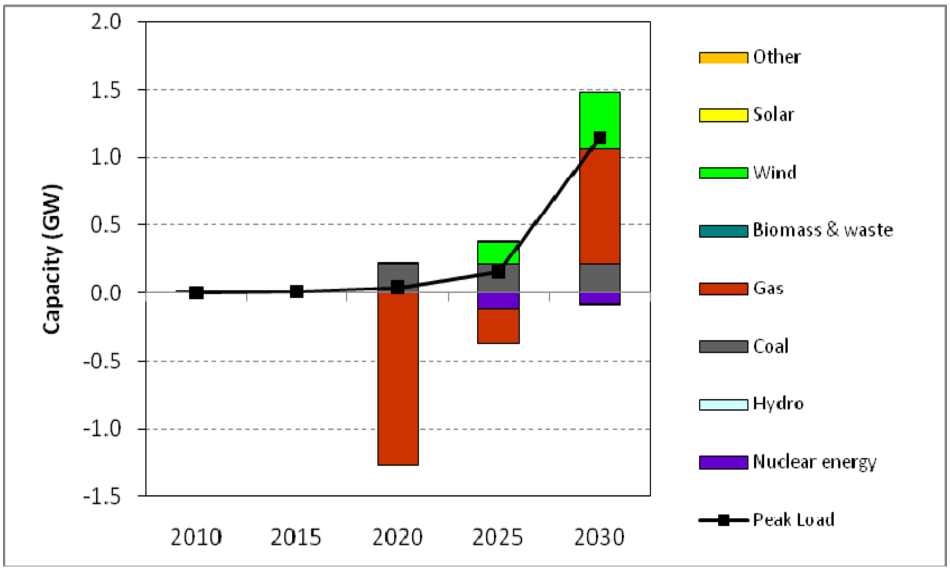
**Figure 69** **Differences in the Nordel-Baltics Block generation mix forecast between Scenario 2 and the Reference Case**




## B.2.7 UK-Ireland Block capacity and generation mix

Figure 70 shows differences from Scenario 2 and the Reference Case in the capacity mix forecast for the UK-Ireland Block. The capacity mix in this region differs from the Reference Case in coal, gas, wind and nuclear fuel types. In 2030 there is more capacity available from coal, gas and wind resources than in the Reference Case. Nuclear resources are slightly lower in Scenario 2 in 2030.

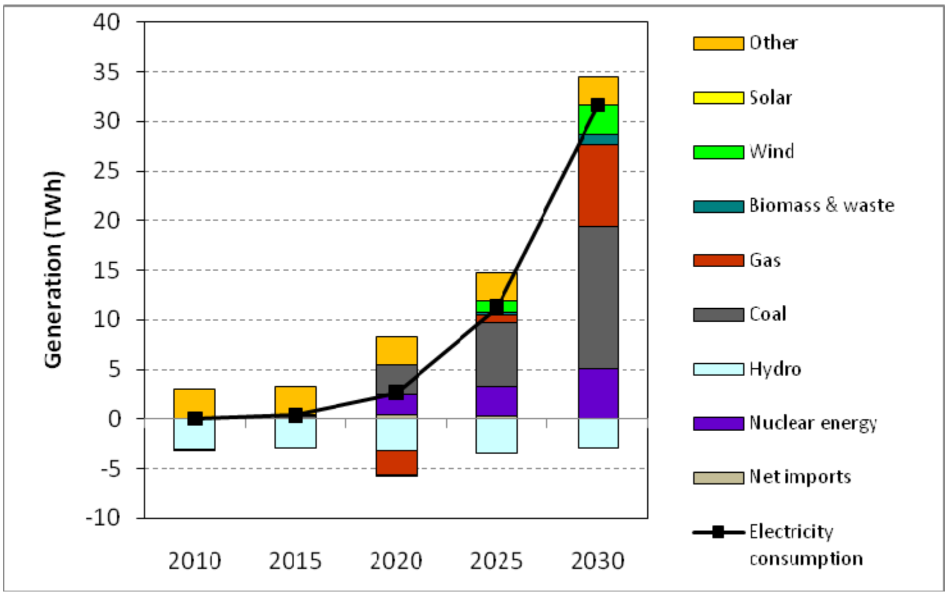
**Figure 70** **Differences in the UK-Ireland Block capacity mix forecast between Scenario 2 and the Reference Case**




The generation mix in this region is has differences across most fuel types. Only solar has a similar generation growth in both Scenario 2 and the Reference Case. Hydro generation is lower in sensitivty 2 than in the refefence case. All other fuel types have higher generation in 2030 in sensitivty 2 than in the Reference Case. Coal has the largest difference between sensitivty 2 and the Reference Case with 14 TWh more generation in 2030.

Figure 71 shows differences from Scenario 2 and the Reference Case in the UK-Ireland Block generation mix forecast.

**Figure 71** **Differences in the UK-Ireland Block generation mix forecast between Scenario 2 and the Reference Case**




## B.3 Scenario 3

The detailed regional impacts on electricity capacity and generation can be found below.

### B.3.1 North-West Mainland Block capacity and generation mix

Total capacity in this region increases the most by 2030 from the Reference Case in comparison to the other regions. The North-West Mainland Block is also the largest contributor to total EU capacity making up over 40% of the EU's total capacity in 2030. Figure 72 shows differences from Scenario 3 and the Reference Case in the capacity mix forecast for the North-West Mainland Block. Gas, wind, and hydro show the largest increases from the Reference Case.

Figure 72 **Differences in the North-West Mainland Block capacity mix forecast between Scenario 3 and the Reference Case**

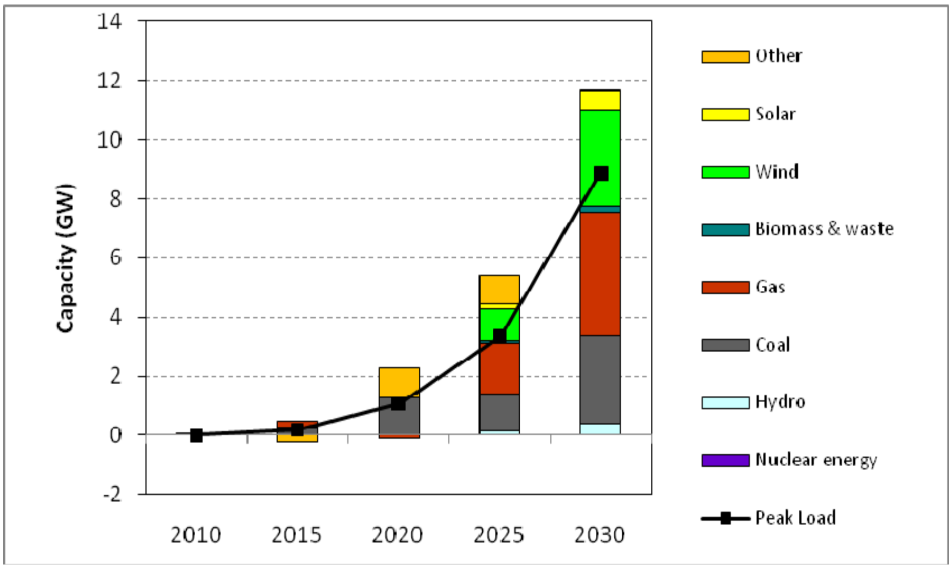
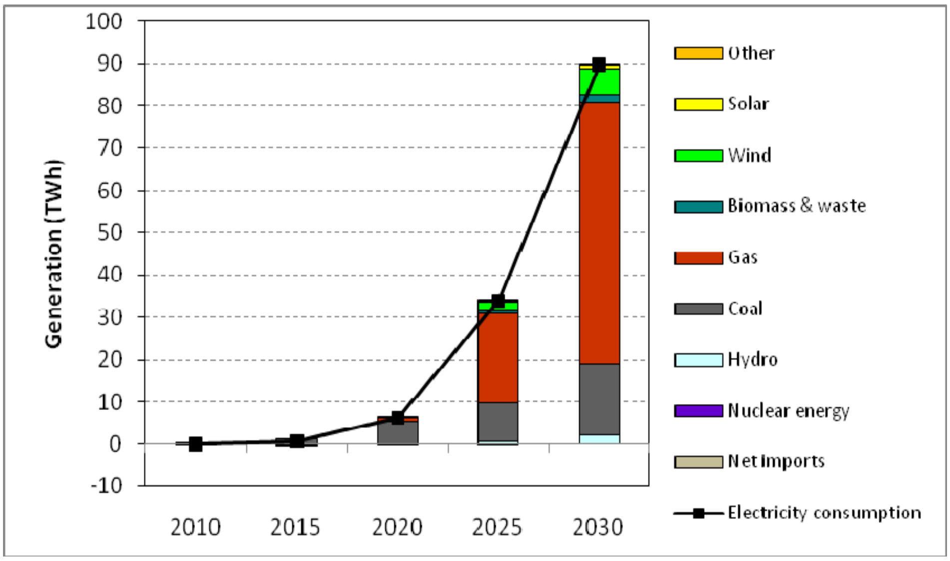



Figure 73 shows differences from Scenario 3 and the Reference Case in the generation mix forecast for the North-West Mainland Block. Gas generation makes up nearly 70% of the difference in generation in Scenario 3 from the Reference Case by 2030. Coal is a distant second, making up less than 20% of there total difference in generation by 2030.

Figure 73 **Differences in the North-West Mainland Block generation mix forecast between Scenario 3 and the Reference Case**




## B.3.2 North-East Block capacity and generation mix

Figure 74 shows differences from Scenario 3 and the Reference Case in the capacity mix forecast for the North-East Block. The only differences in this region from the Reference Case are capacity increases from coal, gas, and other fuel sources. In 2030, there is 6% more gas capacity than in the Reference Case. Coal is the largest contributor to the capacity mix in this region, the increase from the Reference Case is less than a percent.

Figure 74 **Differences in the North-East Block capacity mix forecast between Scenario 3 and the Reference Case**

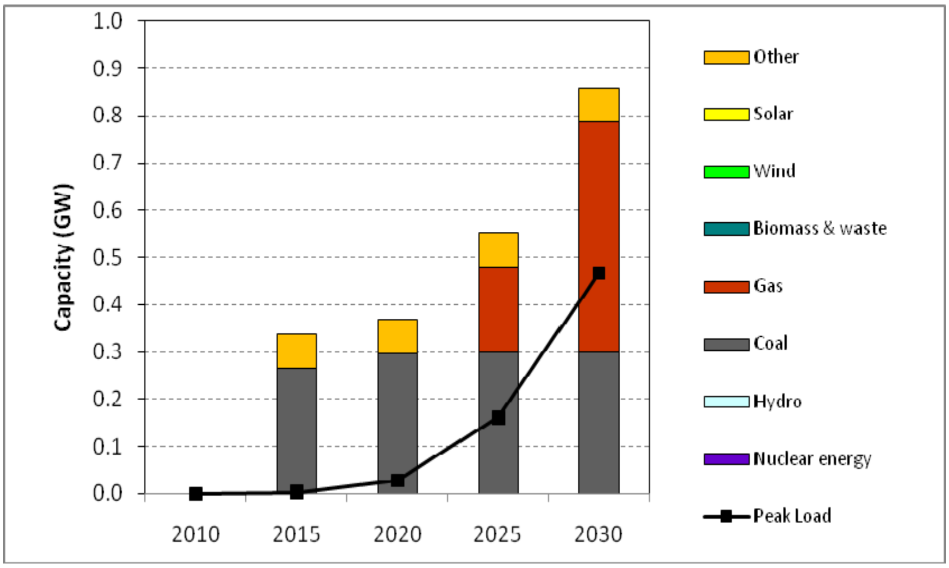
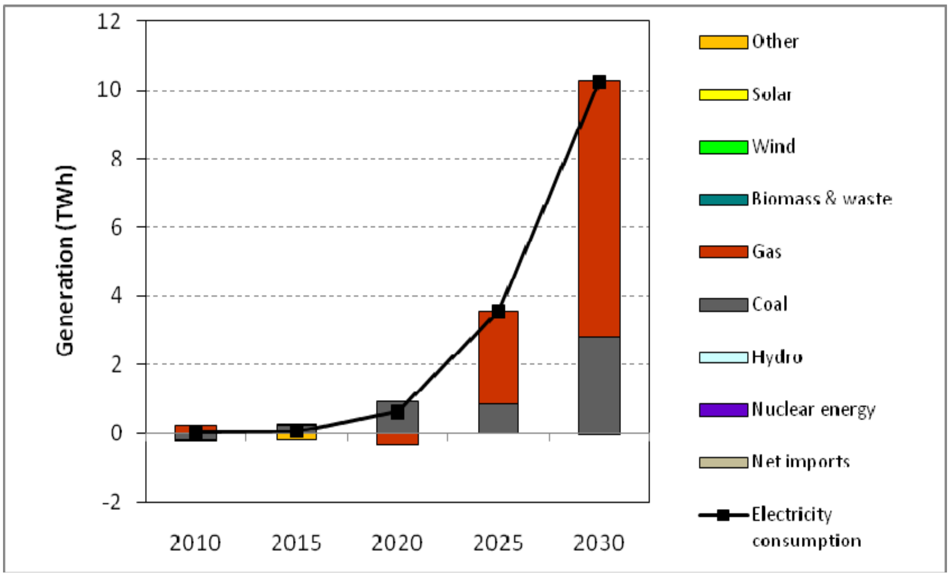



Figure 75 shows differences from Scenario 3 and the Reference Case in the generation mix forecast for the North-East Block. In the early years there are slight decreases in generation from the Reference Case in other and gas fuel sources. However, by 2030 this region generates 10 TWh or 2% more than in the Reference Case. All of this increase coming from gas and coal sources.

Figure 75 **Differences in the Norh-Eastern Block generation mix forecast between Scenario 3 and the Reference Case**




## B.3.3 South-East Block capacity and generation mix

Figure 76 shows differences from Scenario 3 and the Reference Case in the capacity mix forecast for the South-East Block. By 2030, renewable fuels and non-renewable fuels have a near 50-50 split of the total capacity in the South-East Block. Most of the renewable capacity is form wind and hydro sources. As shown below, almost all the increases in capacity in Scenario 3 from the Reference Case are from coal and gas sources.

Figure 76 **Differences in the South-East Block capacity mix forecast between Scenario 3 and the Reference Case**

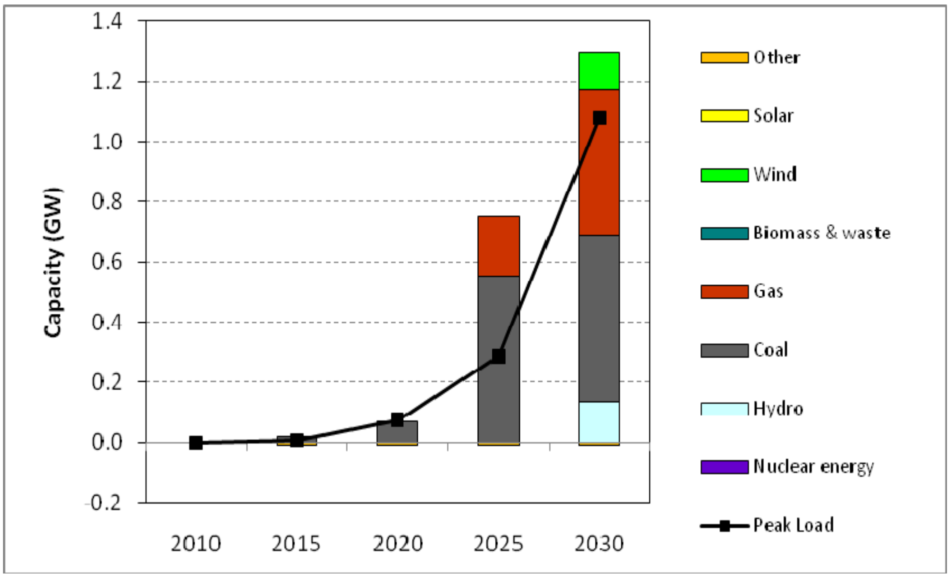
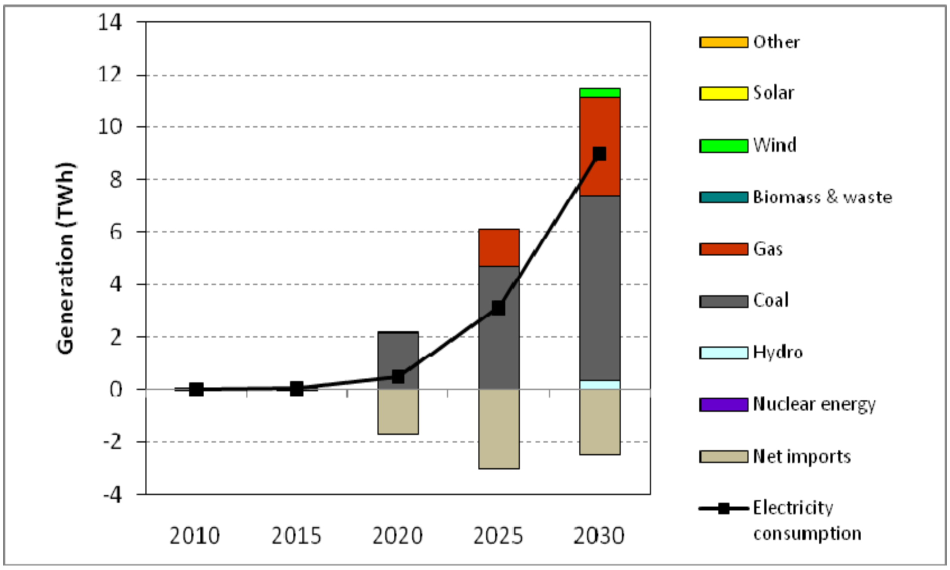



Figure 77 shows differences from Scenario 3 and the Reference Case in the generation mix forecasat for the South-East Block. Total generation in the South-East Block is approimatly 11 TWh higher in sensitivty 3 than in the Reference Case in 2030. Peak demand rises by almost as much from in sensitivty 3, almost 9 TWh greater than the Reference Case. Differences in renewable generation in sensitivty 3 are very little.

Figure 77 **Differences in the South-East Block generation mix forecast between Scenario 3 and the Reference Case**



### B.3.4 Centre-South Block capacity and generation mix

Figure 78 shows differences from Scenario 3 and the Reference Case in the capacity mix forecast for the Centre-South Block. This region is one of the smaller regions in terms of capacity within the EU. In Scenario 3, the total capacity growth for the region was 21%. Most of the increase in capacity is from wind and nuclear sources. By 2030, gas sources are largely unchanged in Scenario 3, but still remain approximately 4 GW higher than in the Reference Case.

**Figure 78 Differences in the Centre-South Block capacity mix forecast between Scenario 3 and the Reference Case**

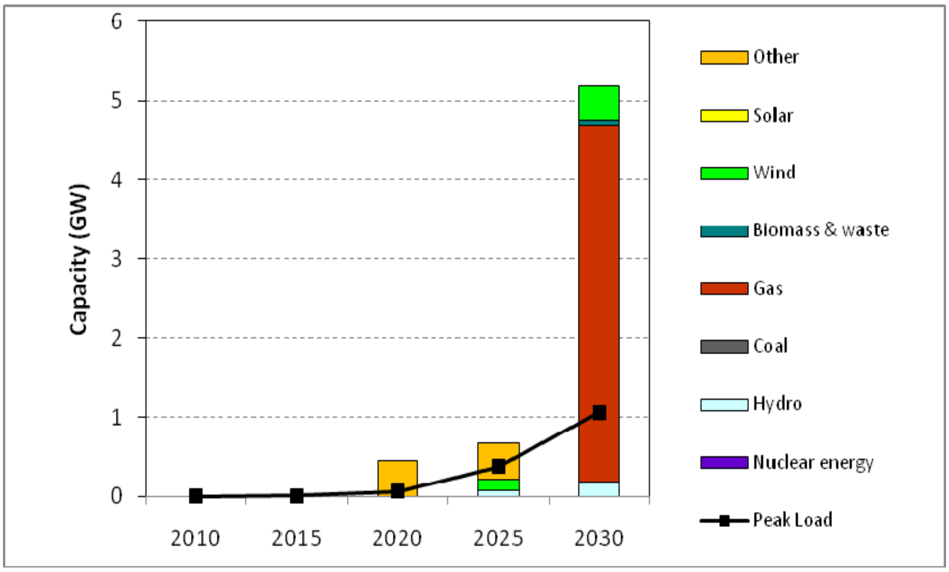
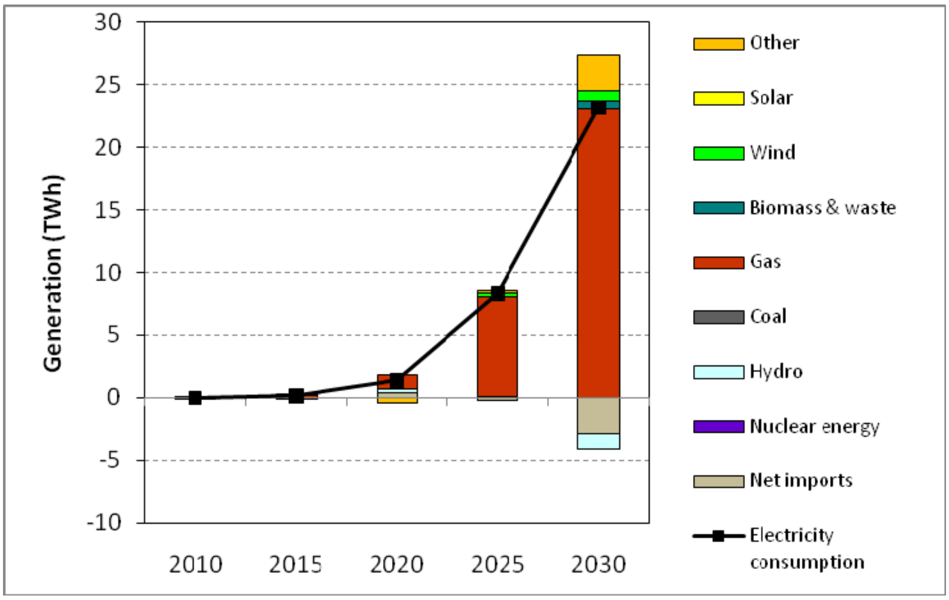



Figure 79 shows differences from Scenario 3 and the Reference Case in the generation mix forecast for the Centre-South Block. This region generates 26 TWh more in sesnistivty 3 than in the Reference Case. As shown in the figure below most of the generation increase is from gas sources. Hydro decreases by more than 1 TWh in 2030.

**Figure 79** **Differences in the Centre-South Block generation mix forecast between Scenario 3 and the Reference Case**




## B.3.5 South-West Block capacity and generation mix

Figure 80 shows differences from Scenario 3 and the Reference Case in the capacity mix forecast for the South-West Block. This region shows very small differences in total capacity between Scenario 3 and the Reference Case. However, in both runs total capacity increases by approximately 40%. Gas makes up 56% of the total difference between Scenario 3 and the Reference Case in 2030. Wind makes 25% of the total difference.

**Figure 80** **Differences in the South-West Block capacity mix forecast between Scenario 3 and the Reference Case**

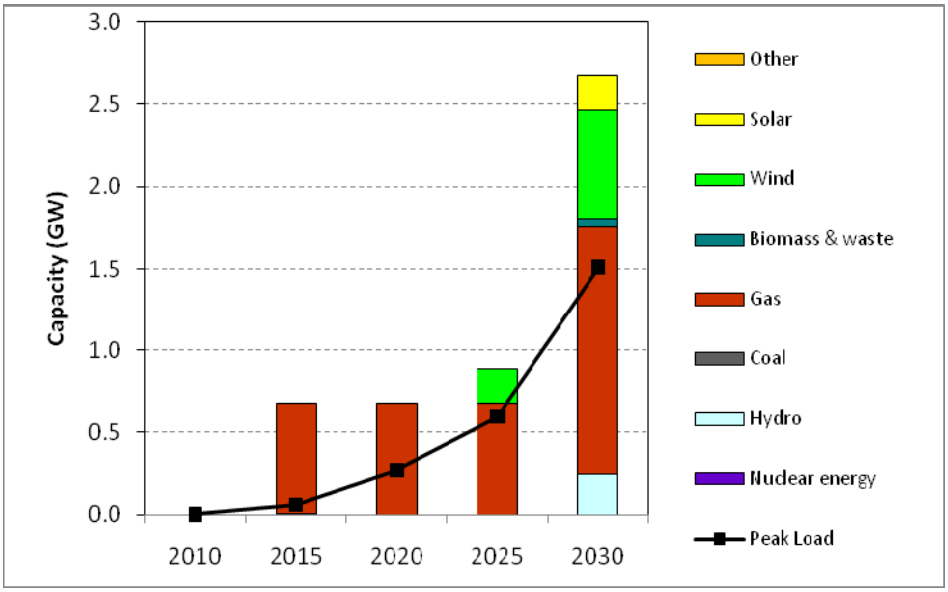
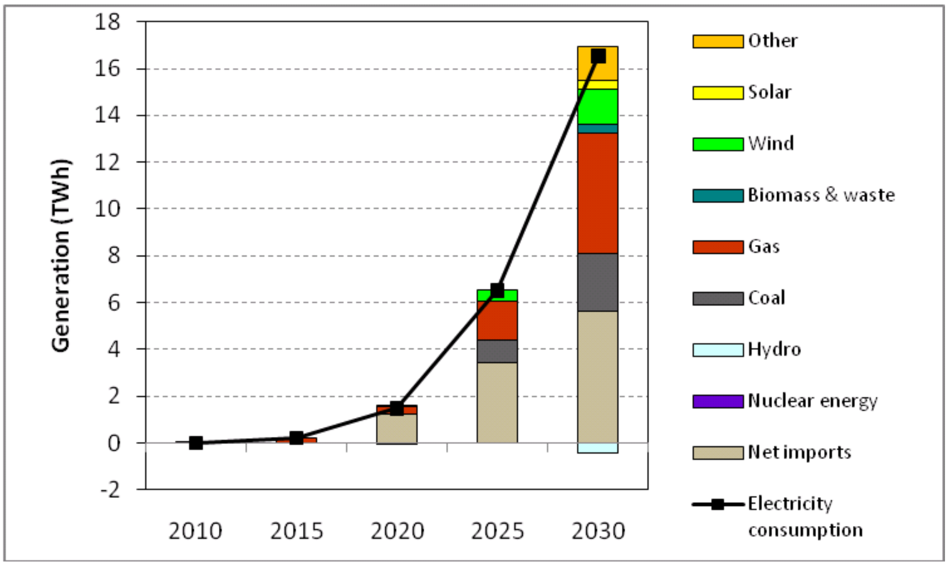


Figure 81 shows differences from Scenario 3 and the Reference Case in the South-West Block generation mix forecast. This region has a total increase of 11 TWh in Scenario 3 from the Reference Case. Most of this is made up by gas fuel sources. Net imports are also significanly higher than in the Reference Case, over 40% higher.

**Figure 81 Differences in the South-West Block generation mix forecast between Scenario 3 and the Reference Case**




### B.3.6 Nordel-Baltics Block capacity and generation mix

Figure 82 shows differences from Scenario 3 and the Reference Case in the capacity mix forecast for the Nordel-Baltics Block. Total capacity in this region increases 16% from 2010 to 2030. Most of this increase is from wind sources. In 2030, this region has 154 MW more capacity than in the Reference Case. Coal increases 608 MW from the Reference Case, the most from all fuel types. Other fuel sources have less capacity in Scenario 3, but in both forecasts these sources decrease overall.

**Figure 82 Differences in the Nordel-Baltics Block capacity mix forecast between Scenario 3 and the Reference Case**

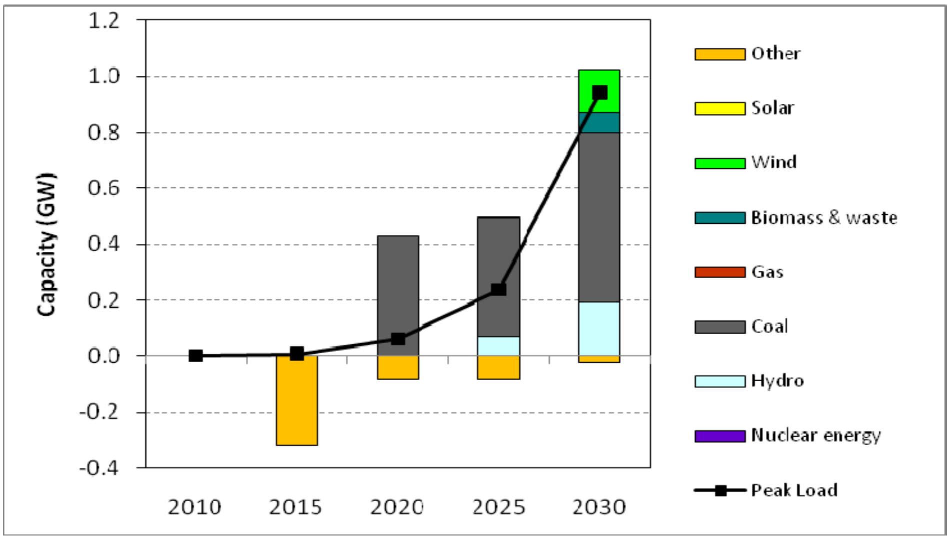
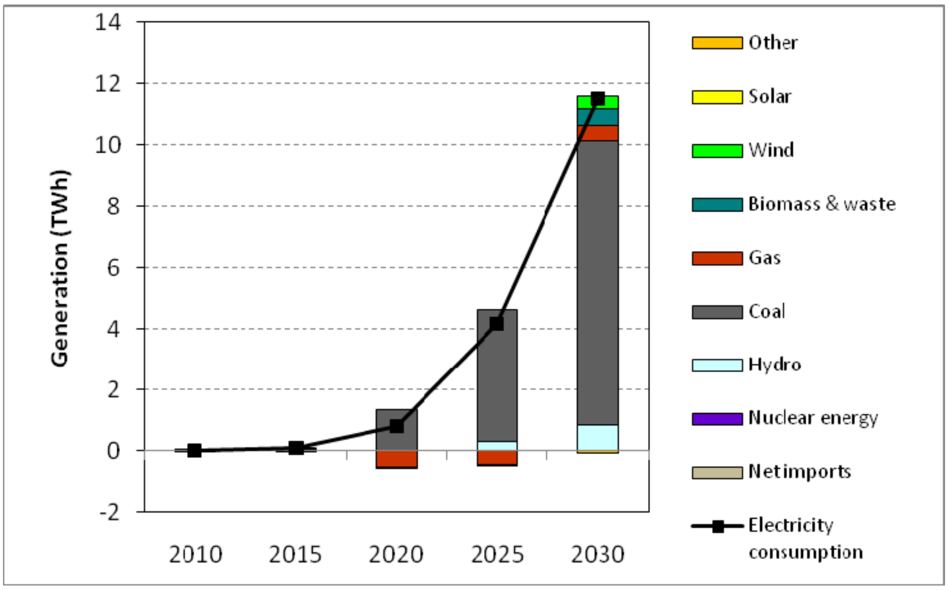


Figure 83 shows differences from Scenario 3 and the Reference Case in the Nordel-Baltics Block generation mix forecast. Coal generation is most different in Scenario 3 than in the refernce case in 2030. By 2030, coal increases generation by approximatly 3 TWh. In the refernce case coal decreases total generation at the end of the forecast by 7 TWh form the beginning. Nuclear generation is the largest component of the region’s generation mix throughout the forecast in both Scenario 3 and the Reference Case.

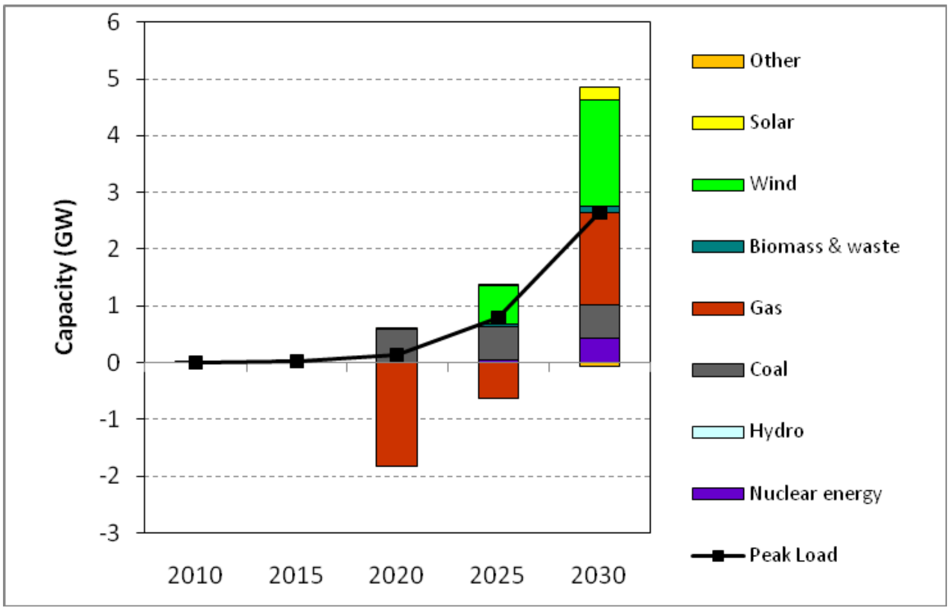
**Figure 83 Differences in the Nordel-Baltics Block generation mix forecast between Scenario 3 and the Reference Case**




## B.3.7 UK-Ireland Block capacity and generation mix

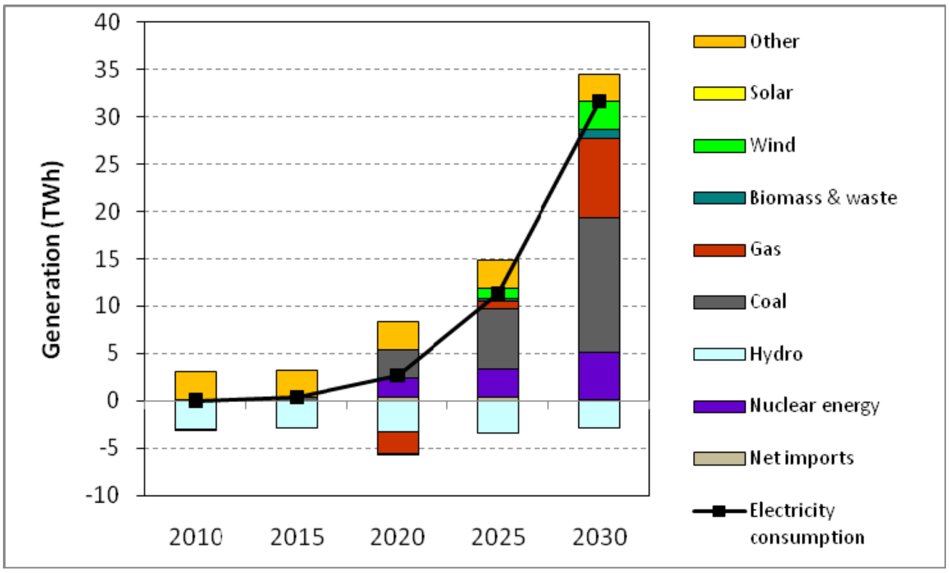
Figure 84 shows differences from Scenario 3 and the Reference Case in the capacity mix forecast for the UK-Ireland Block. Although wind increases the most from the Reference Case by 2 GW by the end of the forecast in 2030, the trend between the two forecasts is largely unchanged. In 2010, renewable capacity was less than 15% of the total capacity in the region in Scenario 3. By 2030, renewable sources contribute more than half the total capacity.

**Figure 84 Differences in the UK-Ireland Block capacity mix forecast between Scenario 3 and the Reference Case**



Total generation in sensitivty 3 for this region increases by more than 30 TWh. Most of the generating differences come from coal and gas sources. The trend for coal and gas generation still resembles the trend in the Reference Case where both continue to decrease throughout the forecast. Figure 85 shows differences from Scenario 3 and the Reference Case in the UK-Ireland Block generation mix forecast.

**Figure 85 Differences in the UK-Ireland Block generation mix forecast between Scenario 3 and the Reference Case**



# Annex C Detailed results of the impact analysis

The main results of the impact analysis are provided in Chapter 3, some of the more detailed results and data are given here.

## C.1 Vehicle sales

Total number of vehicles sold in the EU-27, per scenario and vehicle type.

**Table 17 EU-27 annual car sales, million cars**

| **Reference** | **2010** | **2015** | **2020** | **2025** | **2030** |
|---|---|---|---|---|---|
| Conventional | 13.6 | 18.2 | 17.7 | 16.6 | 18.6 |
| **Scenario 1** | **2010** | **2015** | **2020** | **2025** | **2030** |
| Conventional | 13.6 | 18.0 | 16.8 | 12.2 | 9.0 |
| PHEV | 0.01 | 0.10 | 0.61 | 2.67 | 5.57 |
| EREV | 0.00 | 0.04 | 0.21 | 0.90 | 2.04 |
| FEV | 0.00 | 0.02 | 0.15 | 0.75 | 2.03 |
| **Scenario 2** | **2010** | **2015** | **2020** | **2025** | **2030** |
| Conventional | 13.6 | 18.1 | 17.3 | 14.9 | 15.0 |
| PHEV | 0.02 | 0.08 | 0.32 | 1.09 | 2.43 |
| EREV | 0.00 | 0.02 | 0.09 | 0.30 | 0.64 |
| FEV | 0.00 | 0.01 | 0.06 | 0.26 | 0.58 |
| **Scenario 3** | **2010** | **2015** | **2020** | **2025** | **2030** |
| Conventional | 13.6 | 18.0 | 15.9 | 7.6 | 3.0 |
| PHEV | 0.01 | 0.11 | 1.10 | 5.15 | 8.17 |
| EREV | 0.00 | 0.04 | 0.40 | 2.13 | 4.05 |
| FEV | 0.00 | 0.03 | 0.30 | 1.69 | 3.42 |

The rate at which the EVs enter the market may differ between countries, due to differing government incentives or consumer interest. The effect of the variation of government incentive between countries was modelled as described in Annex D.5.5. Countries with high incentives were Spain, France, Greece, the Netherlands, Poland and the UK. Medium incentive countries were Belgium, Denmark and Sweden. The rest of the EU Member States was considered to have low incentives.
Results of vehicles sales in the various countries, grouped by incentive level, are given in Table 18, Table 19 and Table 20.

**Table 18** **Scenario 1: Vehicle sales per vehicle type in the EU Member State, according to the level of incentives provided for EVs**

| Low incentives | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|
| ICEV | 100% | 99% | 96% | 78% | 54% |
| PHEV | 0% | 0% | 3% | 14% | 27% |
| EREV | 0% | 0% | 1% | 5% | 10% |
| FEV | 0% | 0% | 1% | 4% | 9% |
| **Medium incentives** | | | | | |
| ICEV | 100% | 99% | 95% | 75% | 48% |
| PHEV | 0% | 1% | 3% | 15% | 28% |
| EREV | 0% | 0% | 1% | 5% | 10% |
| FEV | 0% | 0% | 1% | 6% | 14% |
| **High incentives** | | | | | |
| ICEV | 100% | 99% | 93% | 68% | 41% |
| PHEV | 0% | 1% | 4% | 20% | 34% |
| EREV | 0% | 0% | 2% | 7% | 12% |
| FEV | 0% | 0% | 1% | 6% | 13% |

**Table 19** **Scenario 2: Vehicle sales per vehicle type in the EU Member State, according to the level of incentives provided for EVs**

| Low incentives | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|
| ICEV | 99.9% | 99.5% | 97.9% | 92.0% | 83.7% |
| PHEV | 0.1% | 0.4% | 1.4% | 5.4% | 11.0% |
| EREV | 0.0% | 0.1% | 0.4% | 1.5% | 3.0% |
| FEV | 0.0% | 0.1% | 0.3% | 1.1% | 2.4% |
| **Medium incentives** | | | | | |
| ICEV | 99.8% | 99.4% | 97.4% | 90.2% | 80.5% |
| PHEV | 0.1% | 0.4% | 1.7% | 6.1% | 12.2% |
| EREV | 0.0% | 0.1% | 0.5% | 1.6% | 3.2% |
| FEV | 0.0% | 0.1% | 0.5% | 2.0% | 4.1% |
| **High incentives** | | | | | |
| ICEV | 99.8% | 99.1% | 96.6% | 87.5% | 76.0% |
| PHEV | 0.1% | 0.6% | 2.3% | 8.3% | 15.9% |
| EREV | 0.0% | 0.2% | 0.6% | 2.2% | 4.2% |
| FEV | 0.0% | 0.1% | 0.5% | 2.0% | 3.9% |

**Table 20** **Scenario 3: Vehicle sales per vehicle type in the EU Member State, according to the level of incentives provided for EVs**

| Low incentives | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|
| ICEV | 99.9% | 99.2% | 91.8% | 51.0% | 18.5% |
| PHEV | 0.1% | 0.5% | 5.1% | 28.5% | 43.1% |
| EREV | 0.0% | 0.2% | 1.9% | 11.9% | 21.5% |
| FEV | 0.0% | 0.1% | 1.3% | 8.6% | 16.9% |
| **Medium incentives** | | | | | |
| ICEV | 99.9% | 99.1% | 90.4% | 47.9% | 17.4% |
| PHEV | 0.1% | 0.6% | 5.5% | 28.2% | 41.1% |
| EREV | 0.0% | 0.2% | 2.0% | 11.4% | 19.9% |
| FEV | 0.0% | 0.2% | 2.1% | 12.5% | 21.7% |
| **High incentives** | | | | | |
| ICEV | 99.8% | 98.7% | 87.1% | 38.7% | 12.6% |
| PHEV | 0.1% | 0.8% | 7.8% | 35.0% | 45.4% |
| EREV | 0.0% | 0.3% | 2.8% | 14.3% | 22.3% |
| FEV | 0.0% | 0.2% | 2.3% | 12.0% | 19.8% |

Vehicle sales also differ per vehicle category (small, medium and large). These results are shown in the following three tables. Of course, this distribution is quite strongly dependent on actual costs and policies, and developments regarding range, charging points, etc.

**Table 21** **Scenario 1: Vehicle sales per vehicle size category in the EU Member State (in % of total sales in that segment)**

| **Small vehicles** | **2010** | **2015** | **2020** | **2025** | **2030** |
|---|---|---|---|---|---|
| ICEV | 100% | 100% | 97% | 83% | 60% |
| PHEV | 0% | 0% | 2% | 10% | 22% |
| EREV | 0% | 0% | 1% | 4% | 10% |
| FEV | 0% | 0% | 0% | 2% | 7% |
| **Medium vehicles** | | | | | |
| ICEV | 100% | 99% | 93% | 70% | 43% |
| PHEV | 0% | 1% | 4% | 19% | 33% |
| EREV | 0% | 0% | 1% | 6% | 11% |
| FEV | 0% | 0% | 1% | 5% | 12% |
| **Large vehicles** | | | | | |
| ICEV | 100% | 99% | 92% | 65% | 37% |
| PHEV | 0% | 1% | 5% | 21% | 35% |
| EREV | 0% | 0% | 2% | 7% | 12% |
| FEV | 0% | 0% | 1% | 7% | 16% |

**Table 22** **Scenario 2: Vehicle sales per vehicle size category in the EU Member State (in % of total sales in that segment)**

| **Small vehicles** | **2010** | **2015** | **2020** | **2025** | **2030** |
|---|---|---|---|---|---|
| ICEV | 100% | 100% | 99% | 95% | 89% |
| PHEV | 0% | 0% | 1% | 3% | 8% |
| EREV | 0% | 0% | 0% | 1% | 2% |
| FEV | 0% | 0% | 0% | 1% | 1% |
| **Medium vehicles** | | | | | |
| ICEV | 100% | 99% | 97% | 88% | 77% |
| PHEV | 0% | 1% | 2% | 8% | 15% |
| EREV | 0% | 0% | 1% | 2% | 4% |
| FEV | 0% | 0% | 0% | 2% | 4% |
| **Large vehicles** | | | | | |
| ICEV | 100% | 99% | 96% | 86% | 73% |
| PHEV | 0% | 1% | 3% | 9% | 18% |
| EREV | 0% | 0% | 1% | 2% | 5% |
| FEV | 0% | 0% | 1% | 2% | 5% |

Table 23 **Scenario 3: Vehicle sales per vehicle size category in the EU Member State (in % of total sales in that segment)**

| Small vehicles | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|
| ICEV | 100% | 100% | 94% | 55% | 19% |
| PHEV | 0% | 0% | 4% | 24% | 38% |
| EREV | 0% | 0% | 2% | 12% | 22% |
| FEV | 0% | 0% | 1% | 9% | 21% |
| **Medium vehicles** | | | | | |
| ICEV | 100% | 99% | 88% | 42% | 15% |
| PHEV | 0% | 1% | 7% | 34% | 46% |
| EREV | 0% | 0% | 2% | 13% | 21% |
| FEV | 0% | 0% | 2% | 11% | 18% |
| **Large vehicles** | | | | | |
| ICEV | 100% | 99% | 86% | 38% | 13% |
| PHEV | 0% | 1% | 9% | 37% | 50% |
| EREV | 0% | 0% | 3% | 15% | 24% |
| FEV | 0% | 0% | 2% | 9% | 12% |

## C.2 Car fleet

Table 24 **EU-27 car fleet, million cars. The Reference Case is TREMOVE version 3.3.1 alt**

| Reference | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|
| Conventional | 224 | 247 | 262 | 273 | 287 |
| **Scenario 1** | **2010** | **2015** | **2020** | **2025** | **2030** |
| Conventional | 224 | 246 | 259 | 257 | 235 |
| PHEV | 0.0 | 0.3 | 2.1 | 10.3 | 30.9 |
| EREV | 0.0 | 0.1 | 0.7 | 3.5 | 10.9 |
| FEV | 0.0 | 0.1 | 0.5 | 2.7 | 9.7 |
| **Scenario 2** | **2010** | **2015** | **2020** | **2025** | **2030** |
| Conventional | 224 | 246 | 260 | 266 | 266 |
| PHEV | 0.0 | 0.3 | 1.3 | 4.8 | 13.6 |
| EREV | 0.0 | 0.1 | 0.4 | 1.3 | 3.7 |
| FEV | 0.0 | 0.0 | 0.2 | 1.0 | 3.1 |
| **Scenario 3** | **2010** | **2015** | **2020** | **2025** | **2030** |
| Conventional | 224 | 246 | 257 | 241 | 193 |
| PHEV | 0.0 | 0.3 | 3.4 | 19.0 | 52.3 |
| EREV | 0.0 | 0.1 | 1.2 | 7.6 | 23.0 |
| FEV | 0.0 | 0.1 | 0.9 | 5.9 | 18.7 |

**Table 25 Fuel and electricity demand of the passenger car fleet in the EU-27 (in PJ/year)**

| Reference | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|
| Petrol | 3895 | 3667 | 3545 | 3589 | 3627 |
| Diesel | 4164 | 4664 | 4566 | 4282 | 4038 |
| Total EU-27 | 8059 | 8331 | 8111 | 7871 | 7665 |
| **Scenario 1** | **2010** | **2015** | **2020** | **2025** | **2030** |
| Electricity | 0 | 5 | 28 | 138 | 415 |
| Petrol | 3895 | 3663 | 3512 | 3407 | 3092 |
| Diesel | 4163 | 4656 | 4521 | 4061 | 3411 |
| Total EU-27 | 8059 | 8324 | 8061 | 7605 | 6919 |
| **Scenario 2** | **2010** | **2015** | **2020** | **2025** | **2030** |
| Electricity | 0 | 4 | 17 | 60 | 165 |
| Petrol | 3895 | 3432 | 3049 | 2951 | 2771 |
| Diesel | 4163 | 4520 | 4246 | 3794 | 3303 |
| Total EU-27 | 8059 | 7956 | 7311 | 6805 | 6238 |
| **Scenario 3** | **2010** | **2015** | **2020** | **2025** | **2030** |
| Electricity | 0 | 6 | 48 | 272 | 742 |
| Petrol | 3895 | 3662 | 3489 | 3229 | 2652 |
| Diesel | 4163 | 4655 | 4494 | 3880 | 2982 |
| Total EU-27 | 8059 | 8323 | 8031 | 7382 | 6376 |

## C.3 EVs in urban regions

The model distinguishes between urban and non-urban consumers, and assumes that the first group is somewhat less sensitive to driving range restrictions than the latter. This results in different uptake of the various types of EVs in these consumer groups, especially regarding full electric vehicles with clearly less driving range than the other type of cars (see the 'Range' input data of the three scenarios in Table 10, Table 14 and Table 16 respectively).

The resulting shares of urban drivers in the total sales of the EV categories is given in Table 26. These results reflect the assumption stated above: the FEVs are mainly bought by urban drivers. Between 2010 and 2020, urban drivers are responsible for about 70-80% of the FEVs sales. The rest (20-30%) are sold to non-urban consumers. As the ranges of the FEVs are assumed to increase over time, the share of urban buyers of these cars decrease over time – not because urban buyers become less interested but rather because the vehicles become more attractive to other consumers as well. This effect is further enhanced in Scenario 3, where it is assumed that the availability of charging points and fast charging increases over time, to a level where range is hardly an issue anymore in 2030.

The sales of PHEVs and EREVs are distributed more evenly between urban and non-urban consumers: according to these results the urban consumers have a share of somewhat more than 50% in the sales of these cars, where especially PHEV sales seem to shift more to non-urban consumers during the time frame studied here.

**Table 26 Average share of urban drivers in the total sales of EVs**

| Scenario 1 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|
| PHEV | 57% | 55% | 52% | 49% | 48% |
| EREV | 57% | 57% | 57% | 56% | 55% |
| FEV | 78% | 77% | 74% | 69% | 65% |
| **Scenario 2** | | | | | |
| PHEV | 58% | 57% | 57% | 56% | 55% |
| EREV | 57% | 57% | 57% | 56% | 55% |
| FEV | 79% | 78% | 76% | 71% | 70% |
| **Scenario 3** | | | | | |
| PHEV | 57% | 55% | 52% | 48% | 49% |
| EREV | 57% | 57% | 57% | 54% | 51% |
| FEV | 78% | 77% | 71% | 63% | 53% |

# Annex D Modelling methodology: MELVIN

## D.1 Introduction

For the scenario impact analysis of this project, a calculation model was developed with which the EV market uptake could be calculated, as well as the impact on electricity demand, transport emissions and various cost. The methodologies used for these calculations are described in this Annex.

The model was named MELVIN, an acronym for Model for Electric Vehicles Impact and Numbers.

For the modelling of the impacts on the power sector, the IPM model was used which is described in Deliverable 3.

## D.2 Outline of the scenario modelling tool

### D.2.1 Introduction

The main emphasis of the market uptake model is on the comparison of Total Cost of Ownership (TCO) of the various types of EVs versus ICEVs. This is one of the main criteria on which consumers will base their choice of vehicle on.

However, several other considerations may also play a role in consumer choice (and therefore in the model), such as driving range, a short-term cost comparison (e.g. 3 year TCO) and 'green image'. As different types of user will take different considerations into account the model can distinguish between urban and non-urban users, and innovators and laggards.

### D.2.2 Desired outcome

The desired outcome of the modelling tool are several scenarios, each with its own characteristic composition of the vehicle stock and related energy demand, emissions, etc. These scenarios are constructed to compare with the Reference Scenario in which no EVs are sold.

The following list summarises the final outcome and can be split up by country and for the EU in total. The time span of the scenarios is 2010 until 2030, the outcomes are generated in 5-year intervals.

1. Vehicle stock; categorised by vehicle category, vehicle type and fuel type.
2. Vehicle kilometres; categorised by vehicle category, vehicle type and fuel type.
3. Energy demand, distinguishing petrol, diesel and electricity, in PJ.

With this data (vehicle stock, kilometres and energy demand) and the input variables (described in the next paragraph) the environmental and economic analysis is performed. These analyses are derived from the vehicle stock, vehicle kilometres and the energy demand, meaning that no feedback loops are taken up in the model.

### D.2.3 Input and key variables

The model is set up to first calculate on the market uptake scenarios of PHEVs, EREVs and EVs, i.e. it uses a large set of input parameters to derive sales shares of each type of vehicle. The Reference Scenario is based on TREMOVE 3.3., which is a forecast of the EU car sales and fleet composition given current policies. This TREMOVE scenario does not contain any EVs.

The uptake scenarios depend on the following variables:

1. Vehicle catalogue price.
2. Vehicle taxation (i.e. net effect of fiscal policies related to passenger cars).
3. Vehicle maintenance costs.
4. Vehicle insurance costs.
5. Vehicle kilometers.
6. Fuel price (incl. taxes).
7. Electricity price (incl. taxes).
8. Vehicle lifetime.
9. Total driving range (on full battery and/or fuel tank).
10. Fuel and/or electricity use per kilometer.
11. Share of kilometers driven by the electric drive train only per vehicle type (relevant for PHEV and EREV only).
12. Battery life cycle costs.
    - a Battery lifetime.
    - b Battery purchase costs.
    - c Battery resale value.
    - d Battery maintenance costs.
13. Green image of the vehicle[27].

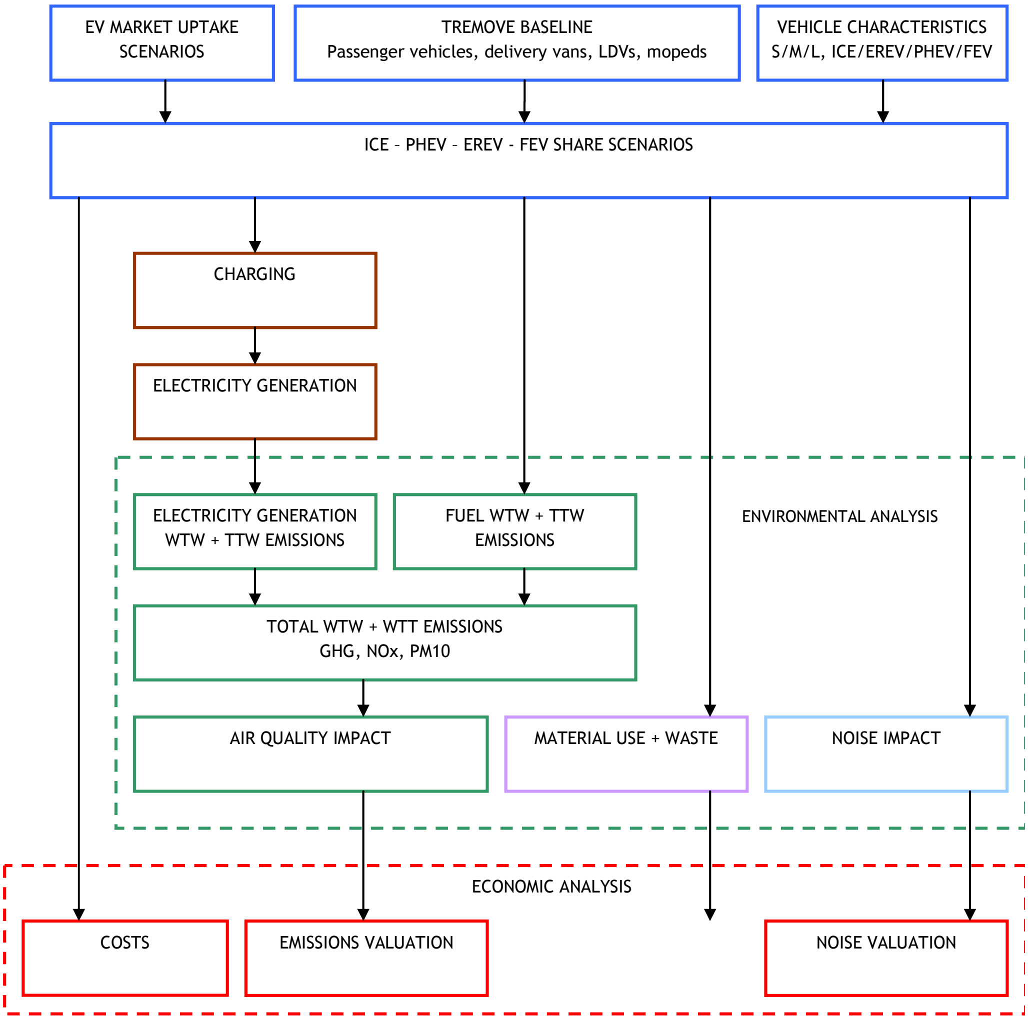
The key variables turn out to be the vehicle catalogue price, government taxation and fuel prices, since these comprise a large share of the TCO. The most common taxes related to passenger cars are vehicle registration and circulation taxes, but also value added tax (VAT), company car taxation and, in some cases, subsidies for specific technologies. Government taxes also impact on fuel and electricity prices, through VAT and excise duties. Electricity costs also include cost of $CO_2$ emissions, via the ETS system.

[27] This is a subjective criteria included here because it is assumed that especially the user groups with 'innovators' will be inclined to choose a vehicle with a greener image.

## D.3 Tool overview

An overview of the modelling tool, starting from market uptake modelling through the impact analysis, is provided in the following graph (Figure 86).

**Figure 86 Overview of the modelling tool and consecutive scenario impact analysis**



## D.4 Reference Scenario

This section briefly describes how the scenario calculations are based on the TREMOVE 3.3. Reference Scenario. From TREMOVE, a set of vehicle characteristics is subtracted to build the baseline scenario. The other scenarios are built by replacing ICEVs by Electric Vehicles and accompanied characteristics.

### D.4.1 Transport baseline data

Tremove data from version 3.3 is used to define the baseline transport demand (composition of the car fleet and average annual vehicle kilometres), emissions and costs for conventional vehicles. The EV scenarios take these data as a starting point for 2010. From that year onwards, part of the ICEV sales in TREMOVE may be replaced by PHEVs, EREVs and FEVs, according to the consumer choice model in MELVIN. This will gradually modify the composition of the EU car fleet of the baseline.

The Reference Scenario is the vehicle stock, vehicle kilometres and energy use for the years 2010-2030. Data are given per:

Fuel type:
1. Gasoline.
2. Diesel.

Vehicle type:
1. Small (< 1.4 L).
2. Medium (1.4 L-2.0 L).
3. Large (>2.0 L).

Region:
1. Metropolitan.
2. Urban.
3. Non urban.

This means that each vehicle type has its own data set, in total 2 x 3 x 3 = 12 different sets of vehicle data are used. The vehicle data per vehicle are the vehicle kilometres, energy use and emission factors.

The MELVIN output uses the same basic characteristics as these ICEV baseline data. The total number of vehicles and the annual vehicle kilometres are taken to be constant in all scenarios, and equal to the TREMOVE baseline.

### D.4.2 Electricity sector baseline data

The electricity Reference Scenario is described in Deliverable 3.

### D.4.3 Emission baseline data

TREMOVE 3.3 provides the following emissions for ICEVs:
1. WTT and TTW $CO_2$ exhaust.
2. WTT and TTW $NO_x$ exhaust.
3. WTT and TTW $PM_{10}$ exhaust.

These can be split up per vehicle category, vehicle type, fuel type and region. From this categorisation WTT and TTW emission factors for all types of vehicles for the years 2010-2030 can be defined.

$CO_2$ emission factors are expressed in ton/PJ and $NO_x$ and $PM_{10}$ emission factors are expressed in gram/vkm. Emissions from electricity use are all expressed in kton/PJ or ton/PJ since emissions per vkm are the same for EVs.

The emission factors are assumed to be homogeneous in the EU-27. The country-specific emissions difference within the EU-27 is based on the number of vehicles and kilometers/year per vehicle type. These two aspects differ per country.

TREMOVE also provides emission factors for electricity, but these are not used in this assessment, as a separate impact analysis on the electricity sector is carried out.

**Table 1 Emissions factors fuel and electricity**

| $CO_2$ emission factor fuel | | | kton/PJ |
|---|---|---|---|
| Conventional | Diesel | Small | 85,3 |
| | Diesel | Medium | 85,3 |
| | Diesel | Large | 85,3 |
| | Petrol | Small | 83,1 |
| | Petrol | Medium | 83,1 |
| | Petrol | Large | 83,1 |

| $NO_x$ emission factor fuel | | gram/vkm | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| Conventional | Diesel | Small | 0,466 | 0,3465 | 0,227 | 0,179 | 0,131 |
| | Diesel | Medium | 0,504 | 0,37 | 0,236 | 0,1835 | 0,131 |
| | Diesel | Large | 0,513 | 0,372 | 0,231 | 0,18 | 0,129 |
| | Petrol | Small | 0,22 | 0,131 | 0,042 | 0,0345 | 0,027 |
| | Petrol | Medium | 0,239 | 0,141 | 0,043 | 0,035 | 0,027 |
| | Petrol | Large | 0,198 | 0,1175 | 0,037 | 0,0315 | 0,026 |

| $PM_{10}$ emission factor fuel | | gram/vkm | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| Conventional | Diesel | Small | 0,023 | 0,0155 | 0,008 | 0,0065 | 0,005 |
| | Diesel | Medium | 0,03 | 0,0195 | 0,009 | 0,007 | 0,005 |
| | Diesel | Large | 0,031 | 0,02 | 0,009 | 0,007 | 0,005 |
| | Petrol | Small | 0,001 | 0,001 | 0,001 | 0,001 | 0,001 |
| | Petrol | Medium | 0,001 | 0,001 | 0,001 | 0,001 | 0,001 |
| | Petrol | Large | 0,0014 | 0,00125 | 0,0011 | 0,0011 | 0,0011 |

## D.5 EV uptake modelling

### D.5.1 Introduction

Future PHEV, EREV and FEV shares are dependent on numerous factors, varying from technical performance characteristics and cost to future behavioural changes and fiscal policies.

Market uptake is primarily modelled on the basis of quantitative technical and costs data and expected technical and economical developments of ICEVs, PHEVs, EREVs and FEVs. The future consumer demand is based on purchase drivers and cross elasticities of demand for each purchase driver. Cross elasticities describe the impact of a certain driver (for example, the TCO of a FEV compared to that of an ICEV) on the demand (in the example, on FEV demand).

Cross elasticities are differentiated for four categories of innovation adopters, roughly based of the Rogers innovation diffusion theory. Rogers' theory distinguishes five categories of adopters:

- Innovators.
- Early adopters.
- Early majority.
- Late majority.
- Laggards.

For this model a somewhat different distinction is made since we expect that the local and regional component of driving strongly influences the purchase decision regarding at least some categories of EVs. The adopters used in this model are:

- Urban innovators (5%).
- Urban laggards (45%).
- Long distance innovators (5%).
- Long distance laggards (45%).

The reason to apply this distinction is for the fact that both the PHEVs/EREVs and FEVs producers are mainly targeting their products on the first group, and various governments target their policies at innovators and early adopters as well. Their limited electric driving ranges make them inherently more suitable for urban drivers than for long distance drivers, at least in the short to medium term.

In this market uptake model the Total Cost of Ownership (TCO) is the leading purchase driver, this determines a large share of the market uptake. Other purchase drivers, such as specific performance characteristics (like range) can also have a positive or negative influence on the market uptake shares.

### D.5.2 The PHEV, EREV and FEV categories in the tool

6 PHEV, 6 EREV, 3 FEV and 6 ICEV models are defined and used in the market uptake model. Each vehicle configuration has its own specific costs and performance characteristics.

**Table 27 Vehicle categories in the model**

| Vehicle # | Fuel | Size | Configuration |
|---|---|---|---|
| 1 | Petrol | Small | PHEV |
| 2 | Petrol | Medium | PHEV |
| 3 | Petrol | Large | PHEV |
| 4 | Diesel | Small | PHEV |
| 5 | Diesel | Medium | PHEV |
| 6 | Diesel | Large | PHEV |
| 7 | Petrol | Small | EREV |
| 8 | Petrol | Medium | EREV |
| 9 | Petrol | Large | EREV |
| 10 | Diesel | Small | EREV |
| 11 | Diesel | Medium | EREV |
| 12 | Diesel | Large | EREV |
| 13 | - | Small | FEV |
| 14 | - | Medium | FEV |
| 15 | - | Large | FEV |
| 16 | Petrol | Small | ICEV |
| 17 | Petrol | Medium | ICEV |
| 18 | Petrol | Large | ICEV |
| 19 | Diesel | Small | ICEV |
| 20 | Diesel | Medium | ICEV |
| 21 | Diesel | Large | ICEV |

### D.5.3 Purchase driving factors

The purchase driving factors considered in this model are:

- Total Cost of Ownership over the vehicle lifetime (TCO).
- Short-term TCO (3 years TCO, where purchase costs are depreciated over 3 years instead of over the whole lifetime).
- Driving range (with full batteries and fuel tanks).
- Image.

The cross elasticity of demand is defined as the relative increase/decrease in demand for ICEVs divided by the relative increase/decrease of the price (or characteristic) of a PHEV, EREV or a FEV.

$$E_{A,B} = \frac{\text{\% change in demand for A}}{\text{\% change in price/characteristic of B}}$$

Where A stands for ICEVs and B stands for PHEV, EREV and FEV, dependent on the vehicle category *E* applies to.
Important to note is that this theory is only valid when A and B can be substituted, and this forms one important assumption in this model.

Different price elasticities were set for the various purchase driving factors, and they were also varied between user groups. This allowed a form of weighing of these factors: a higher price elasticity means a stronger impact on the purchase decision (i.e. market share). The values could also be varied

between scenarios, to vary the responses to the factors. For example, in Scenario 3 it is assumed that in the longer term, fast charging or battery switch systems become available throughout the EU. This will significantly reduce the impact of driving range on consumer choice. Improvements in charging infrastructure, albeit less drastic than in Scenario 3, were also assumed in Scenario 1.
The elasticities were determined by CE Delft, based on expert judgement and (limited) information on expected consumer responses.

**Table 28 Price elasticities used in Scenario 1**

| | Annual TCO | 3 year annual TCO | Range | Image |
|---|---|---|---|---|
| Urban innovator | -4 | -0.5 | 0.3 | 1 |
| Urban laggards | -5 | -2 | 0.8 (reducing to 0.4 in 2030) | 0.2 |
| Long distance innovator | -4 | -0.5 | 1 (reducing to 0.6 in 2030) | 1 |
| Long distance laggard | -5 | -2 | 2 (reducing to 1.6 in 2030) | 0.2 |

**Table 29 Price elasticities used in Scenario 2**

| | Annual TCO | 3 year annual TCO | Range | Image |
|---|---|---|---|---|
| Urban innovator | -4 | -0.5 | 0.3 | 1 |
| Urban laggards | -5 | -2 | 0.8 | 0.2 |
| Long distance innovator | -4 | -0.5 | 1 | 1 |
| Long distance laggard | -5 | -2 | 2 | 0.2 |

**Table 30 Price elasticities used in Scenario 3**

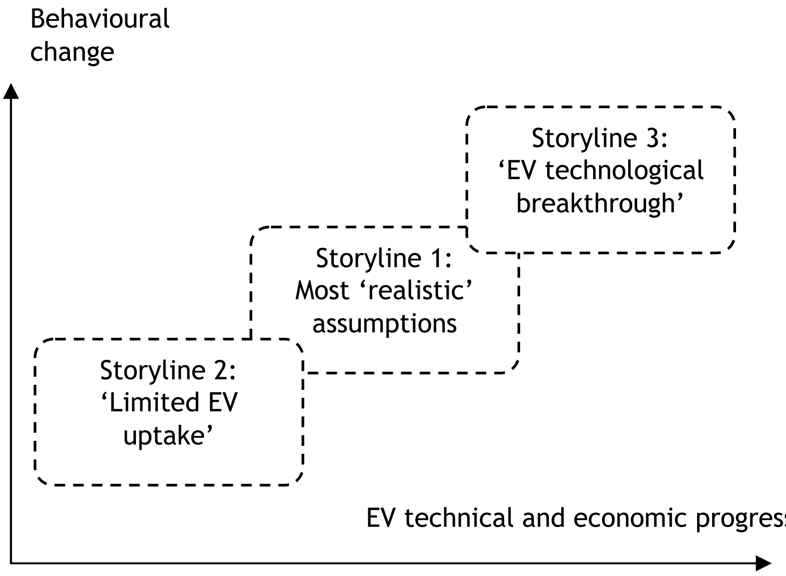
| | Annual TCO | 3 year annual TCO | Range | Image |
|---|---|---|---|---|
| Urban innovator | -4 | -0.5 | 0.3 (reducing to 0.1 in 2030) | 1 |
| Urban laggards | -5 | -2 | 0.8 (reducing to 0.2 in 2030) | 0.2 |
| Long distance innovator | -4 | -0.5 | 1 (reducing to 0.2 in 2030) | 1 |
| Long distance laggard | -5 | -2 | 2 (reducing to 0.5 in 2030) | 0.2 |

Apart from these consumer related factors, especially in the short to medium term, EV uptake will also be limited by limited battery and vehicle production capacities.

### D.5.4 Future storylines

The future storylines method is basically a top-down approach in which scenarios are first defined using various qualitative storylines. From these, quantitative assumptions and input values are derived. These storylines differ on assumptions on future 'behavioural change' of consumers and 'technical and economic progress' of ICEVs, PHEVs, EREVs and FEVs, as outlined in the graph below (Figure 87). The storylines are given in Chapter 2.

**Figure 87 A schematic overview of the three scenarios**




### D.5.5 Government taxes and incentives

In several EU-27 countries, taxes and incentives have a distinctive influence on the cost of ownership of vehicles. For example in Denmark the VRT can be more than 40% of the vehicle catalogue price. In Germany this is 0%. On top of that the annual circulation or road tax is variable for every country as well, and no distinctive correlation found between the height of the VRT and the annual circulation tax. The value added taxes on vehicles do not show these high deviations between countries. VAT varies for most countries between 18 and 22%, with some extremes of 15 and 25%.

In an increasing number of EU Member States, the VRT and circulation tax are differentiated on the basis of $CO_2$ emissions of the vehicles (on official drive cycle test emissions). Again, every country has its own differentiating systematic, although the common factor is that the bigger the vehicle (which implies higher $CO_2$ emissions), the higher the vehicle registration and circulation taxes.

To incorporate all these differences in MELVIN we used average tax values. All country tax regimes have been analysed [28] and classified on the basis of low, medium and high VRT; low, medium and high circulation tax and lastly for low, medium and high EV stimulation.

[28] Source: http://ec.europa.eu/taxation_customs/taxinv/search.do;jsessionid =NhQltq2Q9Xk1LHBMqGNZY2yPtXT91yJF2szbG18KMKlQFn4GnF77!1957097960.

The advantage of this classification is that it represents an average tax regime for the whole EU-27. The disadvantage is that it is not a weighted average, i.e. the tax regime of a small country (few vehicles) has the same impact on the average as the tax regime from a large country. The VRT tax values are expressed as percentages of the catalogue price and the annual circulation tax as a monetary value. All taxes differ per vehicle category and size.

Three tax regimes were created, and classified on the basis of the FEV, PHEV and EREV stimulation, and the 27 EU Member States were divided into these three tax regimes according to their current level of taxes and resulting EV incentives. On top of this, the stimulation is assumed to decrease over time as it can be expected that incentives will be reduced if the share of EVs increases (to keep government revenues constant). High EV stimulation in 2010-2020 becomes medium stimulation in 2020-2030, and this also applies to medium (2010-2020) -> low (2020-2030) EV stimulation.
This results in the tax overview as shown in the following tables (Table 31, Table 32 en Table 33), each representing one tax regime.

**Table 31 VRT and Annual circulation tax for the High Incentive regime: high EV and high PHEV and EREV stimulation**

| VRT | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|
| ICEV petrol small | 7% | 7% | 1% | 1% | 1% |
| ICEV petrol medium | 13% | 13% | 2% | 2% | 2% |
| ICEV petrol large | 24% | 24% | 8% | 8% | 8% |
| ICEV diesel small | 7% | 7% | 1% | 1% | 1% |
| ICEV diesel medium | 13% | 13% | 2% | 2% | 2% |
| ICEV diesel large | 24% | 24% | 8% | 8% | 8% |
| PHEV petrol small | -7% | -7% | 0% | 0% | 0% |
| PHEV petrol medium | -4% | -4% | 1% | 1% | 1% |
| PHEV petrol large | 4% | 4% | 3% | 3% | 3% |
| PHEV diesel small | -7% | -7% | 0% | 0% | 0% |
| PHEV diesel medium | -4% | -4% | 1% | 1% | 1% |
| PHEV diesel large | 4% | 4% | 3% | 3% | 3% |
| EREV petrol small | -7% | -7% | 0% | 0% | 0% |
| EREV petrol medium | -4% | -4% | 1% | 1% | 1% |
| EREV petrol large | 4% | 4% | 3% | 3% | 3% |
| EREV diesel small | -7% | -7% | 0% | 0% | 0% |
| EREV diesel medium | -4% | -4% | 1% | 1% | 1% |
| EREV diesel large | 4% | 4% | 3% | 3% | 3% |
| FEV small | -10% | -10% | -13% | -13% | -13% |
| FEV medium | -8% | -8% | -12% | -12% | -12% |
| FEV large | -2% | -2% | -6% | -6% | -6% |
| **Annual circulation tax** | **2010** | **2015** | **2020** | **2025** | **2030** |
| ICEV petrol small | 108 | 108 | 71 | 71 | 71 |
| ICEV petrol medium | 142 | 142 | 206 | 206 | 206 |
| ICEV petrol large | 183 | 183 | 836 | 836 | 836 |
| ICEV diesel small | 108 | 108 | 71 | 71 | 71 |
| ICEV diesel medium | 142 | 142 | 206 | 206 | 206 |
| ICEV diesel large | 183 | 183 | 836 | 836 | 836 |
| PHEV petrol small | 8 | 8 | 50 | 50 | 50 |
| PHEV petrol medium | 17 | 17 | 183 | 183 | 183 |
| PHEV petrol large | 33 | 33 | 651 | 651 | 651 |
| PHEV diesel small | 8 | 8 | 50 | 50 | 50 |
| PHEV diesel medium | 17 | 17 | 183 | 183 | 183 |
| PHEV diesel large | 33 | 33 | 651 | 651 | 651 |

| Annual circulation tax | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|
| EREV petrol small | 8 | 8 | 50 | 50 | 50 |
| EREV petrol medium | 17 | 17 | 183 | 183 | 183 |
| EREV petrol large | 33 | 33 | 651 | 651 | 651 |
| EREV diesel small | 8 | 8 | 50 | 50 | 50 |
| EREV diesel medium | 17 | 17 | 183 | 183 | 183 |
| EREV diesel large | 33 | 33 | 651 | 651 | 651 |
| FEV small | 8 | 8 | 50 | 50 | 50 |
| FEV medium | 17 | 17 | 150 | 150 | 150 |
| FEV large | 33 | 33 | 600 | 600 | 600 |

**Table 32 VRT and Annual circulation tax for the Medium Incentive regime: high EV and medium/low PHEV and EREV stimulation**

| VRT | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|
| ICEV petrol small | 1% | 1% | 6% | 6% | 6% |
| ICEV petrol medium | 2% | 2% | 7% | 7% | 7% |
| ICEV petrol large | 8% | 8% | 13% | 13% | 13% |
| ICEV diesel small | 1% | 1% | 6% | 6% | 6% |
| ICEV diesel medium | 2% | 2% | 7% | 7% | 7% |
| ICEV diesel large | 8% | 8% | 13% | 13% | 13% |
| PHEV petrol small | 0% | 0% | 1% | 1% | 1% |
| PHEV petrol medium | 1% | 1% | 1% | 1% | 1% |
| PHEV petrol large | 3% | 3% | 4% | 4% | 4% |
| PHEV diesel small | 0% | 0% | 1% | 1% | 1% |
| PHEV diesel medium | 1% | 1% | 1% | 1% | 1% |
| PHEV diesel large | 3% | 3% | 4% | 4% | 4% |
| EREV petrol small | 0% | 0% | 1% | 1% | 1% |
| EREV petrol medium | 1% | 1% | 1% | 1% | 1% |
| EREV petrol large | 3% | 3% | 4% | 4% | 4% |
| EREV diesel small | 0% | 0% | 1% | 1% | 1% |
| EREV diesel medium | 1% | 1% | 1% | 1% | 1% |
| EREV diesel large | 3% | 3% | 4% | 4% | 4% |
| FEV small | -13% | -13% | 0% | 0% | 0% |
| FEV medium | -12% | -12% | 1% | 1% | 1% |
| FEV large | -6% | -6% | 3% | 3% | 3% |
| **Annual circulation tax** | **2010** | **2015** | **2020** | **2025** | **2030** |
| ICEV petrol small | 71 | 71 | 30 | 30 | 30 |
| ICEV petrol medium | 206 | 206 | 67 | 67 | 67 |
| ICEV petrol large | 836 | 836 | 351 | 351 | 351 |
| ICEV diesel small | 71 | 71 | 30 | 30 | 30 |
| ICEV diesel medium | 206 | 206 | 67 | 67 | 67 |
| ICEV diesel large | 836 | 836 | 351 | 351 | 351 |
| PHEV petrol small | 50 | 50 | 25 | 25 | 25 |
| PHEV petrol medium | 183 | 183 | 57 | 57 | 57 |
| PHEV petrol large | 651 | 651 | 319 | 319 | 319 |
| PHEV diesel small | 50 | 50 | 25 | 25 | 25 |
| PHEV diesel medium | 183 | 183 | 57 | 57 | 57 |
| PHEV diesel large | 651 | 651 | 319 | 319 | 319 |
| EREV petrol small | 50 | 50 | 25 | 25 | 25 |
| EREV petrol medium | 183 | 183 | 57 | 57 | 57 |
| EREV petrol large | 651 | 651 | 319 | 319 | 319 |
| EREV diesel small | 50 | 50 | 25 | 25 | 25 |
| EREV diesel medium | 183 | 183 | 57 | 57 | 57 |
| EREV diesel large | 651 | 651 | 319 | 319 | 319 |

| Annual circulation tax | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|
| FEV small | 50 | 50 | 22 | 22 | 22 |
| FEV medium | 150 | 150 | 54 | 54 | 54 |
| FEV large | 600 | 600 | 315 | 315 | 315 |

**Table 33 VRT and Annual circulation tax for the Low Incentive regime: low EV and low PHEV and EREV stimulation**

| VRT | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|
| ICEV petrol small | 6% | 6% | 6% | 6% | 6% |
| ICEVpetrol medium | 7% | 7% | 7% | 7% | 7% |
| ICEV petrol large | 13% | 13% | 13% | 13% | 13% |
| ICEV diesel small | 6% | 6% | 6% | 6% | 6% |
| ICEV diesel medium | 7% | 7% | 7% | 7% | 7% |
| ICEV diesel large | 13% | 13% | 13% | 13% | 13% |
| PHEV petrol small | 1% | 1% | 1% | 1% | 1% |
| PHEV petrol medium | 1% | 1% | 1% | 1% | 1% |
| PHEV petrol large | 4% | 4% | 4% | 4% | 4% |
| PHEV diesel small | 1% | 1% | 1% | 1% | 1% |
| PHEV diesel medium | 1% | 1% | 1% | 1% | 1% |
| PHEV diesel large | 4% | 4% | 4% | 4% | 4% |
| EREV petrol small | 1% | 1% | 1% | 1% | 1% |
| EREV petrol medium | 1% | 1% | 1% | 1% | 1% |
| EREV petrol large | 4% | 4% | 4% | 4% | 4% |
| EREV diesel small | 1% | 1% | 1% | 1% | 1% |
| EREV diesel medium | 1% | 1% | 1% | 1% | 1% |
| EREV diesel large | 4% | 4% | 4% | 4% | 4% |
| EV electra small | 0% | 0% | 0% | 0% | 0% |
| EV electra medium | 1% | 1% | 1% | 1% | 1% |
| EV electra large | 3% | 3% | 3% | 3% | 3% |
| **Annual circulation tax** | **2010** | **2015** | **2020** | **2025** | **2030** |
| ICEV petrol small | 30 | 30 | 30 | 30 | 30 |
| ICEV petrol medium | 67 | 67 | 67 | 67 | 67 |
| ICEV petrol large | 351 | 351 | 351 | 351 | 351 |
| ICEV diesel small | 30 | 30 | 30 | 30 | 30 |
| ICEV diesel medium | 67 | 67 | 67 | 67 | 67 |
| ICEV diesel large | 351 | 351 | 351 | 351 | 351 |
| PHEV petrol small | 25 | 25 | 25 | 25 | 25 |
| PHEV petrol medium | 57 | 57 | 57 | 57 | 57 |
| PHEV petrol large | 319 | 319 | 319 | 319 | 319 |
| PHEV diesel small | 25 | 25 | 25 | 25 | 25 |
| PHEV diesel medium | 57 | 57 | 57 | 57 | 57 |
| PHEV diesel large | 319 | 319 | 319 | 319 | 319 |
| EREV petrol small | 25 | 25 | 25 | 25 | 25 |
| EREV petrol medium | 57 | 57 | 57 | 57 | 57 |
| EREV petrol large | 319 | 319 | 319 | 319 | 319 |
| EREV diesel small | 25 | 25 | 25 | 25 | 25 |
| EREV diesel medium | 57 | 57 | 57 | 57 | 57 |
| EREV diesel large | 319 | 319 | 319 | 319 | 319 |
| FEV small | 22 | 22 | 22 | 22 | 22 |
| FEV medium | 54 | 54 | 54 | 54 | 54 |
| FEV large | 315 | 315 | 315 | 315 | 315 |

Table 34 gives the distribution of EU Member States over these tax regime.

**Table 34 Tax regime/EV stimulation per country**

| Country | EV stimulation | Country | EV stimulation |
|---|---|---|---|
| Austria | Low | Italy | Low |
| Belgium | Medium | Lithuania | Low |
| Bulgaria | Low | Luxemburg | Low |
| Cyprus | Low | Latvia | Low |
| Czech Republic | Low | Malta | Low |
| Germany | Low | Netherlands | High |
| Denmark | Medium | Poland | Low |
| Estonia | Low | Portugal | High |
| Spain | High | Romania | Low |
| Finland | Low | Sweden | Medium |
| France | High | Slovenia | Low |
| Greece | High | Slovakia | Low |
| Hungary | Low | United Kingdom | High |
| Ireland | Low | | |

* Low means either low EV stimulation or no data available for that country.

### D.5.6 Calculation of TCO and 3 year TCO

The TCO is considered to be the most influential decisional parameter for consumers to purchase a new vehicle. The TCO is influenced by numerous variables, and fiscal policy can influence these considerably.

TCO is calculated as follows:

$$TCO_{vehicle\ i} = [\ (\ CP_{vehicle\ i} \cdot (\ REGTAX_{vehicle\ i} + VAT - 1\ ) - RV_{vehicle\ i}\ )\ /\ LT_{vehicle\ i}\ ]$$

$$+ \Sigma\ (CIRCTAX_n + FUEL_n + MAINTENANCE_n + INSURANCE_n\ )\ /\ LT_{vehicle\ i}\ ]$$

Where:

$$FUEL_n = VKM_n \cdot FUELPRICE_n$$

$$FUELPRICE_n = (FUEL\ COMM.\ PRICE_n + FUELTAX) \cdot (1+VAT)$$

*i* = vehicle type
*n* = year
TCO = Total Cost of Ownership
CP = Catalogue Price
REGTAX = Registration Tax
VAT = Value Added Tax
RV = Residual Value
LT = Lifetime
CIRCTAX = Circulation Tax (annual)
FUEL = Fuel costs (annual)
MAINTENANCE = Maintenance costs (annual)
INSURANCE = Insurance costs (annual)
VKM = Vehicle Kilometres (annual)
FUELPRICE = Fuel Price, market price
FUEL COMM. PRICE = Fuel Commodity Price
FUELTAX = Fuel Tax

## D.6 From market uptake to vehicle shares

Once the development of purchase shares of the various vehicles types are calculated for the various scenarios, these have to be translated to car fleet composition. These calculations were done for each EU Member State and vehicle category, using the TREMOVE car fleet data. Each EV that entered the fleet was assumed to replace an ICEV of the same vehicle type.

## D.7 Calculation of the environmental impact

From the market uptake results, the energy use of road transport per country is derived for each scenario. The energy use per country is based on the and energy efficiencies (in terms of litre/km fuel and kWh/km electricity) assumed in the scenarios, vkm's and number of vehicles per vehicle type for the period 2010-2030.

The impact on $NO_x$ and $PM_{10}$ emissions from the fossil fuel use in transport (in ICEVs, PHEVs and EREVs) could then be estimated by combining the results from the market uptake modelling with the TREMOVE emission factors, for each vehicle type. The impact on $CO_2$ emissions could be estimated by combining total fuel use results with the well-to-wheel $CO_2$ emissions given in (Concawe, 2007).

For the impact on the electricity sector, the results of vehicle electricity demand per year were fed into the IPM model. Separate data were provided for each EU Member State. Note that emissions from the power sector are only direct emissions caused by the power production, and do not take upstream emissions into account.

Another impact that was calculated was the additional demand for lithium, used in the batteries of the EVs. This effect was calculated using the assumptions regarding battery capacity per vehicle as shown in Table 35 (source: calculations by Ricardo/TNO based on input data from Deliverable 2), the amount of lithium per kWh is taken to be 0.1-0.13 kg/kWh (based on estimates from Deliverable 2)[29].

**Table 35 Assumptions regarding battery capacity per vehicle (kWh/vehicle) of the various EVs**

| | | 2010 | 2020 | 2030 |
|---|---|---|---|---|
| PHEV | Small | 5.95 | 5.95 | 5.95 |
| PHEV | Medium | 6.45 | 6.45 | 6.45 |
| PHEV | Large | 6.35 | 6.35 | 6.35 |
| EREV | Small | 5.75 | 5.75 | 5.75 |
| EREV | Medium | 6.15 | 6.15 | 6.15 |
| EREV | Large | 6 | 6 | 6 |
| FEV | Small | *16* | 16 | 27 |
| FEV | Medium | *21* | 21 | 36 |
| FEV | Large | *24* | 24 | 42 |

29 Note that these data were not used to estimate the electric driving ranges in the scenario calculations, there were estimated based on the storylines and more top-down assumptions.

## D.8 Economic analysis

Vehicle sales and use generate taxes for government. The impact on VAT revenues could be calculated using the market uptake results for the scenarios, and combining these with the vehicle catalogue prices and an average VAT rate of 20.5% (EU average). Impacts on fuel and electricity taxes were estimated using the petrol, diesel and electricity demand results, and combining these with average excise duties and taxes in the EU (0.507 €/l for diesel, 0.721 €/l for petrol and 0.020 €/kWh for electricity) and the average 20.5% VAT rate.