MARKET PENETRATION SCENARIOS OF ELECTRIC-DRIVE VEHICLES

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Abstract
Electric-drive vehicles (EDVs) are currently emerging in the market for personal cars and are viewed as a promising option towards road transport that is less carbon intensive, less polluting and less oil dependent. The adoption and diffusion of EDVs does not only depend on demand for such vehicles but is also subject to supply side restrictions which include battery performance and cost, and the level of access to charging infrastructure.
This paper aims to (i) assess the future market penetration of BEVs and PHEVs and the resulting impacts CO_2 emissions at the EU level and (ii) identify the impact of key factors determining electromobility, i.e. battery costs and performance and access to recharging infrastructure. Based on projections of battery performance and costs and access to charging infrastructure we develop various contrasting scenarios for the future market for electric cars. Next, we use the TREMOVE transport policy model with a modified version of the nested logit choice module in order to provide indicative estimations of the market penetration of BEVs and PHEVs for the different scenarios.
The analysis leads to the following conclusions. First, deployment of BEVs is expected to remain limited until at least 2020. Access to charging infrastructures at home, work and in urban public areas forms the main barrier to large scale market development, both in the short and longer term. For PHEVs more rapid market penetration is expected once they will be widely commercialised (around 2020). A voluntary development of standards on charging technology and infrastructure would contribute to achieve a substantial market penetration of both BEVs and PHEVs by 2030. Second, technological progress in battery performance and costs would strongly improve both the cost performance and (all electric) autonomy range. The full benefits would be manifest if combined with rapid deployment of charging infrastructure. Third, the impact of EDVs on fuel and electricity consumption of road passenger transport will be negligible until 2020. In the most positive scenario electric vehicles could bring about a four to fifteen percent reduction in CO_2 emissions compared to the reference scenario.

Keywords
Electromobility, Mode choice modeling, Sustainable transport, Transport policy

1. INTRODUCTION

Electric-drive vehicles (EDVs) are currently emerging in the market for personal cars and are viewed as a promising option towards road transport that is less carbon intensive, less polluting and less oil dependent. For these reasons, world governments are pledging billions to fund development of electric vehicles and their components. EDVs are characterized by having a battery-powered electric motor for propulsion and a plug to connect to the electrical grid in order to recharge the battery. Examples include battery-electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEV). The adoption and diffusion of EDVs does not only depend on the demand for such vehicles but is also subject to supply side restrictions. The market for EDVs is characterised (as markets for emerging technologies often are) by supply side restrictions that limit demand, while at the same time the limited demand slows down the investment in and development of supply infrastructure. In the case of EDVs, supply side bottlenecks concern *inter alia* battery performance and cost, and the level of access to charging infrastructure.

This paper develops a prospective analysis focusing on two of the key aspects which currently represent the bottleneck for the diffusion of electric vehicles, i.e. (i) battery performance and cost, and (ii) the access to charging infrastructures. Starting from assumptions about possible trends in these two factors, four scenarios are built. Based on these scenarios, we derive indicative estimations of the market penetration of BEVs and PHEVs and of the impacts on CO_2 emissions at EU level. For this purpose, a modelling approach was adopted which is based on a modification of the vehicle choice module within the TREMOVE transport policy model.[1]

The paper is structured as follows. Section 2 discusses the main barriers and drivers in the market for EDVs. Section 3 briefly discusses the TREMOVE model. Section 4 describes four scenarios based on possible trends in key factors determining the future electromobility. Furthermore this section discusses the assumptions and modelling approach underlying the analysis. Section 5 discusses the results in terms of market penetration and CO_2 emissions of EDVs. Section 6 concludes.

2. THE MARKET FOR ELECTRIC DRIVE VEHICLES: BARRIERS AND DRIVERS[2]

2.1 Introduction

Deployment of electric vehicles will depend on a large variety of factors, including battery performance and costs, access to the electricity grid, the business model implemented to supply the consumer with reliable batteries and electricity, the acceptance by the consumer and driving habits.

The diversity of and interrelationships between these factors make market projection extremely difficult and invalidates the definition of a single scenario of the penetration of electric vehicles. Several combinations of assumptions can be made on the above-mentioned aspects, resulting in different expectations on the market penetration of electric cars. Figure 1 and 2 illustrate the variation in market penetration projections of BEVs and PHEV found in the literature.

Sections 2.2-2.4 summarise the key elements underlying our scenario assumptions regarding future possible trends, focusing mainly on battery performance and cost and development of charging infrastructure.

Figure 1: Projections of the market penetration of BEVs (share in new car fleet)

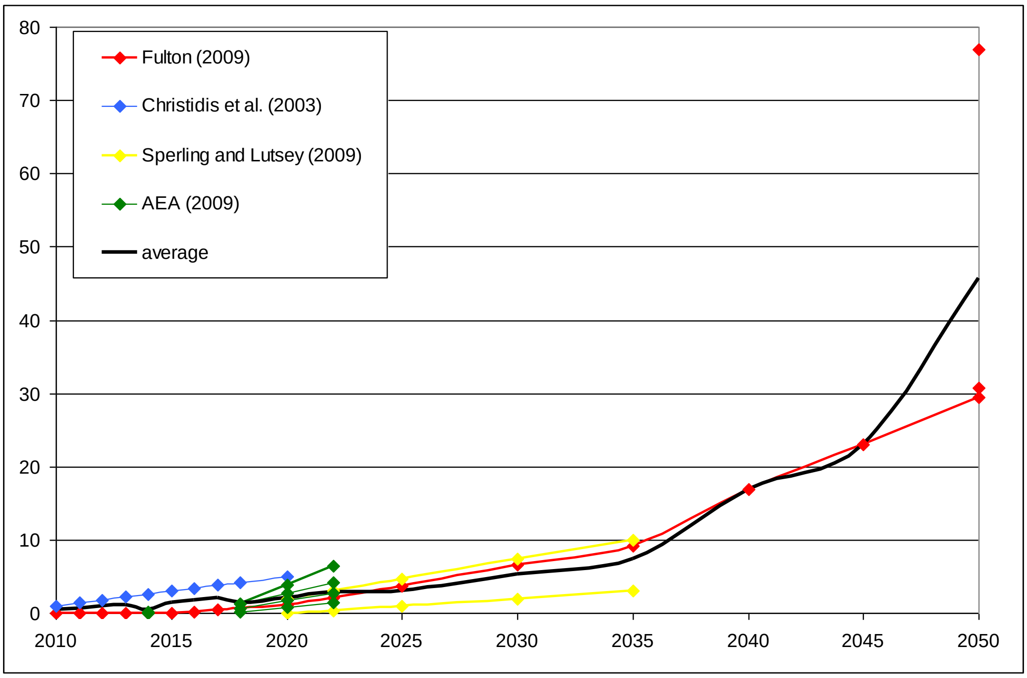
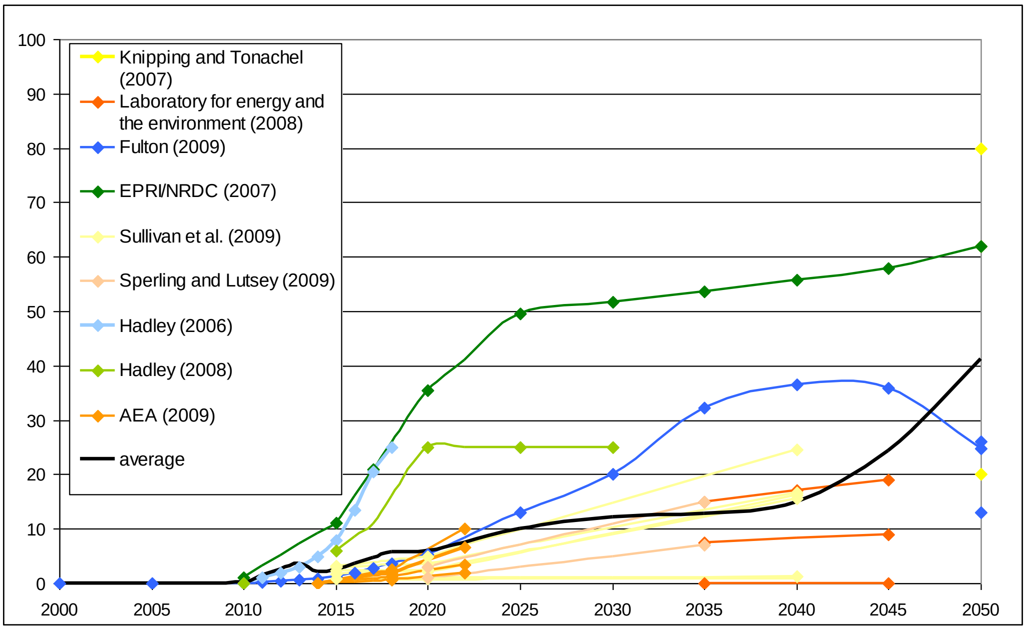


Figure 2: Projections of the market penetration of PHEVs (share in new car fleet)



2.2 Vehicle performance and costs

In the longer term, significant technical and process developments are expected, especially in the field of batteries

2.2.1 Battery performance

Energy and power density[3] of batteries are expected to increase in the future, resulting in larger autonomy ranges, which, in the case of BEVs, could double from 100 to 150 kilometres in the near future to 200 to 300 kilometre (see for instance IEA, 2010). The new roadmap established by NEDO in Japan suggests the possibility of an even bigger improvement in power density, although the precise level remains unclear. Due to suboptimal charging patterns, driving behaviour, weather conditions and on-board energy consumption[4], the actual autonomy range could be 20 to 30 percent lower than the stated value, thus reducing the near-term range to about 70 to 120 kilometres (IHS Global Insight, 2009).

Current battery life is more than three years, and could increase to more than ten years in 2014 (IHS Global Insight, 2009). Options currently envisaged for a second life of batteries not suitable anymore for use in vehicles would further extend economic battery life.

2.2.2 Battery costs

Nemry et al. (2009) found current battery costs in a range from 700 to 1000 $/kWh. More recent information (Lache et al., 2010) suggests the lower bound of this range (and possibly even a lower value) to be more realistic. Future cost reductions are expected mainly as a result of innovations in production processes and components (Anderson, 2009). Learning effects and economy of scale effect[5] will further contribute to such reductions. The extent of cost reduction is subject to more speculation. The literature reports a wide range of expectations, some as low as 300 to 400 $/kWh by 2020. In its Technology Roadmap (IEA 2009) on electric vehicles, the International Energy Agency considers that, in the case of BEVs, economies of scale can be achieved after an annual production of 50,000 to 100,000 vehicles. In the case of PHEVs, economy of scale effects would be attained sooner because hybrid vehicles are already produced and sold.

2.3 Commercial strategies

2.3.1 Car manufacturing plans

Electric vehicle manufacturing plans by OEMs have been recently reviewed in various literature sources (see for example Westminster City Council, 2009; Hacker et al., 2009). Several BEV models are already commercialised in small quantities, or planned to be commercialised very soon, by various companies.[6]

Commercialisation of PHEVs in Europe is not yet announced, although several companies report developing activities. PHEVs are not expected to be commercialised before 2015 and not before 2020 at a large scale. However, once commercialised, they offer important advantages over BEVs (longer autonomy range, the promotion effect from the already existing hybrid cars) and could thus be more successfully penetrate the market. From a different perspective, PHEVs are sometimes seen as a transition technology until a wider market deployment of BEVs will be enabled by sufficient progress on battery performance and costs.

Table 1 summarises the main assumptions about the marketing of EDVs in different market segments based on vehicle size.

Table 1: Expectations about the marketing of BEVs and PHEVs in the market segments for small, medium and large vehicle size.

	BEV	PHEV
Small	The immediate candidate for BEV. Early models fall in this category	Vehicle packaging problem and excessive price are obstacles
Medium	Very few models are expected in the short term. They would however emerge later with battery cost decline and increased performance	Privileged segment, but marketing is unlikely before 2020.
Large	Large cars are usually used for long distance trip. Battery capacity is an obstacle. Limited to specific markets (e.g. luxury cars).	Privileged segment, but marketing is unlikely before 2020.

2.3.2 Business models

The main barrier to the market penetration of EDVs relates to batteries. First, reflecting the battery cost in the vehicle price will result in high upfront costs compared to conventional cars. Second, risks associated with EDVs are mainly linked to the battery (durability, energy capacity, technology maturity).[7]

To cope with this consumer risk perception, various business models are being explored and tested, involving the automotive industry and new emerging business companies that are investing in the area. These include battery leasing, mobile phone style subscription service, vehicle leasing and car sharing systems.

2.4 Charging infrastructure

Next to costs, access to charging infrastructure and autonomous range of the vehicle are two obvious key factors in the purchase of EDVs. This section briefly reviews the different types of charging options and discusses the possible needs and limitations of deploying these options.

2.4.1 Types of charging spots, costs and mode of payment

Charging options can be categorized into three types, i.e., standard charging, semi-fast charging and fast charging. Table 2 summarizes the characteristics of each type, including technical requirements, potential placement locations and associated costs (see Morrow et al., 2008 and Westminster City Council, 2009).

2.4.2 Car use patterns and charging infrastructure requirement

The bulk of car trips occurs during the day and relate to commuting trips. This implies that owners of electric cars need the option to charge their car before leaving in the morning.

Under the currently prevailing car ownership model[8], it is likely that the electric car will be recharged at home. This means that the limited share of the population with a garage or private parking place forms a barrier to the market penetration of electric cars, at least in the near future. According to Eurostat, 24 percent of the EU population live in an urban environment. Assuming garage ownership rates for urban and non-urban residents of 10 and 30 percent, respectively, this would imply a garage ownership rate of about 25 percent at

EU level. However, not all garages and parking places are fitted with the appropriate plug with which to charge an electric car.[9] It seems reasonable to assume that not more than ten percent of car purchasers could be in a position to charge their car at home. For urban areas much lower figures (about 2.5 percent) are even reported in the literature (Westminster City Council, 2009).

Table 2: Characteristics of different methods for recharging

	standard charging	semi-fast charging	fast charging
Voltage / Amperage	230V / 16A	230V / 32A	480 VAC
Typical charging power	3.5 kW	7-10 kW	60-150 kW
Charging speed for a 10 kWh battery	5-8 hours	1-2 hours	<10 minutes
Compatibility charging facility	Private charging facility	Private and collective charging facilities	Collective charging facilities
Vehicle equipment requirement	Higher battery capacity required	Higher battery capacity required	Low battery capacity required
	On-board charger	On-board charger	
Infrastructure requirement	Cable from electricity outlet to the vehicle New dedicat circuit	Stationary charger Cable from electricity outlet to the vehicle New dedicated circuit	Stationary charger Three phase
Installation cost (euro/charger)	650	1084	6000
Maintenance (euro/year)	-	267	267
Administration	-	4000	4000
Annual total cost	65	4375	4867
Applicable location	Dwellings, public parking in residential areas	Office and apartment parkings, leisure areas (e.g. dining, shopping)	Motorways, urban areas, shopping centers

Source: SWELTRAC (2007), Vande Bosshe et al.

Charging facilities in workplaces are still rare. For commuting trips longer than about forty kilometres, the round trip would therefore in many cases be risky with an electric car. Extending the number of charging facilities at the work place is thus a key condition to promote electric cars.

For non-commuting short trips, similar needs for charging infrastructure need to be met, especially in urban zones (e.g., car parks near shopping areas or restaurant zones) where people tend to stay over one to two hours during which the car could be recharged.[10]

Whereas the majority of trips in EU zone are short distance trips, vehicle choice is based on maximal rather than typical requirements in terms of performance and range. On long trips, the limited AER of BEVs may invoke feelings of concern about the risk of battery discharge before reaching a recharge station. Moreover, while fast charging enables charging within ten minutes, long queues can increase the waiting time considerably.[11] Hence, in the near term, electric-vehicles are still unlikely to meet the requirements, unless as a second car or complemented with public transport or other alternative transport modes.[12]

On non urban roads the distance between recharging spots should in theory be matched to the typical car autonomy range (about eighty kilometres). The literature assesses that in reality a forty kilometre distance would be required to remove any risk perception for the driver.

For urban areas it is not straightforward to estimate an optimal density and distribution of charging spots and of the number of charging sockets per spot. The required density in the case of London was estimated at 4.3 charging points per square kilometre, corresponding to about 2.6 per 1000 inhabitants (BERR and DfT, 2008). Other sources (Westminster City Council, 2009) suggest required densities could be lower than that.

2.4.3 Cost estimates for the EU

Based on the assumptions on costs and infrastructure densities and road network and population statistics from Eurostat, the order of magnitude for the overall expenditure entailed by a full charging infrastructure deployment at EU level is estimated to be about three billion Euros for the EU27, 98 percent of which refers to costs in urban zones (see Table 3). In ETE (2009) even higher costs are reported.

Table 3: Estimation of annual costs related to charging infrastructure

	Urban		Motorways		Total
Network scope	Urban population	118,983	Motorway length	55,533 km	
Assumption on charger density	# Chargers / 1000 ihabitants	13	Distance between stations	40 km	
Number of chargers	1,546,779		13,883		1,560,662
Standard chargers	1,082,745				
Fast chargers	464,034		13,883		
Costs per charging unit	-		-		
Annual cost (mln €)	3,001		56		3,057

Source: own calculations

2.5 Current and planned policies

In various European countries, central and local governments are implementing policies and planning investments favouring electromobility. These include (i) financial and fiscal incentives for the purchase of electric vehicles by private consumers (e.g. subsidies, tax exemption), (ii) Green Purchase Procurement, and (iii) investments in charging infrastructures.

Through these initiatives governments aim to achieve certain targets in terms of EDV market sales. Table 4 gives an overview of the sales targets announced in some European countries.

Table 4: Announced national EDV sales targets (×1000) for 2020.

Denmark	200	Netherlands (2015)	10
France	2,000	Spain (2014)	1,000
Germany	1,000	Sweden	600
Ireland	350	UK	1,550
Total	6,710		

Source: IEA (2010)

Charging infrastructure plans are adopted by central and local governments (Portugal, Denmark, Netherlands, Spain, Germany), public utilities companies and private companies[13].[14] The question of when, how much and where to invest in charging infrastructure is however not an easy one.[15]

In many cases, government plans are targeting specific areas and networks (first residential areas and urban zones) and niche markets; several plans currently concentrate in large cities (Berlin[16], Paris[17], London)[18]. In such a staged approach, risky investments are kept limited while experience is gained in different aspects of electromobility, contributing to cost reductions after sufficient market deployment. In a next stage, the experience and improvements in charging infrastructure combined with a better assessment of "optimal" density and location would facilitate wider infrastructure deployment.
In addition to extending the public charging infrastructure network, incentives are created to extend the access to the grid at home and work place. For instance, the French government plans to require new apartment buildings with parking to include charging stations by 2012, and to make the installation of charging sockets mandatory in office parking lots by 2015. Belgium is introducing fiscal incentives based on a 21.5 percent tax exemption for companies to install recharging spots at the workplace. In Sheffield (UK) the requirement of installing charging infrastructure is integrated into sustainable housing policy and renewable energy targets.

3. THE TREMOVE MODEL[19]

TREMOVE is a policy assessment model for studying the impact of transport and environmental policies on the emissions from the transport sector. Given a policy measure, the model estimates the effects on transport demand, resulting modal shifts, vehicle stock renewal, emissions of air pollutants and welfare effects. The model enables analysis of different types of policy including road pricing, public transport pricing, emission standards and subsidization. TREMOVE models both passenger and freight transport, and covers the period 1995 - 2030. The model consists of 31 parallel country models[20], each consisting of three inter-linked modules: (i) a transport demand module, (ii) a vehicle turnover module and (iii) an emission and fuel consumption module (see Figure 11).
The transport demand module describes transport flows and the users' decision-making process underlying modal choices. Starting from the baseline level of demand[21] for passengers and freight transport per mode, period, region etc., the module describes how a policy measure will affect the choice of consumers and firms between different transport modes.[22] The output of the demand module consists of demand per transport type in terms of passenger kilometres (pkm) and tonne kilometres (tkm), which is then converted into vehicle kilometres (vkm).
The vehicle stock turnover module describes how changes in demand for transport or changes in vehicle price structure influence the composition of the stock in terms of vehicle age and type. The output of the vehicle stock module consists of total fleet and vkm for each year per vehicle type and age.
The fuel consumption and emissions module calculates the fuel consumption and the emissions of greenhouse gas and air pollutants, using as inputs the vehicle stock composition, the number of vkms by vehicle type, and the driving conditions.[23]
Certain outputs from the vehicle stock and fuel consumptions and emissions modules which influence usage costs (and thus transport demand and modal split) are fed back into the demand module. These outputs are fuel consumption rates, vehicle stock composition and usage.

In addition to the three core modules, the TREMOVE model includes a well-to-tank emissions module which calculates the emissions during the production of fuels and electricity, and a welfare cost module, which enables a calculation of the cost to society associated with emission reduction scenarios in European urban and non-urban areas.[24]

4 SCENARIOS DEFINITION AND MODELLING APPROACH

This paper aims to draw some likely trends about the future market of electric cars, based on a scenario building exercise which focuses on two key drivers discussed in the previous section, i.e., (i) the expected progress regarding batteries (capacity, durability and costs) and (ii) the expected deployment of charging infrastructure. For both drivers, two contrasted scenarios are considered, resulting in four different combined scenarios on the market deployment of electric cars.

4.1 Common assumptions

Table 5 summarizes the main common assumptions for the four scenarios:

Table 5: Common assumptions for all scenarios

Conventional cars	Energy efficiency (grammes of CO2/vkm) improves in accordance to the EU target (135 in 2015, 115 in 2020, 95 in 2025-2030). This is assumed to be achieved with vehicle motor technology improvement and additional measures (low resistance tyres and labelling; low viscosity liquids)
Batteries	Battery costs: 700€/kWh in 2010
	Durability: 6 years in 2010
	Battery capacity: Energy capacity enabling a 100 km real car autonomy in 2010
BEV production	Small BEVs: from 2011, medium BEVs: from 2015, no large BEVs produced
PHEV production	Medium and big: from 2020. No small PHEVs produced.
Business model	Business models are in place that offer the consumer the possibility to spread battery costs over the vehicle lifetime
Charging infrastructure	Residential places (garages, private parkings): 10% in 2010
	Other places (mainly work places): 0.5% in 2010
Electricity	Cost: In a first assumption, electricity is assumed to be charged to consumers according to the current tariffs (domestic or commercial).
	WTT emissions assumed for electric cars is based on the PRIMES energy system model reference scenario 2009. Emission factors for each country for electricity are assumed accordingly.

4.2 Scenario assumptions

Both the performance and the costs of the battery are expected to improve in the future, consequently affecting the achievable AER and battery weight. Battery durability is expected to increase as a result of both technological improvements and options to extend the battery life in non-automotive applications.

Two contrasted scenarios (BATT1 and BATT2) are considered, assuming different trends in battery performance and cost factors (
Table 6). In the BATT1 scenario, technical progress is slow and limited to an increase in durability. Battery costs reduce by four percent per year, achieving about 300 €/kWh by 2030. In the BATT2 scenario, technology progress results in a much improved durability and a higher useable SOC window. The

reduction in cost is assumed to be faster (six percent per year), attaining 200 €/kWh by 2030.

Table 6: Assumptions on battery lifetime and unit costs for two scenarios

	Batt1			Batt2		
	Battery life (yrs)	Battery cost (€/kWh)	Useable SOC window (%)	Battery life (yrs)	Battery cost (€/kWh)	Useable SOC window (%)
2010	6,0	700	0,7	6,0	700	0,70
2015	7,7	571	0,7	9,7	514	0,74
2020	9,8	465	0,7	15,0	377	0,77
2025	10,0	379	0,7	15,0	277	0,81
2030	10,0	309	0,7	15,0	203	0,85

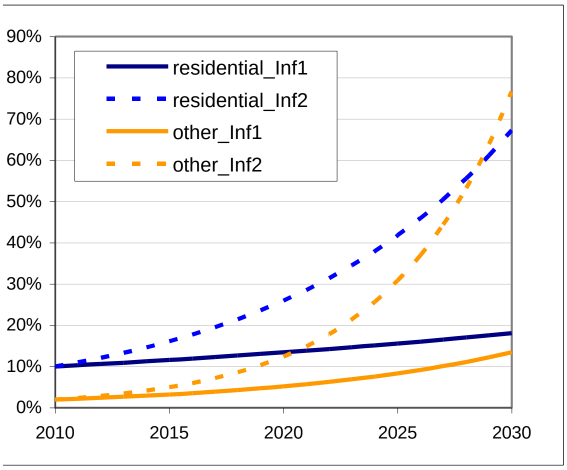
The battery improvements achieved in the BATT1 scenario translate into limited improvements in AER and annual costs. In the BATT2 scenario, the improvements result in a more substantial increase in the AER and a significantly larger reduction in the annual cost of the battery (Table 7 shows the case of medium sized vehicles).

Table 7: Assumptions on AER and battery cost for medium sized electric cars.

	Batt1		Batt2	
	Annual cost (€/yr)	AER (km)	Annual cost (€/yr)	AER (km)
2010	3,208	100	3,208	100
2015	3,301	161	2,185	161
2020	3,274	250	1,544	259
2025	2,609	250	1,621	400
2030	2,127	250	1,104	400

Given the currently planned investments in various countries, the access to charging facilities can be assumed to improve in the future. In fact, in many countries the network of those charging options that are already in use – mainly at homes that have a garage – is already being extended, or will be so in the near future. We consider two contrasted scenarios (Figure 3). The INF1 scenario assumes that development of charging infrastructure follows currently planned national investments but will not become more ambitious in the future. In contrast, the INF2 scenario assumes larger scale infrastructure charging development for all countries.

Figure 3: Assumptions on the progress of charging infrastructure

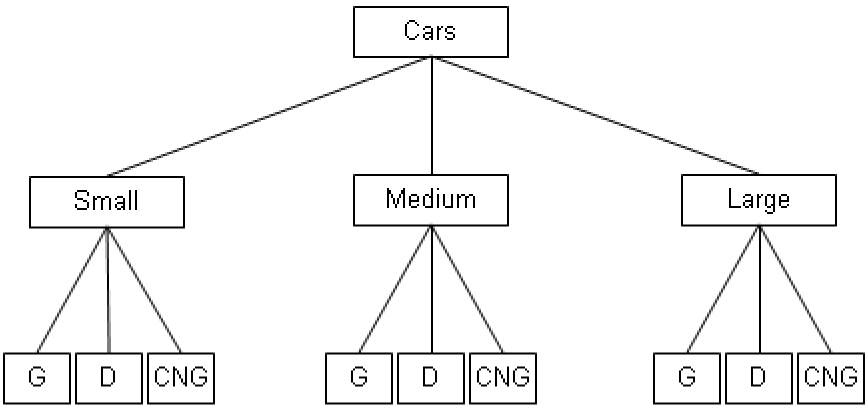


Combining the two sets of assumptions described above results in four combined scenarios labelled as: (i) BATT1_INF1, (ii) BATT2_INF1, (iii) BATT1_INF2 and (iv) BATT2_INF2. The analysis in this paper is based on a comparison of these combined scenarios.

4.3 Modelling the car purchase choice

The vehicle choice module in TREMOVE v3.1 does not include electric cars as choice alternatives. The market share allocation to different conventional car alternatives is based on a two-level nested logit model which determines the choice of both car size and fuel technology (see Figure 4). The choice of car type depends inter alia on the performance (acceleration) and various cost elements (annualized non fuel costs and fuel costs). The set of coefficients that represent the impact of each of these explanatory variables on the choice probability were estimated (calibrated) based on historical data on these variables and the sale shares of each car type within the choice set.

Figure 4: Structure of the nested logit model in TREMOVE v3.1



G=Gasoline, D=Diesel, CNG= Compressed natural gas

Historical data on consumer choice for EDVs are not yet available. Furthermore, the choice for EDVs is not only determined by performance and cost elements but also by AER and access to charging infrastructure. In order to cope with these limitations, we develop a two step approach.
The first step consists of allocating the estimated number of car purchases for any given year in the modelled period into three tiers. Tier 1 corresponds to

purchases by consumers with access to the charging infrastructure required by BEVs. When buying a car, they choose between conventional cars, BEVs and PHEVs. Tier 2 is composed of car purchases made by consumers with access to the charging infrastructure required by PHEVs, but not to that required by BEVs. These consumers choose between conventional cars and PHEVs. Tier 3 concerns consumers who do not have sufficient access to charging infrastructures. When buying a car they choose a conventional car.
The boundaries between the three tiers are determined by the AER, access to charging infrastructure and other exogenous assumptions as follows. PHEVs are assumed to be a choice option for households with access to charging infrastructure at home or at the activity end of the trip. As regards BEVs, the market for cars is divided into two main segments according to intended car use, i.e., (i) the market for cars that are intended to be used for short distance trips only and (ii) the market for cars that are intended to be used for both short and long distance trips. For the first segment, BEVs are a choice option if (i) there is the option of charging at home[25] and (ii) the autonomous range is sufficient to cover the distance from home to the activity-end of the trip and back or, alternatively, the autonomous range is sufficient to cover the distance from home to activity-end plus there is the option of charging at the activity-end. The potential share of households in the second segment considering a BEV is assumed to increase linearly from zero to one as the autonomous range increases from 100 to 400 kilometres. Additionally, the same conditions hold as for the first segment.

Figure 5: Tier boundaries for the four scenarios

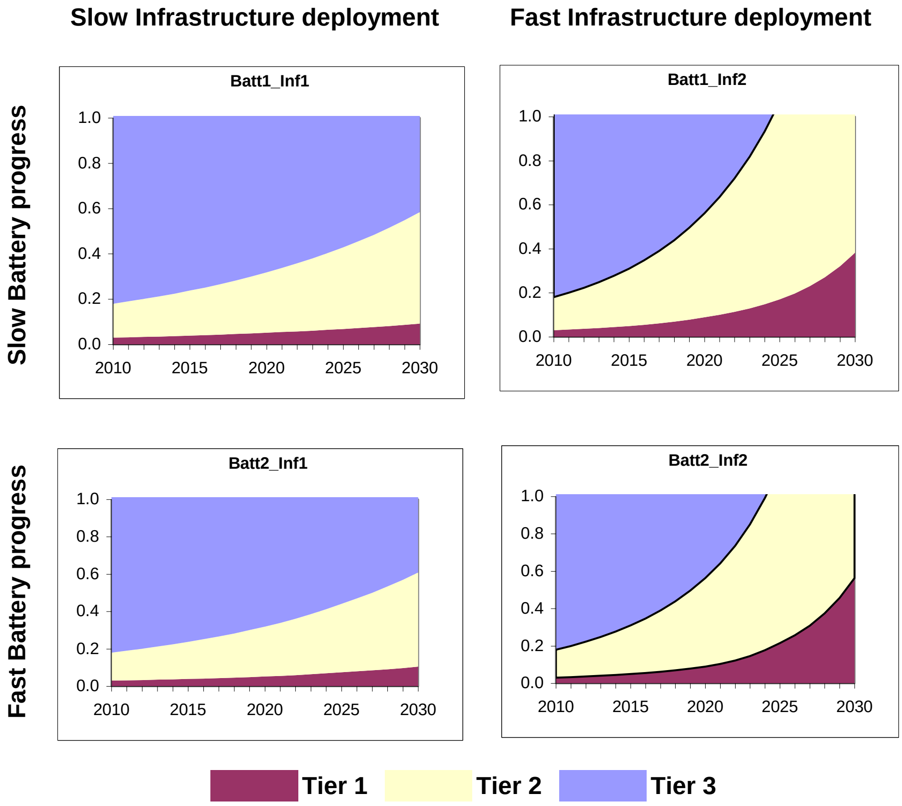
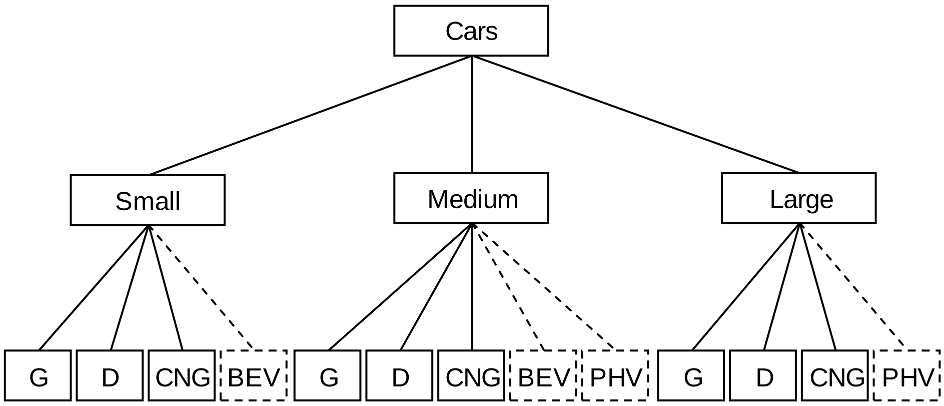


Figure 5 shows an overview of the relative size of the three tiers for each of the four combined scenarios. The infrastructure deployment has a large impact on the tier shares; the scenarios with fast infrastructure deployment show a more

rapid increase in the share of consumers considering PHEVs and/or BEVs (Tiers 1 and 2) than the other scenarios. The pace of battery progress has only a small impact on the tier shares.
The second step of our modelling approach consists of the use of nested logit model to estimate the share of choice alternatives within each tier. As for each tier the set of feasible choice alternatives is different, three 'tier-specific' nested logit models are employed. For tier 3 the unmodified model structure is used (Figure 4). In the 'tier 2 model', PHEV is added as an alternative at the lower level choice sets within the nests "medium" and "large". For tier 3, PHEV is added as in the 'tier 2 model' and BEV is added at the lower level choice sets within the nests "small" and "medium" (see Figure 6).
For each of the three models we assume that the set of attributes that determine consumer choice as well as the impact of these attributes is the same as in TREMOVE 3.1. This means that the utility of each alternative is a function of fuel costs, non-fuel costs, performance and income and that the calculation of the utility level is based on the attribute coefficients estimated during the calibration phase of TREMOVE 3.1.

Figure 6: Nesting structure of the car type choice model with BEVs and PHEVs included as choices in the lower level subsets.



G=Gasoline, D=Diesel, CNG= Compressed natural gas, PHV=Plug-in hybrid electric vehicles

5 SCENARIO RESULTS

The approach outlined in the previous sections was implemented as a new version of the TREMOVE model. The model results provide first indicative trends regarding plausible market penetrations and well-to-wheel CO_2 emissions at the EU level[1]. These were compared with the results from a reference scenario in which electric cars are assumed to be unavailable up to 2030.

5.1 Sales shares and fleet composition

Figure 7 and Table 8 compare the four scenarios in terms of the projected market penetration of BEVs and PHEVs up to 2030 at the EU27 level. According to expectations, the estimated market shares of electric cars are higher if battery progress and charging infrastructure deployment are fast. However, in all four scenarios BEV sale shares remain limited until 2020 (0.5 to

[1] Greece, Cyprus, Slovenia and Malta could not be incorporated in the exercise as the model choice in the current version is not implemented. Exogenous shares are indeed considered.

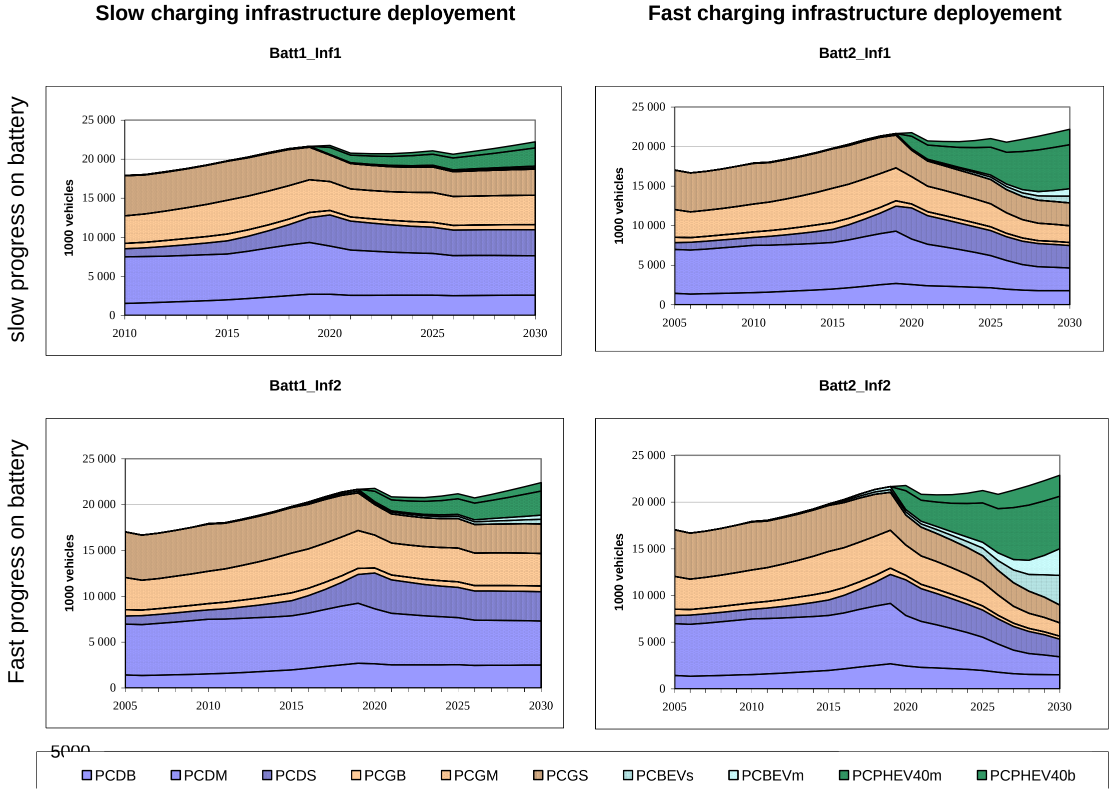
3.0 percent). In contrast, PHEVs rapidly penetrate the market once they are available, due to weaker battery and charging infrastructure constraints. Charging infrastructure deployment has the strongest influence, especially during the period 2020-2030. When deployment is slow the expected shares for BEVs remain limited, while rapid deployment would result in substantial sales shares in 2030 even with modest battery improvement.

In the most ambitious scenario, BEVs seem to catch-up with PHEVs in terms of sales. This results from the combined effect of cheaper batteries, increasing AER and widely deployed charging infrastructures, which strongly increases the attractiveness of BEVs. In such a scenario, PHEVs could be envisioned as a transitional technology option.

Table 8: Sales shares in 2020 and 2030 for four scenarios

		Batt1_Inf1	Batt1_Inf2	Batt2_Inf1	Batt2_Inf2
2020	conventional	94,5%	90,2%	92,0%	85,7%
	PHEV	5,0%	8,9%	6,4%	11,4%
	BEV	0,5%	0,9%	1,6%	2,9%
2030	conventional	84,6%	58,5%	80,0%	38,4%
	PHEV	13,5%	32,5%	15,4%	32,6%
	BEV	1,9%	9,0%	4,7%	29,0%

Figure 7: Comparison of scenarios in terms of vehicle sales at the EU level



The penetration of electric cars in the total fleet is slower (Figure 8 and Table 9). Across the scenarios the expected fleet shares range from 1 to 2 percent by 2020 and 7 to 27 percent by 2030.

Table 9: Fleet shares in 2020 and 2030 for four scenarios

		Batt1_Inf1	Batt1_Inf2	Batt2_Inf1	Batt2_Inf2
2020	conventional	99,3%	98,8%	98,7%	97,9%
	PHEV	0,4%	0,7%	0,5%	0,9%
	BEV	0,3%	0,5%	0,8%	1,2%
2030	conventional	92,7%	81,4%	90,1%	73,4%
	PHEV	6,3%	15,6%	7,6%	17,9%
	BEV	1,0%	3,0%	2,3%	8,7%

Figure 8: Comparison of scenarios in terms of fleet share at the EU27 level

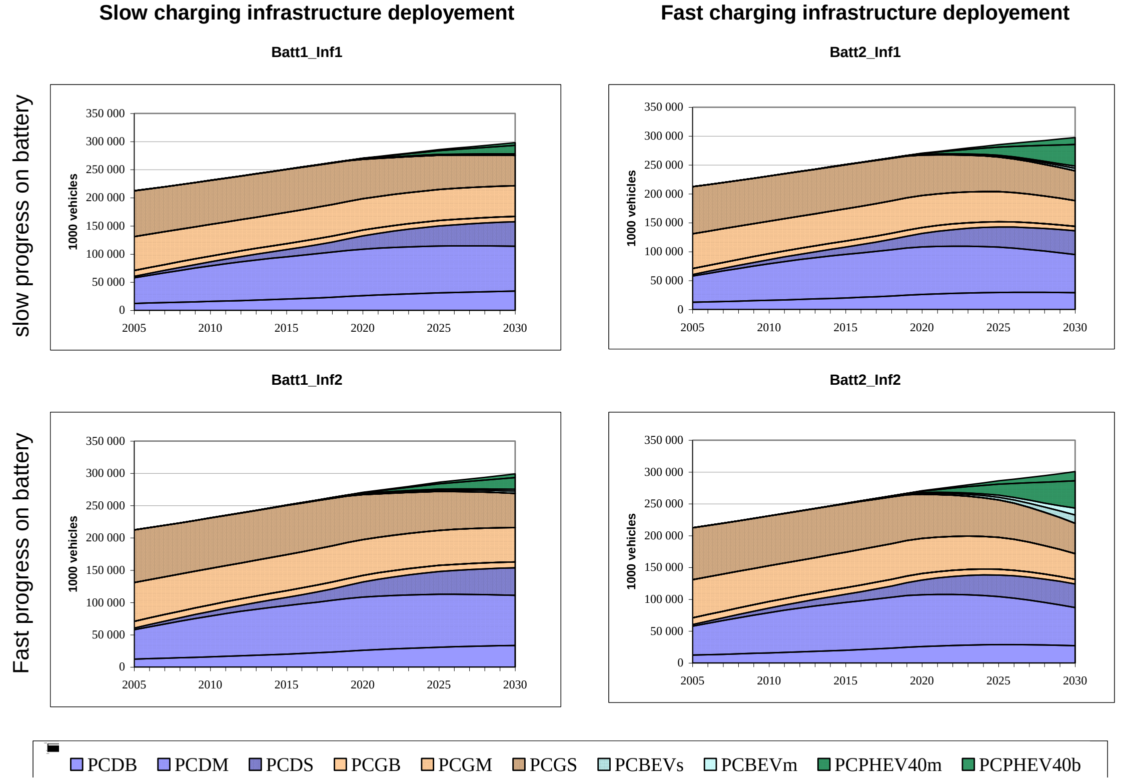


Table 10: CO_2 emissions by fuel and vehicle type (2020 and 2030)

		Batt1_Inf1		Batt1_Inf2		Batt2_Inf1		Batt2_Inf2	
2020	WTT (fuel)	85,7	*(15,0%)*	84,9	*(15,0%)*	85,2	*(15,0%)*	84,1	*(14,9%)*
	WTT (electricity)	3,5	*(0,6%)*	5,5	*(1,0%)*	4,9	*(0,9%)*	7,7	*(1,4%)*
	TTW (Conv cars)	480,7	*(84,2%)*	475,7	*(83,8%)*	477,5	*(84,0%)*	470,7	*(83,4%)*
	TTW (PHEV)	0,9	*(0,2%)*	1,4	*(0,2%)*	1,1	*(0,2%)*	1,7	*(0,3%)*
	total	570,9		567,5		568,7		564,2	
	% reference	99%		98%		99%		98%	
2030	WTT (fuel)	69,1	*(14,5%)*	62,0	*(14,0%)*	67,7	*(14,4%)*	57,9	*(13,7%)*
	WTT (electricity)	9,3	*(2,0%)*	22,8	*(5,2%)*	12,3	*(2,6%)*	31,5	*(7,5%)*
	TTW (Conv cars)	395,1	*(82,8%)*	348,6	*(78,8%)*	386,4	*(82,1%)*	323,0	*(76,4%)*
	TTW (PHEV)	3,8	*(0,8%)*	9,0	*(2,0%)*	4,5	*(0,9%)*	10,4	*(2,5%)*
	total	477,2		442,4		470,9		422,8	
	% reference	95%		88%		94%		84%	

5.2 CO2 emissions

The increase in the market share of BEVs and PHEVs will result in a partial substitution of fossil fuel with electricity. Final energy consumption from passenger cars will thus change, both in total amount and in terms of its composition by fuel type. Exhaust gas CO_2 emissions will decrease because of the shift from fuel to electricity consumption, but also because of the better performance of PHEVs in charge sustaining mode. Tank-to-wheel emissions are therefore expected to decline, partly compensated by an increase in well-to-tank emissions from the electricity production. The results in
Table 10 indicate that well-to-wheel CO_2 reductions are about fifteen percent in the most ambitious scenario.

6 CONCLUDING REMARKS

This paper aims to provide a prospective analysis of the adoption and diffusion of BEVs and PHEVs within the EU in relation with battery performance and cost and access to charging infrastructure. We adopt a model-based approach in which we develop various scenarios for the future market for electric cars, based on projections of battery performance and costs and access to charging infrastructure. Next, by means of a nested logit choice module we provide indicative estimates of the market penetration of BEVs and PHEVs. The analysis results enable (i) to assess the future market penetration of electric vehicles and the resulting impacts on CO_2 emissions at the EU level and (ii) to identify the impact of key factors determining electromobility, i.e. battery costs and performance and access to grid for recharging.
The analysis results in the following conclusions. First, deployment of BEVs is expected to remain limited at least until 2020. Access to charging infrastructures at home, work and in urban public areas forms the main barrier to large scale market development, both for the short and the longer term. For PHEVs more rapid market penetration is expected once they will be widely commercialised (around 2020). A voluntary development of standards on charging technology and infrastructure would contribute to achieve a substantial market penetration of both BEVs and PHEVs by 2030.
Second, due to the battery cost, upfront costs are much higher for EDVs than for conventional cars. The attractiveness of EDVs could be improved by spreading battery costs over the vehicle lifetime via one of the different business models currently envisaged. Even so, from a lifetime perspective

EDVs are currently still more expensive than their conventional counterparts. Progress in battery performance and costs would strongly improve both the cost performance and AER and as such represents the second key driver for the future success of the market for EDVs in general, and BEVs in particular. The full benefits would be manifest if combined with rapid deployment of charging infrastructure.
Third, the impact of EDVs on fuel and electricity consumption of road passenger transport will be negligible until 2020. In the most positive scenario electric vehicles could bring about a four to fifteen percent reduction in CO2 emissions compared to the reference scenario.

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[1] The approach is mainly demand driven in the sense that the effects on and possible constraints from the electricity grid and the power generation sector are not considered.

[2] The analysis in this paper, in particular parts in Sections 2 and 4, builds upon the vehicle technology characterization developed in Nemry et al. (2009), which includes estimates of fuel and electricity consumption and costs of different vehicle technologies (BEV, PHEV40). The current version of the paper is based on literature available up to 2010.

[3] Energy density refers to the amount of energy (measured in joules) per unit volume (or mass). Power density refers to the amount of power (measured in watt) per unit volume (or mass).

[4] IHS Global Insight (2009) reports that extensive use of HVAC systems for cabin heating and cooling will increase energy consumption and reduce the range by as much as 40%

[5] Learning and economy of scale effects are mostly expected at battery pack manufacturing level, e.g. moving from batch to continuous manufacturing process.

[6] Some of the models announced are actually correctly classified as quadri-cyles, not all of which comply with car safety standards (e.g. G-Wiz by REVA). Some others fall into the minivan category.

[7] AEA (2009) has identified three main risks as follows. First, battery failure would translate into an important bill for the car owner. Second, the value of the battery upon re-sale of the vehicle will represent a large proportion of the value of the vehicle. In case of vehicle re-sale, the battery may need to be inspected prior to re-sale. The question is also how the residual battery value would be priced, given that battery performance (with most battery chemistries) degrades with use and charging. In general a massive penetration of EDVs might significantly affect the second-hand car market in the future. Third, the use of lithium-ion battery technology is still relatively new in the automotive market. This could aggravate concerns amongst consumers about battery failure.

[8] It is likely that new car ownership models will develop together with the marketing of electric cars. Car sharing and car leasing might for instance gain more popularity as it would release the burden of car charging by the user. Nevertheless, it would take considerable time for such models to become widely spread.

[9] Extension of the electric circuit, in compliance with safety standards, would for instance be needed in many cases.

[10] Via semi-fast charging (see section 2.4.1).

[11] Battery swapping, which would take about ten minutes, is currently investigated by Renault in collaboration with the company Better Place. Large scale implementation for all electric car types is not yet proven to be feasible; standardization of battery pack and location where it is fitted to the vehicle would be needed.

[12] The development of more attractive and flexible car rental or car sharing solutions would provide even more incentives for consumers to combine (electric) cars for short distance trips with other transport options for the longer trips.

[13] Total S.A., for example, committed to install charging spots in gasoline stations in Belgium.
[14] Ex ante assessments of these plans in terms of effects on the electric car market (and consequences on environment and energy) and on public budget were not found. It is not clear to what extent the expenditures will eventually be charged to the car user.
[15] Based on a survey Skippon and Garwood (2011) find that among public locations the likeliness of buying a BEV is increased mostly by the availability of recharging infrastructure at the work location, followed by town centre car parks or roadside, supermarket car parks, and petrol stations. The same ranking in public locations was found when respondents were asked about their intended main recharging point, although home charging was the most popular option. In contrast, in a survey carried out on behalf of the South and West London Transport Conference, the most popular location for charging points appear to be town centres, followed by home, work and supermarkets (Heller, 2007).
[16] Two projects planned covering 100 electric vehicles and 500 charging points (Daimler and RWE)
[17] A network charging was already installed by EDF over the last ten years (84 charging points through 20 arrondissements in Paris)
[18] An issue that deserves attention is that incentivising electric cars in cities might encourage the use of cars in urban areas, possibly at the expense of public transport. Car sharing could in the future represent an intermediate option between these two alternatives (see for instance the Autolib electric car-sharing system in Paris, with a 4000 car fleet, also planned to be extended to other European cities with 700,000 electric vehicles)
[19] For a comprehensive and detailed overview of the TREMOVE we refer to De Ceuster et al. (2007).
[20] EU27 countries + Norway, Iceland, Switzerland and Turkey
[21] TREMOVE is not a transport network model and does not enable to project baseline transport activity. It therefore requires an exogenous baseline demand projection.
[22] Choices are assumed to be made based on the generalized price for each mode, i.e., costs, taxes or subsidy and travel time cost per kilometre travelled.
[23] Driving conditions using the COPERT methodology
[24] The welfare effect of a policy change is calculated as the discounted sum of changes in utility of households, production costs, external costs of congestion and pollution and benefits of tax recycling. These benefits of tax recycling represent the welfare effect of avoiding public funds being collected from other sectors, when the transport sector generates more revenues.
[25] Either a garage, private parking place or public parking place with charging facilities.