Driving electric? A financial analysis of electric vehicle policies in France

Elisabeth Windisch

Université Paris-Est

Ecole Doctorale Ville Transports et Territoires
Laboratoire Ville Mobilité Transport (LVMT)

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A financial assessment of electric vehicle policies in France

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par Elisabeth Windisch

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Sous la direction de Fabien Leurent

Composition du jury :
Marc IVALDI, Ecole des Hautes Etudes en Sciences Sociales, Président
Bruno FAIVRE D'ARCIER, Université de Lyon, Rapporteur
Barbara LENZ, Humboldt-Universität zu Berlin, Rapporteur
Francis PAPON, IFSTTAR, Examinateur
Fabien LEURENT, Ecole des Ponts ParisTech, Directeur de thèse

Summary

In recent years, electric vehicles have come to the forefront of public transport policies. They are seen as remedy for various pressing public concerns and are thus increasingly benefiting from supportive policy measures. Such measures remain contested: their impact on actual vehicle uptake rates, their sustainability, usefulness and justification are far from being self-evident.

This study aims at uncovering the effect of financial demand-side public policy measures on i) the uptake rate of electric vehicles among private households in France, and ii) the public budget.

First, the context within which electric vehicles are to evolve is sketched. A comprehensive overview of the potential opportunities that come with the introduction of electric vehicles is given. An international policy review depicts public policy levers that are currently deployed in order to support the uptake of electric vehicles. A focus is put on financial demand-side measures. Preliminary conclusions on their effectiveness with regards to observed electric vehicle uptake rates in the various countries reviewed are drawn.

Next, the potential market for electric vehicles among French households is explored. Besides financial aspects, socio-economic obstacles to electric vehicle uptake among private households are analysed. With the aid of scenario analysis that accounts for the many uncertainties with regards to future vehicle developments, costs and market trends, a forecast of the electric vehicles' potential up until 2023 is given. The applied disaggregate approach based on the database of the French National Transport Survey 2007/2008 allows identifying the most promising sets of financial public policy measures that are likely to guarantee certain electric vehicle uptake rates over the next decade.

Lastly, the effect of replacing one conventional vehicle by one electric vehicle on the public budget is investigated. Both, vehicle manufacture and use aspects are considered. The set up valuation model hereby accounts for direct and indirect financial impacts on the public budget. These comprise direct purchase subsidies, tax breaks, and tax income, as well as effects of changing employment situations that alter the amount of social contributions and unemployment benefits.

The study's findings and considerations allow for various suggestions for vehicle manufacturers and policy makers willing to support the uptake of electric vehicles. These are listed in the conclusions section which also sketches directions for further research.

Résumé

Au cours des années récentes, les véhicules électriques sont revenus sur le devant de la scène des politiques publiques en matière de transport. Considérés comme un remède possible à diverses préoccupations pressantes des pouvoirs publics, ils bénéficient d'un soutien croissant de leur part. De telles mesures de soutien demeurent contestées : en effet, leur impact sur le décollage effectif des ventes, leur soutenabilité, leur utilité et leur justification sont loin d'aller de soi.

Cette étude vise à éclairer l'impact des politiques publiques destinées à influencer la demande sur i) le taux de pénétration des véhicules électriques auprès des ménages français, et ii) les finances publiques.

Dans un premier temps sera brossé le tableau du contexte dans lequel les véhicules électriques ont vocation à se développer. Il sera proposé un panorama large des opportunités potentielles offertes par l'introduction des véhicules électriques. Une revue internationale des politiques publiques est conduite, qui décrit les leviers de politique publique qui sont aujourd'hui actionnés en soutien au véhicule électrique de par le monde. L'accent y est mis sur les mesures destinées à agir sur la demande. Des conclusions préliminaires seront proposées sur l'efficacité de ces mesures au regard des taux observés de pénétration du véhicule électrique.

Dans un deuxième temps, l'étude s'attache à évaluer le marché potentiel des véhicules électriques auprès des ménages français. L'analyse porte non seulement sur les déterminants financiers de la demande, mais aussi sur les obstacles socio-économiques à l'adoption des véhicules électriques par ces ménages. S'appuyant sur une analyse par scénarios qui permet de rendre compte des nombreuses incertitudes relatives aux évolutions à prévoir des véhicules, des coûts et des tendances de marché, une prévision du potentiel de demande à l'horizon 2023 est avancée. L'approche désagrégée qui est appliquée à partir de la base de données de l'Enquête Nationale Transports et Déplacements 2007/2008 permet d'identifier les combinaisons de instruments financiers de politique publique les plus à même de garantir certains niveaux de pénétration du véhicule électrique dans la prochaine décennie.

Enfin, l'impact sur les finances publiques du remplacement d'un véhicule conventionnel par un véhicule électrique est étudié. L'analyse porte à la fois sur les phases de production et d'usage du véhicule. Le modèle d'évaluation développé à cet effet tient compte des impacts directs et indirects sur les finances publiques. Sont pris en compte les subsidies directes à l'achat, les allègements fiscaux, les recettes fiscales, ainsi que les effets sur l'emploi.

Les conclusions et observations tirées de l'étude permettent de formuler diverses suggestions à l'attention des constructeurs automobiles et des décideurs publics affichant la volonté de soutenir l'essor du véhicule électrique.

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Abbreviations

ADEME	Agence de l'Environnement et de la Maîtrise de l'Energie (French Environment and Energy Management Agency)
ACEA	Association des Constructeurs Européens d'Automobiles (European Automobile Manufacturers Association)
ACORE	American Council On Renewable Energy
ARRA	American Recovery and Reinvestment Act
AVEM	Association pour l'Avenir du Véhicule Electrique Méditerranéen (Association for the Future of the Electric Vehicle in the Mediterranean)
BMLFUW	Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft (Austrian Ministry for Agriculture and Forestry; the Environnment and Water Resources)
BEV	Battery Electric Vehicle
CAS	Centre d'Analyse Stratégique (French Strategic Analysis Center)
CBS	Centraal Bureau voor de Statistiek (Statistics Netherlands)
CCFA	Comité des Constructeurs Français d'Automobiles (Committee of French Carmakers)
CGDD	Commissariat Général au Développement Durable (French General Commission for Sustainable Development)
CRS	Congressional Research Service (United States)
CV	Conventional Vehicle
DCENR	Department of Communications, Energy and Natural Resources (Ireland)
DfT	Department for Transport (United Kingdom)

DGDI	Direction Générale de la Documentation et de l'Immigration (French General Commission for Documentation and Immigration)
DGEC	Direction Générale de l'Energie et du Climat (French General Commission for Energy and Climate)
DGFP	Direction Générale de la Fonction Publique (French General Directorate of)
DOE	Department of Energy (United States)
EC	European Commission
EIA	Energy Information Administration (United States)
EM	Electromobility
ERTRAC	European Road Transport Research Advisory Council
EPoSS	European Technology Platform on Smart Systems Integration
ESB	Electricity Supply Board (Ireland)
ESMT	European School of Management and Technology
ETC/ACC	European Topic Centre on Air and Climate Change
EV	Electric Vehicle
FCEV	Fuell Cell Electric Vehicle
HEV	Hybrid Electric Vehicle
IA-HEV	Implementing Agreement for co-operation on Hybrid and Electric Vehicle Technologies and Programmes (of the IEA)
IEA	International Energy Agency
INSEE	L'Institut National de la Statistique et des Etudes Economiques (French National Institute for Statistics and Economic Studies)
ITF	International Transport Forum
KBA	Kraftfahrt-Bundesamt (Austrian Federal Motor Vehicle Transport Authority)
LME	London Metal Exchange
MEDDE	Ministère de l'Ecologie, du Développement Durable et de l'Energie (French Ministry of Ecology, Sustainable Development and Energy); former MEEDDM

MEEDDM	Ministère de l'Ecologie, de l'Energie, du Développement durable et de la Mer (French Ministry of Ecology, Energy, Sustainable Development and the Sea); later MEDDE
METI	Ministry of Economy, Trade and Industry (Japan)
NOISE	Noise Observation and Information Service for Europe
NPE	Nationale Plattform Elektromobilität (German National Platform for Electromobility)
OLEV	Office for Low Emission Vehicles (United Kingdom)
PEV	Plug-in Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
SAE	Society of Automotive Engineers (United States)
SEAI	Sustainable Energy Authority of Ireland
SNLVLD	Syndicat National des Loueurs Longue Durée (French National Association of Long-Term Car Rental Agencies)
TCO	Total Cost of Ownership
SOeS	Service de l'Observation et des Statistiques (French Observation and Statistics Department); (of the CGDD)
UCLA	University of California, Los Angeles (United States)
UN	United Nations
Urssaf	Unions de recouvrement des cotisations de sécurité sociale et d'allocations familiales (French Social Security and Family Allowance Contribution Collection Offices)
USAID	United States Agency for International Development
WHO	World Health Organisation
WRI	World Resources Institute

Abstract

In recent years electric vehicles have come to the forefront of national and international transport policies. Electric vehicles are seen as panacea for many pressing public concerns and are thus increasingly benefiting from supportive and potentially costly public policy measures. These policies remain, however, contested. Their impact on actual vehicle uptake rates, their sustainability, usefulness and justification are far from being evident.

This work attempts to uncover the effect of public policy measures on the uptake of electric vehicles. A focus is put on demand-side fiscal policy measures that are to render electric vehicles increasingly interesting for private households. Also, the impact of electric vehicle manufacture and use on the public budget is traced. Conclusions on whether replacing a conventional vehicle by an electric vehicle is financially advantageous for the public purse are drawn.

We address the topic of this study by giving first a comprehensive overview of potential opportunities that electric vehicles are expected to bring about. The necessity of public policy for assuring a sustainable development of an electromobility system and for initiating their successful introduction is explained. Market barriers and drivers are explored that help in identifying where and how electric vehicles are likely to evolve first. Subsequently, we explore specific demand-side policy measures that have been put in place on the European level and in France. Also various other nations are explored serve as a suitable benchmark. An international overview of electric vehicles sales up until the end of 2012 allows preliminary conclusions on the effectiveness of policy measures and vehicle offers.

Subsequently, we address the single vehicle user in France in more detail. A financial analysis of vehicle purchase and usage costs reveals cost differences between electric and conventional vehicles. Conclusions on the financial viability of electric vehicles are drawn. Several cost parameters are explored in more detail in order to derive the specific conditions under which the purchase of an electric vehicle is more financially advantageous for a private household than the purchase of its conventional counterpart.

The calculation model developed is then used to identify potential EV households in France. Potential EV households are defined to be households that i) are motorised, ii) show to have access to an adequate car parking space where battery recharge infrastructure can be installed, iii) show vehicle usage behaviour that is in line with the range limitations of an electric vehicle, and iv) show household and vehicle usage characteristics that allow for a cost advantage with respect to the electric vehicle when compared to its conventional counterpart. With the help of the French National Transport Survey 2007/08, households that comply with this defined set of criteria and are identified. Further characteristics of the households identified are analysed. We believe that the identified households will be the first among which private demand for this "new" vehicle technology will evolve.

Forecasts on the development of cost parameters, technological developments and electric vehicle acceptance allow then for predictions on the evolution of the identified electric vehicle potential in the future. Various policy scenarios are tested in order to derive a set of financial policy measures that allows maintaining the identified electric vehicle potential within certain thresholds. For estimating the actual vehicle demand that is likely to evolve from the identified potential, we revert to macroeconomic data on vehicle sales. This helps to identify the annual number of households that constitute the electric vehicle potential and that will actually be in a vehicle purchase process within the years in question. Approximations on cumulative sales numbers up until 2023 under the various established scenarios are made.

Finally, we set up a comprehensive valuation model that allows tracing the financial impact of an electric vehicle on the public budget. Vehicle manufacture and use factors are accounted for and compared with those of a conventional vehicle. The valuation model takes industrial and social effects (i.e. social contributions and unemployment benefits) on the public budget into account. These are a result from activity changes in the concerned industry sectors.

The application of the set up models give manifold insights into the potential electric vehicle market in France, the effectiveness of policy measures and their impact on the public budget. French households appear to be generally well adapted to the needs and limitations of electric vehicles: 35 % of French households are motorised, have access to parking infrastructure where recharge infrastructure installations could be carried out, and show vehicle usage behaviour that would not be constrained if a limited-range vehicle were to be integrated in the household's fleet. Under the policy settings as of end 2012 (implying an electric vehicle purchase bonus of EUR 7,000), 28 % of French households are found to demonstrate the above characteristics *and* to be able to generate a financial advantage from an electric vehicle purchase when compared to the purchase of a conventional vehicle. In case the vehicle purchase bonus

was to be at a level of EUR 5,000 (as in the first half of the year 2012) the percentage found drops to 3.5 %. This underlines the sensitivity of results of our study to the purchase bonus. Regional differences identified are remarkable: whereas households in predominantly rural areas appear to be much better adapted to electric vehicle uptake than households in dense urban areas, the latter will be able to more easily generate a financial advantage from an electric vehicle purchase. Especially preferential parking policies and tariffs for electric vehicle owners will make such cost advantages possible.

Up until 2023, the purchase bonus appears to be an important policy measure in order to maintain a "financially" reasoned EV potential from which actual EV demand is expected to evolve. In case the purchase bonus does not drop underneath EUR 4,000, we estimate in our baseline scenario potential cumulative EV sales to private households of up to 3.9 million vehicles up until 2023. However, for this number to actually materialise, all identified potential electric vehicle households being in a vehicle purchase decision have to decide for an electric vehicle. Certainly, various (public policy) measures will be a primordial condition for this to happen and also for avoiding the excessive public spending for the costly purchase bonus. Indeed, we identify that the domestic manufacture and use of an electric vehicle entail financial gains for the public budget when replacing a conventional vehicle. However, this is only valid without considering the transfer of the purchase bonus. This latter consideration results in a net loss for the public purse.

These findings allow for several suggestions for vehicle manufacturers and public policy makers willing to support the uptake of electric vehicles.

We suggest vehicle manufacturers and their respective retailers to be present all along a customer's vehicle purchase experience. Customers are to be made aware of the electric vehicle technology itself as well as of possible purchase modalities and supplementary offers. They should be accompanied throughout the whole process in order to learn and reflect about the rationale behind their vehicle purchase behaviour, their actual mobility needs, and hence, the actual requirements on the private vehicle. Especially managers of corporate or public fleets – the likely first niche markets for the electric vehicle – should be closely accompanied and assisted in their vehicle purchase process. Further, vehicle manufacturers are suggested to reflect upon "all-in" solutions that provide the vehicle purchaser not only with the vehicle but also with the necessary recharge infrastructure. The latter could be provided and installed by the vehicle manufacturer (or his contractors), maybe even at his costs in case where this is a viable option (e.g. in predominantly rural areas where recharge infrastructure installation will frequently entail little construction works).

Policy makers are suggested to reflect upon the efficiency of the national purchase bonus. A configuration of the purchase bonus to customers' needs appears to be appropriate: in regions where a cost advantage for an electric

vehicle is comparatively easy to achieve (e.g. in dense urban areas where preferential parking tariffs can have a significant financial impact on the private vehicle user) the vehicle purchase bonus might be more effective in the form of an infrastructure installation bonus. Especially in urban areas the installation of such infrastructure is expected to be frequently costly and tedious for the private vehicle owner. Further, especially in such urban areas, strong policy measures with regards infrastructure installation will be a primordial condition to the uptake of electric vehicles. The French "droit à la prise", giving an electric vehicle user the right to install recharge infrastructure in co-owned parking facilities, is likely to be insufficient for stimulating electric vehicle demand among those who rely on such co-owned facilities.

France proves to combine various EV-advantageous framework conditions which could enable the country to be a lead market in electromobility: the French electricity mix allows for an EV-favourable carbon-footprint; French public authorities appear to be highly EV-supportive and have started already early with the deployment of EV-favourable public policy measures; the French car manufacturers were (are) among the first ones to launch electric-drive fleets of the "new generation" on the market. This gives reason for hope that France can be successful in developing a domestic market for EVs, in becoming an internationally important player in electromobility, and in hereby benefiting from all the opportunities electromobility brings about.

Introduction

Context

In recent years there has been demonstrably increasing public interest in electric vehicles[1]. First models of the "new generation" of these vehicles have had their market launch in developed and in fast developing nations (IEA, 2011a; IEA, 2011b). The vehicle technology is believed to be a panacea for many pressing public concerns: a remedy for the automobile industry after the years of crises, a key to reducing the country's energy dependency, an answer to the increasing environmental impact of the transport system, an opportunity for the energy sector that is increasingly under pressure, and, finally, also a cost-effective, convenient alternative to the conventional vehicle that satisfies the consumer's evolving needs and expectations (EC, 2011b; ETC/ACC, 2009).

For taking advantage of all possible benefits, a whole electromobility *system* is to evolve (Sadeghian *et al.*, 2013). The system is to assure the best service to the consumer and, hence, ensure the successful uptake of this vehicle technology. Within this new system, traditional transport providers will interact with new mobility providers. The latter will not only assure the access to, and provision of, single transport means, but also their interconnection. They will provide new products and services that guarantee mobility services to the "connected" user, who will increasingly optimise their trips, energy needs, and vehicle recharging activities thanks to smart grids, smart phones, and real time information flows (Wallner, 2011).

Public policy makers have recognised the many potential opportunities that the introduction of electric vehicles can bring about. For ensuring their successful introduction and, moreover, a system development that is to the advantage of society as a whole, policy support has been initiated on various

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[1] In the context of this dissertation the term electric vehicles refers to *plug-in* electric *cars*. These cars' batteries can be recharged by connecting them to the electricity grid. While the plug-in *hybrid* electric car offers the opportunity to also rely on fuel, the *full* electric car imperatively relies on an external electricity source for charging its battery.

administrative levels, with various means, focusing on various concerned stakeholders.

Problem statement

Given that the introduction of electric vehicles (EVs) signifies not only the launch of a new product on the market, but also the build up of new supportive info- and infrastructures, the success of the EV's development lies in the hand of many stakeholders that are to work together. Consequently, public authorities wanting to support the system's development face a complex task.

A large portfolio of supportive policy measures is available to choose from: command and control instruments, economic instruments, procurement instruments, collaborative instruments, and communication and diffusion instruments. Many of the policy measures implemented so-far support the system's development by initiating the demand for EVs: demand-side stakeholders are incentivised by monetary means, such as a purchase subsidy, and non-monetary means, such as the provision of public recharge infrastructure, to take up the recently introduced EVs. Such policy incentives are disputed for various reasons.

First, the *justification* of such policy measures from a public welfare perspective is not apparent (ADEME, 2009; CGDD, 2011; Deutsche Bank, 2011). Materialising the EVs' potential benefits is far from self-evident: it necessitates the interplay of many stakeholders on national and international level. As long as framework conditions are not created that assure the right interplay of the concerned parties, EVs might develop without the awaited benefits for society as a whole (ETC/ACC, 2009). Public authorities that might follow diverse public policy objectives are likely to take different positions with regards to the justification issue. Whereas for some public authorities the introduction of electric vehicles primarily represents a means for reviving the automobile industry, other authorities might be primarily concerned with the environmental performance of an electric vehicle compared to the one of a conventional vehicle. Consequently, the potential benefits of electric vehicles might be weighted and valued differently by the concerned authorities. Such different possible perspectives give reason to the difficultly of creating an incontestable opinion on the justification of the vehicles' introduction and political support.

Second, the *sustainability* of such policy measures is questionable. The EV uptake rate will depend on many more determinants than only on the supportive public policy measures that are put in place. Besides prevailing market trends (i.e. electricity and oil prices), the market offer of electric vehicles and all their supportive info- and infrastructure will be a predominant factor for their success (Sadeghian *et al.*, 2013). All stakeholders of the electromobility system are to render the electric vehicle as an attractive alternative to the

conventional vehicle for the vehicle user and will play an important role in influencing the electric vehicle's uptake rate. Given that market trends and the future offer of electric vehicles are subject to many uncertainties, forecasting the whole electromobility system's development is a challenging task. Conceiving public policy measures that adequately respond to these developments is even more difficult: the financial impact of monetary measures on the public budget, as well as the effects of non-monetary measures on the transport system (for example with regards to preferential access rights) of public policy measures can only be vaguely estimated. Consequently, policy measures run the risk of resulting in unwanted effects and/or in an inequitable distribution of public resources (Kley *et al.*, 2010).

Third, the *cost-effectiveness* of such policy measures is put into question. There are certainly also other vehicle technologies that come with potential environmental and/or industrial benefits and that would consequently deserve public support in order to alleviate public concerns with the regards to the future of the prevailing transport system. Next to such alternative vehicle technologies, there are also other means to address current public concerns. The question arises whether electromobility is a cost-effective and indispensable alternative in comparison to other available options (Vogt-Schilb and Hallegatte, 2011; McKinsey, 2009b).

Objectives

This dissertation mainly addresses the potential outreach and financial sustainability of policy measures stimulating the demand for electric vehicles. It does so by investigating the effect of demand-side measures on the EVs' potential in the private household market. The interrelation between policy measures and resulting potential vehicle demand is uncovered. For doing so, the characteristics of households and their vehicle usage behaviour are analysed. This allows identifying those households for which the purchase of an electric vehicle is, on the one hand, practically feasible and, on the other hand, a financially interesting alternative to the purchase of a conventional vehicle. Demand-side public policy measures that aim at making sure that an electric vehicle increasingly becomes such a practically feasible and financially interesting solution for households are taken into account. A focus is put on *financial* measures – measures whose impact on the private vehicle user can be directly derived. The analysis takes territorial characteristics into account in order to derive which type of territory shows most electric vehicle-favourable characteristics.

The work further provides a methodology for a thorough investigation of the potential impact of the introduction of electric vehicles on the public finances – an analysis that goes far beyond the evaluation of direct financial policy measures.

This study does not attempt to quantify any non-financial aspects of the introduction of electric vehicles. However, they are not left aside and recurrently serve as object of discussion. Further, the study does not attempt to make any conclusion on the actual sustainability of specific measures in the country's current economic context. However, it does provide a number of considerations that can facilitate such analyses in the future.

The study is limited to an analysis of the market of electric vehicles among private households. Potential sales to firms or public authorities are not investigated. The geographic scope of the study is France. A specific focus is put on the Île-de-France region (the Paris region). Investigated public policy measures mainly refer to financial demand-side measures that have direct impact on the private (electric) vehicle user. Financial measures supporting research and development activities are not object of this study.

Approach

The approach followed in this work in order to tackle the issues raised above is threefold:

- The study proposes an *economic analysis* of the impact of electric vehicles. First, this economic analysis is applied to households in order to deduce potential electric vehicle uptake rates in the household market: the household takes the role of the vehicle purchase decision maker and is put in the centre of the study. Private households and their purchase decisions are seen as main drivers or barriers to the whole development of an electromobility system. Second, the economic analysis is applied to public funds: the direct and indirect financial impacts of the production and use of an electric vehicle are investigated in order to verify whether the public support of electric vehicles can be justified from a financial perspective.
- The study is based on a *systems thinking*: instead of exploring solely the impact of electric vehicles, also the importance, necessity and impact of their accompanying info- and infrastructures is recognised. With the introduction of electric vehicles a whole electromobility system is to evolve. Various considerations on how and in which form such a system might develop are discussed. The respective impact on the private vehicle user and the consequences for the public budget are analysed.
- *Prospective thinking* that underlies this work allows analysing various possible futures: scenarios of possible futures are designed and assessed in order to derive most reasonable fields of actions for policy makers and vehicle manufacturers. Extreme case scenarios explore the expected bandwidth of the electric vehicles' potential over the upcoming decade.

The following section describes in more detail how specific research questions are tackled.

Thesis overview

Structure

Figure 0.1 gives a graphical interpretation of this dissertation's structure. Chapter 1 outlines the background and framework of the study. It serves as input for all subsequent chapters. The international policy review of Chapter 2 is a self-standing study. Its findings serve all subsequent chapters for defining necessary assumptions and scenarios. Chapters 3, 4 and 5 constitute a logical sequence of work. They build up on each other and progressively introduce the applied methodology that allows identifying the EVs' potential up until 2023. As Chapter 2, Chapter 6 can also be seen as a self-standing piece of work. Underlying assumptions of Chapter 6 build up on findings obtained from Chapter 2 and 3. All chapters result in findings that are comprehensively summarised and discussed in the conclusion.

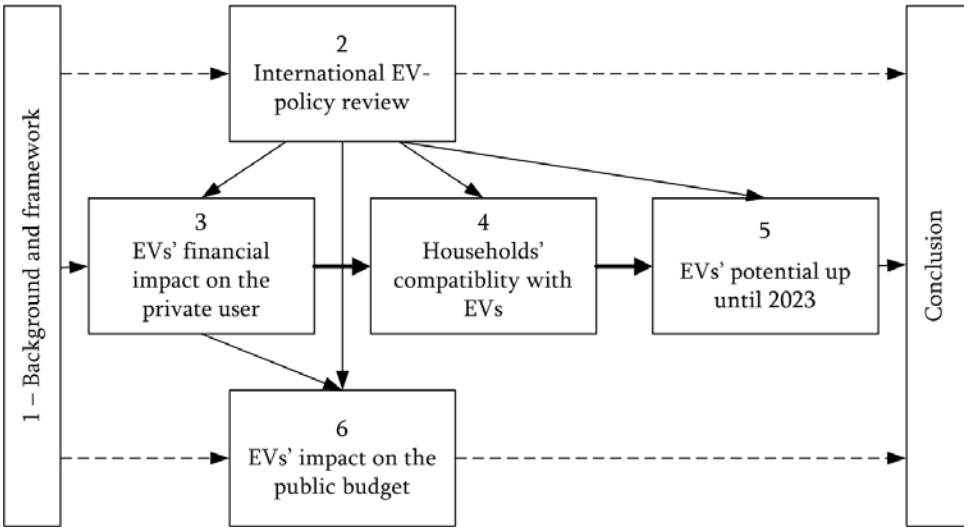

Figure 0.1: Thesis structure

Contents and specific research questions

Chapter 1, *Background and framework*, shows the framework in which electric mobility is to evolve. The vehicle technology in question is introduced, and its potential benefits for France are sketched. The crucial role of public policy measures is made clear. The reader gets a comprehensive overview of market barriers and market drivers of this new technology. Approaches to understanding and predicting vehicle purchase behaviour are introduced. This helps the reader to situate this study's approach to uncovering the EVs' potential within existing methods for tackling similar research questions. Based on mainly recent literature, the chapter mainly deals with the following questions:

- *What are the characteristics of the EV technology?*
- *What are the potential opportunities that come along with the introduction of EVs?*
- *What is the role of public authorities in the EV introduction and uptake phase?*
- *What are the barriers and drivers to private EV uptake? Where are the expected first market niches?*
- *What are the techniques for identifying and predicting the EV's potential?*

Chapter 2, *International EV-policy review*, aims at creating understanding of possible policy levers that can be applied for supporting EV technology. Based on reviewed literature, an inventory of possible public policy measures is developed. A review of official policy documents as well as of secondary literature allows identifying main intentions behind the public support of electric vehicles of the reviewed nations. Deployment objectives and policy measures of the reviewed countries are compared with each other. The EV deployment progress, as of mid or end 2012 is examined. This allows preliminary conclusions on the effectiveness of the policy measures put in place. Mainly the following questions are tackled:

- *What are the means for public policy support for alternative fuel vehicles?*
- *For what reasons and by which means do public authorities support the uptake of electric vehicles?*
- *How effective have public policy measures been so far? How effective can they be expected to be?*

Chapter 3, *EVs financial impact on the private user: a total cost of ownership approach*, provides an analysis of the total cost of ownership (the TCO that comprise a vehicle's purchase *and* operating costs) of different vehicle types for a private vehicle user. The set up calculation model accounts for various monetary policy measures that have effect on the either the vehicle purchase or the vehicle usage costs. Further, the model allows investigating the impact of various household and vehicle usage characteristics that have impact on the TCO of electric or conventional vehicles. Also market trend parameters important for estimating future cost items are integrated in the model. Sensitivity analysis reveals the most crucial parameters to the TCO of different vehicle types; break-even analysis shows under which circumstances an EV is cost competitive to a CV (conventional vehicle). The chapter deals with the following research questions:

- *Can EVs be cost competitive to their conventional counterparts from a private consumer's perspective? If yes, under which circumstances?*

- *What are the most decisive cost parameters? Consequently, which are the most promising financial policy levers for influencing the TCO of either vehicle type?*
- *Among the currently offered EV technologies and EV business models explored here, which is the most interesting one for the private consumer?*

Chapter 4, *Households' compatibility with EVs: a constraints analysis*, introduces the next step in exploring the EV's potential among private consumers in France. Next to the financial aspect, also more practical aspects of EVs that will have impact on their uptake rate are explored. With the aid of the French national transport survey 2007/08, the compatibility of French households with EVs is explored: only households that show i) to be capable of recharging an EV at their residence as well as ii) vehicle usage behaviour that is compatible with an EV's range limitations (in case of the full electric vehicle) are considered to be potential EV buyers. Those households for which the EV furthermore turns out to be a financially interesting alternative (hereby using the set up TCO calculation as introduced in Chapter 3) are considered to be "EV-qualifying" households. They constitute the pool from which EV sales to households are likely to materialise – the EVs' *potential* among households. The sketched approach allows tackling the following main research questions:

- *What percentage of French households shows to be compatible with EVs from a practical and/or financial perspective?*
- *What are the regional differences of EV-compatibility? Which type of region shows to be most adapted to the uptake of EVs by private households?*
- *What are the most constraining factors to EV uptake by private households? Which policy measures therefore appear to be most effective?*
- *What are the specific characteristics of households compatible with EVs?*

Chapter 5, *Forecasting the EVs' potential up until 2023*, builds up on Chapter 4. It explores how the EVs' potential will develop over time. In order to account for changing cost parameters, advancing technologies and evolutions in consumer attitudes over time, various scenarios are introduced and modelled. The impact of diverse policy packages is tested. Further, policy packages that allow maintaining a certain level of the EVs' potential until 2023 are identified. Macro-economic data on vehicle sales then allows estimating the EV's "realisation potential" – the actual EV sales that might materialise among the households that qualify for an EV (under all stated, motivated and discussed hypotheses). The following research questions are dealt with:

- *What are plausible forecasts for the various parameters defining the total cost of vehicle ownership of different vehicle technologies?*

- *Which development trends demand which policy packages in order to maintain a stable EV potential up until 2023?*
- *Which share of the identified EVs' potential can be expected to materialise in EV sales? Which cumulative EV sales to private households can therefore be expected up until 2023? Under which conditions? Assuming which policy packages?*

Chapter 6, *EVs' impact on the public budget: an integrated evaluation model*, proposes a methodology that allows estimating the impact of the replacement of a CV with an EV on the public budget. Vehicle manufacture and use factors are considered. Different scenarios vary the assumptions behind the localisation of the manufacture and use of the vehicle (either within or outside the French territory). The set up model accounts for financial proceeds stemming from i) taxation policies (in the production and use phase of the vehicle), ii) EV-specific financial policy measures, as well as from iii) employer's and employee's social contributions, and iv) unemployment benefits as a result of changes in the country's employment situation, which is, in turn, a result of changing levels of activity in the concerned industry sectors. The application of the model allows embarking upon the following research questions:

- *How is the public budget impacted by the replacement of a CV with an EV considering the financial proceeds stemming from manufacture and use of the vehicle?*
- *Which type of financial proceeds has the most important impact on the public budget?*
- *How do the financial proceeds change with changing assumptions on the localisation of vehicle manufacture or use? Which is the most favourable manufacture and use scenario for France's public budget?*

The **Conclusion** provides the reader with a summary of the study's contribution, major results, and suggestions for EV manufacturers and policy makers. Propositions for further research are outlined.

Author's comments

This dissertation is based on various research reports on behalf of the Renault group, on publications and on conference proceedings that have been published in the period from 2011 to 2013 (or that are, as of February 2013, in the process of review). The author was partly main author, partly co-author of this work.

More specifically, this dissertation is based on the following (including 1 publication and 6 conference proceedings – see the bibliography for details):

Windisch (2013a), Windisch (2013b), Leurent and Windisch (2013), Windisch (2012), Windisch (2011a), Windisch (2011b), Leurent and Windisch (2011)

Most of these references were largely adapted, modified and updated in order to fit into the specific context of this dissertation. However, there are two exceptions with regards to the most recent conference proceedings: Chapter 3 largely equates to *Windisch (2013)*; Chapter 6 largely equates to *Leurent and Windisch (2013)*. For this reason, the author of this dissertation does not claim Chapter 6 to be a result of her independent work.

The research underlying this dissertation was partly financed by the Renault group thanks to a research contract established between Renault and the Ecole des Ponts ParisTech in the framework of the 'Sustainable Mobility Institute Renault ParisTech'. Nevertheless, it was carried out in the author's complete independence of reasoning. The author is the sole responsible for all assumptions and findings stated in this dissertation.

Chapter 1
Background and framework

1.1 Overview

1.1.1 Objective of this chapter

This chapter gives the background of the work presented subsequently. The reader obtains a comprehensive overview of electric vehicle technology, its justification, the opportunities it creates and the challenges it faces in the prevailing mobility system. Step-by-step, the main object of this doctoral research is introduced: the private individual as decision maker who faces the EV as a new vehicle choice alternative under the influence of policy measures.

The context under which electric vehicles are to develop is uncovered in more detail, and potential opportunities that come with the introduction of electric vehicles are discussed. Uncertainties around the electric vehicle market development are sketched, and methods that attempt market forecasts are presented. These help understand this work's approach to understanding and predicting the electric vehicle's potential among private households.

1.1.2 Chapter outline

First, Section 1.2 introduces the chapter by giving the broad context of this study: the reader understands why the introduction of EVs entails the build up of a whole electromobility (EM) system. Section 1.3 gives the definition of the object of this work by providing a brief overview of the current EV technology and by delimitating the exact technology we are interested in. Section 1.4 uncovers the potential opportunities related to the introduction of EVs. We identify opportunities for the French (automotive) industry, for society in general as well as for the energy sector. In Section 1.5, we discuss the primordial

role of public authorities. Section 1.6 reveals the framework conditions under which a potential EV market is to develop. Barriers and drivers to EV uptake from a private customer's perspective, the focus and main object of this doctorial research, are listed and discussed. Section 1.7 introduces familiar approaches to EV market forecasts and analyses their limitations.

1.2 From EV to EM system

Plans for the development and distribution of electric vehicles have recently come to the forefront of transport policies both in developed countries and in fast-developing countries. Especially plug-in electric vehicles (collectively abbreviated in this work as *EVs*), that can or imperatively need to be powered by electricity sourced from connecting the vehicle's battery to the electricity grid, are frequently seen as panacea for many pressing public concerns. These range from the energy security of nations to the recent downturn of several nations' automotive industries and the environmental impact of the transport system. [2]

In spite of the electric vehicles' potential benefits, their development and deployment are neither an evident nor a natural consequence of any public concerns. Introducing electric vehicles means offering a new means of transport, which has to find its legitimacy next to the existing modes in order to gain market share. In the case of the electric vehicle, this is not a straight-forward task: its characteristics largely resemble the ones of the conventional internal combustion engine vehicle (CV) – the product of a well-established industry sector that is supported by well-functioning distribution, supply and service channels that developed with the increasing diffusion of CVs. While the CV could develop and gain momentum at a time when no alternative individual means of transport allowed for a comparable freedom, the EV will face fierce competition from this latter vehicle technology. Given that the EV does not offer any additional speed or range advantages, its success is certainly not self-evident. Especially the full electric vehicle, that relies on external electricity supply and is considered a "limited-range" vehicle[3], does not appear to be a convincing vehicle technology for the private vehicle user at first instance.

Furthermore, deploying EVs is more complex than introducing a new transport means in the existing mobility system: Essentially, it entails the

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[2] Unless stated differently, in the particular context of this doctoral dissertation, plug-in electric vehicles (EVs) refer to plug-in electric *cars*, and conventional vehicles (CVs) refer to diesel- or petrol-driven *cars*.

[3] Its range lies with approximately 100-200 km – depending on the capacity of the vehicle's battery as well as on the usage of the vehicle – well beneath the range of a typical conventional vehicle.

creation of a whole new sub-system, an *electromobility system*, that will co-exist with the already established public transport, 'soft' mode, and conventional vehicle sub-systems. Every one of these existing systems is characterised by its spatial reach, its specific way of rooting in the relevant territory, and its set of stakeholders – as also the electromobility system will be. Since EVs are not expected to fully replace CVs in the short or medium term, their introduction will not entail the disappearance of the CV system or of any of its entities (Sadeghian *et al.*, 2013). Rather, the CV system will have to evolve and to expand in order to successfully create and establish the electromobility system. Existing stakeholders' strategies will have to change and their respective fields of activity will need to widen in case these stakeholders want to play an active role in the electromobility system. New value chains are to be created, new services and business models to be established. In this perspective, the appearance of new stakeholders in the mobility landscape is likely. In an increasingly service-oriented mobility system, traditional vehicle manufacturers could certainly remain the main providers of individual mobility, or, at least, of the transport means. However, service-oriented mobility 'packages', which provide the customer not only with a vehicle, but also with the necessary information system, energy, asset financing, insurance, and maintenance services – for example on the basis of a mileage-based subscription fee – could, for example, also be provided by the up until now "traditional" data or energy providers. EVs, which come with an increased demand for information that allows optimising the vehicle's usage, as well as with the need for new battery recharge infrastructure, might make the latter scenarios increasingly likely. Whichever reality will evolve, changes in "old" and "new" stakeholders' relationships and partnerships will be a consequence of, but also a paramount condition for the successful development of the electromobility system. Only then, the virtuous cycle of increasing EV demand, increasing economies of scale in manufacturing, and decreasing sales prices will be set in motion. In consequence, the deployment of recharge infrastructure will become more and more justified, resulting in the provision of a denser infrastructure net, and in an increasing customers' confidence in the workability and benefits of this vehicle technology. And only then, demand-side actors will be willing to accept the range limitations and recharge requirements of full electric vehicles, turning them also into a viable alternative transport means (Sadeghian *et al.*, 2013).

Public authorities, the steering stakeholders of the existing and evolving system, will play a crucial role in helping overcome any system's inertia to changes. It will be their responsibility to initiate the system's evolution and to make sure its development is in line with the public interest. The electromobility system will then carry the potential to contribute to the well-being and development of our society as a whole, as many other technological developments have in the past.

The manifold stakeholders and their interrelations are cause for the difficulty of forecasting the system's development, and, more specifically, the potential demand for EVs in the upcoming years. As it is the case with any new product introduced on the market, EV demand (expressed by the system's demand-side actors) will be heavily dependent on the market supply (provided by supply-side actors). Both groups of actors will act under the influence of public policy measures (coordinated by the public authorities, the steering actors) that can change form, magnitude, and effect over the years. Reciprocally, these policies will likely evolve in accordance with the electromobility system's development. Finally, demand-side, supply-side, and steering actors act under the influence of market trends and their forecasts. Here, especially energy prices and their evolution are expected to have a major effect on the electromobility system's development, and the actors' willingness to supply and adapt to a new vehicle technology and its accompanying infrastructure. Figure 1.1 illustrates the discussed interrelations within the electromobility system.

The discussion makes clear that the development of the electromobility system is difficult to foresee, as is its potential impact on its stakeholders, or the actions of these latter ones either as a response to or as an incitation of the system's development. Electromobility's benefits and potential downturns for one or more current system's stakeholders can certainly only remain vague from today's point of view.

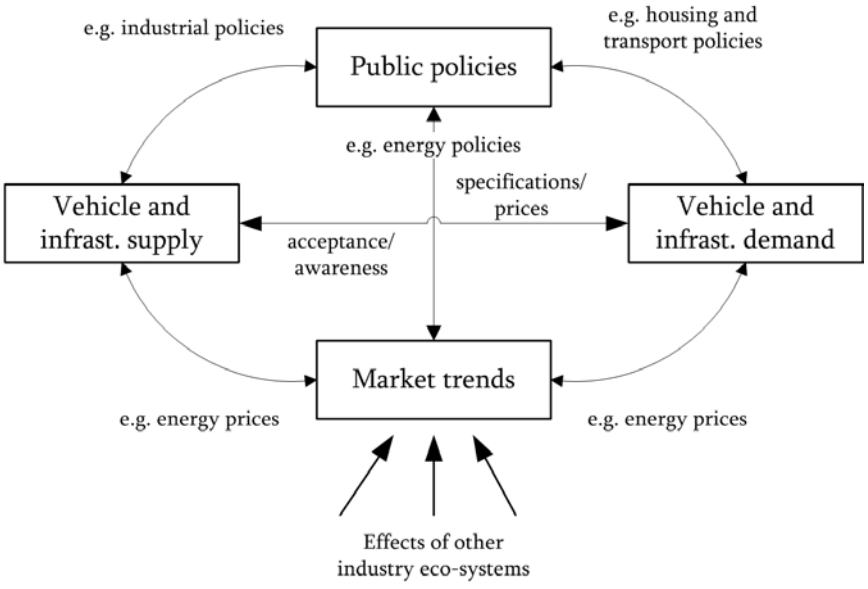


Figure 1.1: Interdependencies within the electromobility system

1.3 Overview of electric vehicle concepts

The electrification of the vehicle's drive train embraces a wide range of technology options. Different vehicle concepts have changing degrees of vehicle electrification. Besides hybrid electric vehicles that combine a conventional internal combustion engine with an additional electric propulsion system to improve the overall efficiency of the vehicle, there are also fully electrified vehicles which are exclusively driven by an electric power-train (ETC/ACC, 2009). Figure 1.2 indicates five progressive levels of hybridisation and two types of all-electric power-train vehicles (Michelin, 2011a), which are all described thereafter.

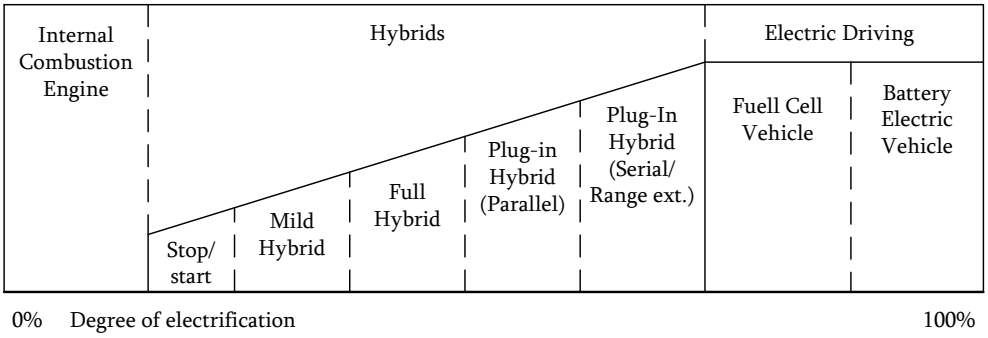


Figure 1.2: Degrees of electrification of different vehicle drive-train concepts (from Michelin, 2011a)

Micro hybridisation characterised by the vehicles' start and stop technology is the first level of hybrid functionality. The engine stops when the vehicle comes to a halt and automatically restarts when the vehicle accelerates again. Fuel economy gains in urban use can be up to 15 %. Micro-hybridisation does not need a specific battery; a starter generator acts as an electric motor to assist the reinitiating of the internal combustion engine motor. The pioneer series vehicle for this technology was the Citroen C3, launched in 2004. (*ibid.*)

Mild hybrid vehicles have two additional functionalities compared to the micro hybrids, namely: regenerative braking and assisted acceleration (boost). Upon braking, the kinetic energy is no longer only dispersed as heat; the electric motor works as a generator and sends some of the energy back towards accumulators (batteries or ultracapacitors) which are thereby recharged. A small electric motor provides acceleration assistance. The pioneer series vehicle for this technology was the Honda Insight launched in 1999. (*ibid.*)

Full hybrids (HEV) show a more advanced electrification that allows the vehicle to be propelled by the electric motor, thanks to a disconnection from the internal combustion engine. This 'zero-emission' mode is possible for around several kilometres only because of the low capacity of the batteries used. The

size of the internal combustion engine can be significantly reduced because of the electric assistance in acceleration and stop-and-start driving situations. The dual power-train allows the internal combustion engine to operate in more favourable and continuous conditions. The hybrid system seamlessly switches between the electric motor and the ICE depending on the power demand. Full hybrid vehicles show fuel consumption benefits of about 25 to 30 % in standard test driving cycles, compared to conventional ICE vehicles.

The hybrid-vehicle components can be arranged in a variety of ways. In a ***series hybrid***, the electric motor drives the vehicle, whereas the ICE is not directly connected to the drive train. The ICE is used to drive an electric generator which provides electricity for the electric motor and charges the battery. ***Parallel hybrid*** systems allow combined and individual propulsion of the vehicle by the electric motor and the ICE as they are both connected to the drive-train. The ***split hybrid*** combines both systems and allows benefiting from the advantages of the two latter systems. Today's most popular split hybrid vehicle is the Toyota Prius, which has been introduced in 1997. (Michelin, 2011a; ETC/ACC, 2009)

In the **rechargeable hybrid** (a hybrid electric vehicle with a plug-in option, a PHEV), the battery is not only charged by the on-board generator, but can also be charged with electricity from the power grid by connecting it to according recharge infrastructure. The electric motor and the batteries are respectively dimensioned in power and capacity to allow for an electric range of several tens of kilometres. The ICE alone, reduced in size and power in a process of downsizing, can drive the vehicle over long distances in optimised engine phases. General Motors' Chevrolet Volt (launched in 2010) is proposed with a particularly high electric driving range due to a large traction battery, whereas the conventional engine, a so-called 'range extender', mainly functions as generator in case of a low status of battery charge. The ICE does not in any case directly activate the drive train and simply extends the vehicle's range thanks to its battery charger function This engine is controlled by on-board electronics (Michelin, 2011a; ETC/ACC, 2009).

The **fuel cell electric vehicle** (FCEV) uses hydrogen as fuel to produce its electric energy on-board and autonomously. Batteries and/or ultra-capacitors can serve as back-up for the fuel cell. (Michelin, 2011a)

The **full electric vehicle**, also called **battery electric vehicle** (BEV), is the simplest form of an electric vehicle and has a minimalist architecture of battery/controller/electric motor, without any auxiliary internal combustion engine or electricity generator (except if the electric motor is used for kinetic energy recovery). The battery is thus recharged by plugging the car into a charging device. Battery electric vehicles show the highest tank-to-wheel energy efficiency of all vehicle propulsion systems due to the efficient operation

of the electric motor and efficiency gains through regenerative braking. In contrast to these favourable characteristics, the vehicle is limited with regards to performance and driving range by the battery technology's potentials (*ibid.*).

The focus of this study is plug-in electric vehicles, grouping the rechargeable plug-in hybrid electric vehicles (PHEVs) and the battery electric vehicles (BEVs). If not stated differently, the term electric vehicle (EV) collectively refers to both PHEVs and BEVs. The study's specific focus is put on BEVs that imperatively rely on battery recharging infrastructure on private or public grounds.

1.4 EV benefits – the opportunities for France

The development of an electromobility system as described in the introduction of this chapter comes along with several opportunities for a nation like France. In the following we describe opportunities that are, from our point of view, of major interest. First, we focus on opportunities that are likely to open up for a set of industry stakeholders (1.3.1). Next, opportunities for society as a whole are analysed (1.3.2) – opportunities that are difficult to allocate to a more specific stakeholder. They concern the nation as a whole. Finally, we discuss the important role of the energy sector (1.3.3) in a developing electromobility system, and how also this sector can benefit from the introduction of EVs.

We deliberately choose not to discuss the potential benefits of EVs for the single vehicle user. Seeing the single user as the main driving source, or, alternatively, main hindrance, to the success of the electromobility system, we put the single user in the centre of this work. Barriers and drivers to EV uptake from a single user's standpoint will be discussed separately, in Section 1.6 of this chapter, before the large remainder of this work is specifically dedicated to their perspective.

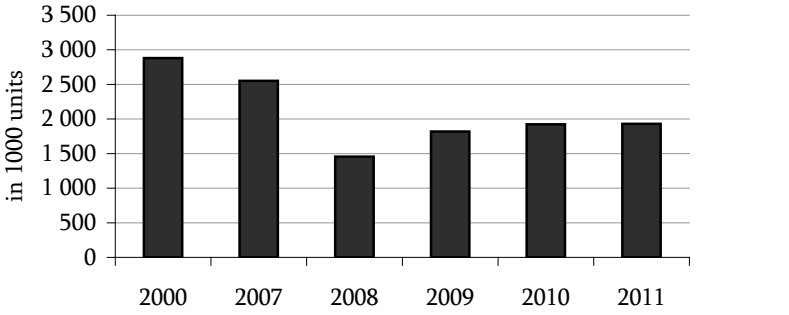
1.4.1 An opportunity for the French (car) industry

Recent trends in the French car industry

The French automotive industry has been facing severe problems in recent years. Figures 1.3 to 1.6 sketch some observable trends between 2000 and 2011. The most important observations that can be drawn for the stated time period are summarised as follows:

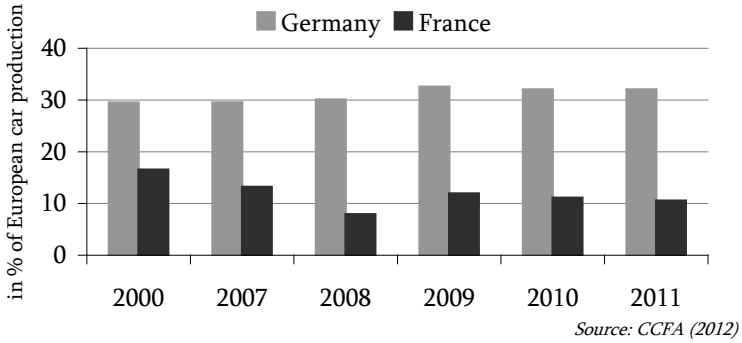
- domestic passenger car production volumes fell by over 30 % (see Figure 1.3 for the total production volumes)
- France's share of European passenger car production volumes decreased from around 15 % to 10 %, while that of Germany increased from 29 % to 32 % in the same period (see Figure 1.4)

- the number of jobs directly related to the car manufacturing sector decreased by almost 30 % (see Figure 1.5), entailing an approximately fivefold higher employment loss in the related industry sectors (ACEA, 2012c)
- the sector's trade balance has turned from markedly positive to increasingly negative (see Figure 1.6), which is reflected by the fact that in 2011, only one third of newly registered vehicles in France were produced in France (MRP, 2012).



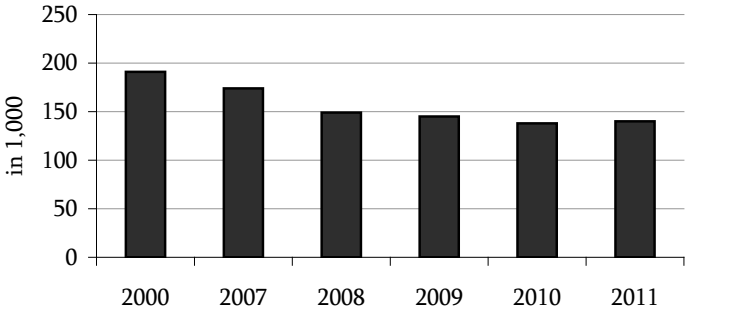
Source: CCFA (2012)

Figure 1.3: Domestic passenger car production in France



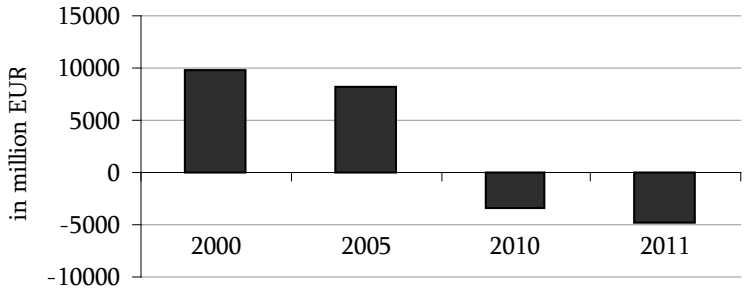
Source: CCFA (2012)

Figure 1.4: Share of European passenger car production volumes



Source: CCFA (2012)

Figure 1.5: Number of jobs in the car manufacturing sector in France

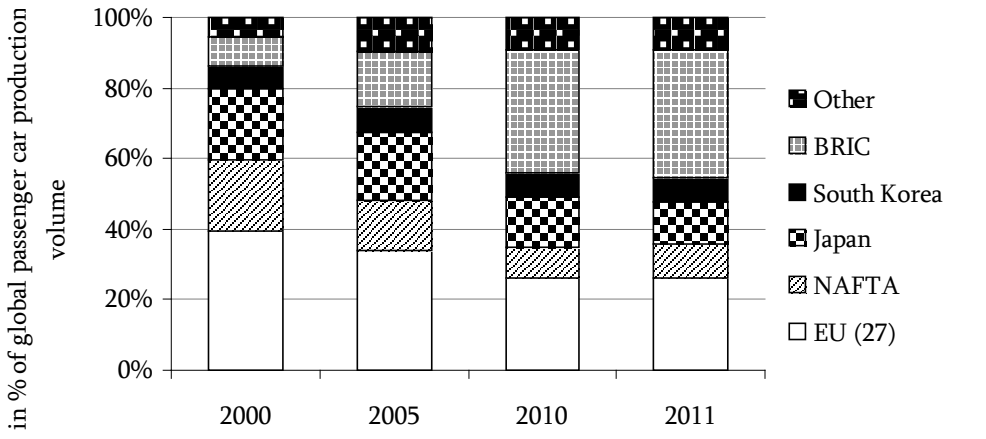


Source: CCFA (2012)

Figure 1.6: Trade balance of the French car manufacturing sector

Since the car manufacturing sector is strongly linked to many other industry sectors, these observations are all the more alarming: the loss of one unit of value added in the car manufacturing sector entails the loss of 4.1 value units in the whole national economy (MRP, 2012). Hence, reducing production levels in the car manufacturing sector causes activity loss and, consequently, employment cuts in the whole industry. More specifically, the total number of jobs that are related to car manufacture or use and that are put at risk in case of reduced production levels is estimated at approximately 1.25 million (of which around 45 % fall onto the vehicle manufacture-related sectors, and 55 % fall onto the vehicle use-related sectors). This number represents around 5 % of the total French job market (CCFA, 2012). The importance of maintaining a 'healthy' and strong car industry for the overall well-being of the nation becomes apparent.

For maintaining or even increasing production levels, France's car industry has to face the increasing competition from automotive 'newcomers' which are gradually gaining market share. Figure 1.7 depicts how the market share of 'traditional' auto producing nations has dropped from 85 % to below 55 % of worldwide production within only a decade. The share of the BRIC nations has increased from 10 % to 35 %.



Source: ACEA (2012)

Figure 1.7: Split of global passenger car production by nation/region

How EVs could turn around current trends

Within the context of the difficulties sketched above for the French car industry, the introduction and take-up of EVs are frequently seen as a potential cure.

An evolving EV market that is supplied by domestically produced vehicles is seen to revitalise the French automotive sector. The tendency of increasing (conventional) vehicle imports could be turned around by supplying domestically produced (electric) vehicles. Simultaneously, a strong domestic electric vehicle industry that acquires experience and knowledge on the home market, could gain enough competitiveness to reposition the French automotive industry on the international scene. Given the increasing interest in EVs by developing and fast developing nations, an international EV market is already evolving. France could seize the opportunity to become a global player in this market.

On a national level, an evolving national and/or international EV market to which France contributes by domestic production opens up plenty of new business opportunities. As mentioned in the introduction of this chapter, the take-up of EVs will have to go in hand with the development of a whole electromobility system. New value chains are to be created; added value for EV manufacturing will be created in 'untraditional' sectors to the automotive industry, and new services that come along with the use of the electric vehicle will be needed. These may concern the second life of vehicle batteries, new pay-as-you-go services for electricity usage, and new information service providers that help optimise recharging and vehicle usage. The industry's restructuring phase is likely to reduce entry barriers to new system stakeholders. This can allow small- and medium-sized enterprises to enter into the sector which has traditionally been dominated by a limited number of large vehicle manufacturers. Also necessary investments in infrastructure will create economic growth, create wealth and jobs, as this has been the case with previous investments in transport infrastructure (EC, 2011b).

Furthermore, the French car manufacturers can derive financial benefit from the sale of EVs: The European Union's Regulation No 443/2009 (EC, 2009a) that sets emission performance standards for new passenger cars compels car manufacturers to achieve average fleet emissions for their new passenger vehicle sales of no more than 130 CO_2 g/km by 2015 (and sets intermediate CO_2 vehicle emission targets since 2012). Electric vehicles can severely reduce the fleet average – especially battery electric vehicles that are, by the EU's definition, zero-emission vehicles and count as 3.5 cars in the manufacturer's fleet (NB: this value is valid until the end of 2013, and then gradually reduced to 1 by 2016). Providing and selling EVs can reduce a car manufacturer's average CO_2 emissions significantly and can consequently avoid penalty payments to which a car manufacturer with a too high CO_2 fleet emission level is compelled. These

latter 'excess emission premiums' are to be paid for each registered car of the car manufacturer's sales. They amount to EUR 5 for the first g/km exceeding the limit, EUR 15 for the second g/km, EUR 25 for the third g/km, and EUR 95 for each subsequent g/km. In July 2012, a further emission reduction target setting the limit value to 95g CO_2/km by 2020 have been proposed by the European Commission. This proposal still requires approval by the European Parliament and Council to become a binding regulation (EC, 2012).

The risk of new dependencies – or the role of a battery recycling industry

The building up of an EV industry comes with increasing demands on certain raw materials. This bears the risk of creating new resource dependencies on foreign nations.

Modern batteries are expected to increasingly rely on **lithium** technology (IEA, 2012; CAS, 2011). While worldwide lithium reserves appear to be abundant and will provide sufficient supply to develop a significant electromobility system (even under optimistic EV penetration scenarios; Mohr *et al.*, 2012), the geopolitical concern lies in the geographic concentration of these reserves. They are, above all, situated in Bolivia, Chile, and China (CAS, 2011, Deutsche Bank, 2011) – countries that have to prove to be reliable suppliers for lithium. The low number of lithium-producing companies dominating the market, and the prospective growing lithium demand might lead to continuous price increases. These are, however, expected to have only negligible effect given the lithium's minor share in the total cost of the battery system[4] (*ibid.*).

EVs are also more **copper**-demanding than conventional vehicles. The EVs demand for copper is estimated to be at around 65 kg per vehicle (compared to around 25 kg for a CV, *ibid.*). While, as for lithium reserves, existing copper reserves give little concern about future supply (*ibid.*), the copper's price increases[5] might turn out to be more risky than those of lithium.

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[4] Assuming a lithium demand of 0.3 kg/kWh battery capacity (in line with Abbel and Oppenheimer, 2008), a battery capacity of 22 kWh (as provided in Renault's BEV models), a lithium price of 10 EUR/kg (in line with Deutsche Bank, 2011), and total battery pack production costs of 650 EUR/kg in 2012 (in line with Zero Emission Vehicles, 2010; approximate), the lithium's share of the battery pack costs amounts to not even 0.5 %.

[5] Due to the increased demand of copper in wires, cables, electronics, and electric motors, price increases have been significant in recent years: the London Metal Exchange registered an increase in the copper price by 350 % in the time period from 01/10/2003 to 01/10/2012. The average copper price in January 2013 (as of 26 January 2013) increased to 6,037 EUR/tonne (LME, 2013).

Batteries for EVs also rely on **rare earths**. As of 2010, China owns 50 % of worldwide rare earth proven reserves, but is responsible for more than 97 % of the global production volume. Lax environmental standards and preferential policies of the Chinese government turned China into this dominant low-cost supplier in the 1990s. Given the rather negligible use of rare earths in battery production, here also, price development can be considered to be insignificant compared to the relatively elevated risk of not having access to sufficient supply: this risk is especially increasing since China is facing rising rare earth demand on the domestic market, and since environmental standards have become more severe, also in China. As a consequence, export restrictions on rare earths have been enacted by China. In doing so, China aims at attracting foreign investors into the country that are to participate in building up a more value-adding rare earth industry in the country in exchange for rare earth outputs – a policy that has been internationally contested (CRS, 2012a; CRS, 2012b).

Given these potential supply risks for certain materials used in the EV industry, the strategic importance of a domestic battery recycling industry becomes apparent. Besides the environmental and economic advantages of battery recycling, such an industry ensures that raw materials used in the EVs' batteries can be reprocessed and reused. This reduces potential supply risks related to these materials. Increasing material prices will make such processes more and more economically viable; the new industry sector will create new employment opportunities.

1.4.2 An opportunity for society

EVs' contribution to society's development can be seen to be mainly twofold: EVs contribute in a reduction of the (road) transport's energy dependency on foreign oil, as well as in a reduction of the transport sector's environmental impact on a global and a local level. In the following, these topics and their potential cure thanks to EVs will be discussed in more detail.

Alleviate the transport system's energy dependency

In 2011, 31 % of France's total primary energy sources (266 Mtoe) was oil. The transport sector was responsible for 56 % of this oil demand, and relied itself to only 7 % on any other energy sources (4.8 % on renewable energy, 2.0 % on electricity, and 0.2 % on gas) (CGDD, 2012a). More than three quarters of the transport sector's oil demand is due to fuel consumption in road transport (see next section). In the time period from 2003 to 2011, the oil consumption of the transport sector changed only marginally (a total decrease of 3.2 % can be observed – see Figure 1.8). In the same time period, the petroleum sector's foreign trade imbalance in volume, measured in Mtoe, decreased by 13 % (Figure 1.8). If measured in monetary terms, this foreign trade deficit

experienced an increase of over 170 %. In 2011, the trade deficit of the petroleum sector reached over EUR 50 billion. It hereby contributed almost 70 % to the nation's total trade deficit (Figure 1.9), and 82 % to the nation's energy trade deficit (CGDD, 2012a). The cause for the petroleum sector's increasing trade deficit is more explicitly shown in Figure 1.10: the international crude oil price continuously increased from 30 US $/barrel to 113 US $/barrel (nominal values) in the period from 2003 to 2011. Only in 2009, a price decrease resulting from the economic crisis was observed.

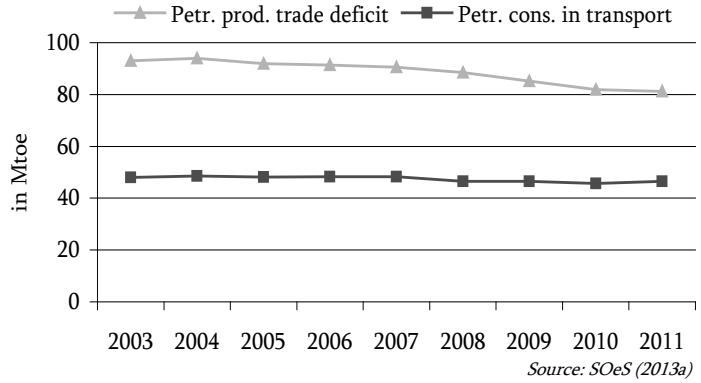


Figure 1.8: Petroleum products – Trade deficit in volume and consumption in the French transport sector

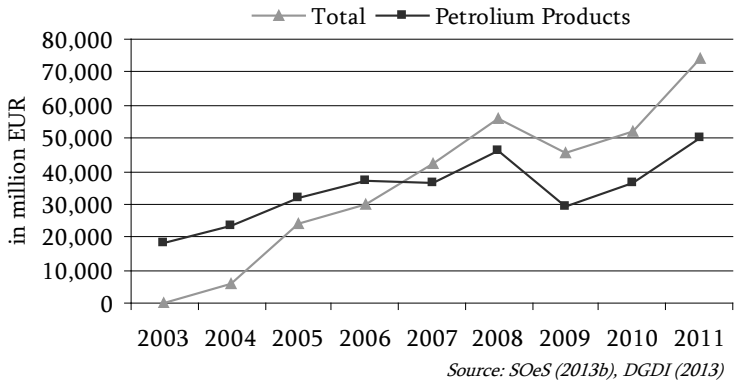


Figure 1.9: Trade deficit of France

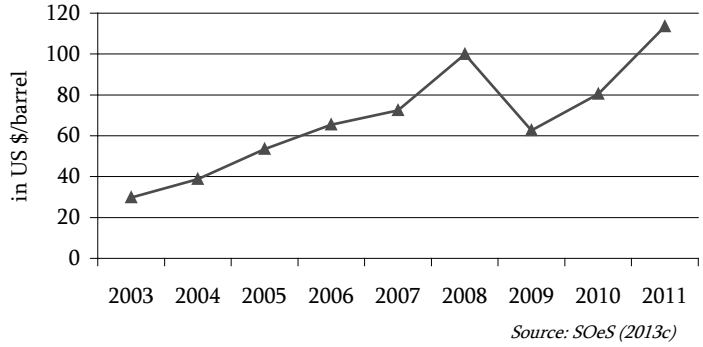


Figure 1.10: Average crude oil price (international import/export price)

The trends presented show how even a declining trade imbalance in the petroleum sector (if measured in volume units) resulted in a steadily increasing foreign trade deficit (if measured in monetary terms). Its harm can be multiple and can range from macro-economic damage for the nation and financial drawbacks for the single oil-dependent vehicle user to geopolitical risks for France. Increasing unbalanced monetary flows out of the country will contribute in destabilising the Euro and increasing the costs of imports – costs that will have to be paid by the consumer. Consumers, i.e., vehicle users, are moreover directly at the mercy of petrol price increases and have to suffer rising costs for their daily mobility needs. Consequently, this can lead to losses in the productivity of the country, as well as to increasing social imbalances. Increasing oil prices and oil dependency of the transport system (and of France in general) allows oil-exporting nations to gain strategic power – a development certainly not in the geo-political interest of France: questions of supply security arise, especially in the context of increasing fears as to peak-oil scenarios materialising in the foreseeable future (e.g. IEA, 2012).

Under the condition that the electricity used for powering EVs does not stem from oil, EVs provide a means to reduce the country's energy dependence and damp down its unwanted effects. This will, however, only be the case if EVs primarily replace diesel-driven vehicles: France is a net importer of crude oil. This crude oil serves the production of diesel and petrol, of which the production ratio is fixed. Due to the increasing domestic demand of diesel[6], the sales of petrol have become increasingly difficult for refineries, with the effect that first refineries already became unprofitable and stopped their production in 2010 and 2011 (CGDD, 2012a). Replacing exclusively petrol-driven vehicles with EVs would even impair the situation: Crude imports for diesel production will remain on a similar level, while petrol sales will become increasingly difficult. Eventually this would have the effect of a declining refinery sector, and increasing imports of diesel.

To make sure that no new or increasing dependency on foreign resources for electricity supply is created, the additional electricity demand resulting from the deployment of EVs, will best be covered by electricity stemming from domestically available renewable energy sources.

Moderate road transport's environmental impact

…with regards to CO_2 emissions

In 2005, 14 % of global greenhouse gas emissions (in CO_2 eq.) came from the transport sector, of which 72 % were due to CO_2 emissions in road transport

[6] The share of the French private vehicle fleet that runs on diesel has increased from 27 % in 1994 to 56 % in 2008 (CGDD, 2010)

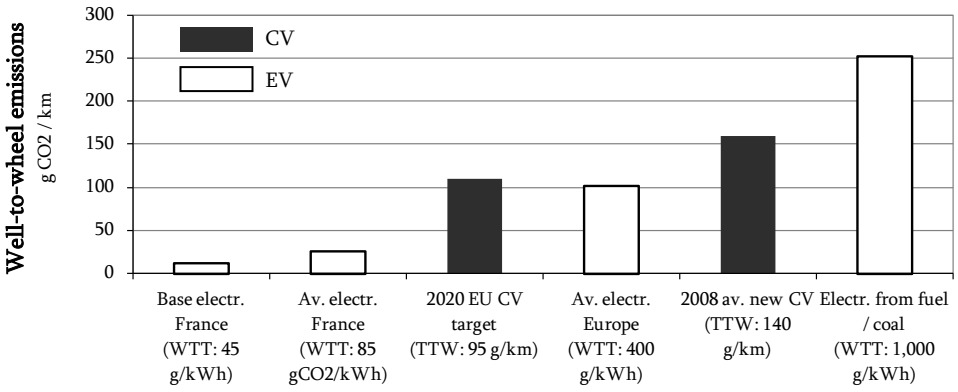
(WRI, 2009). In France, in 2008, 28 % of total greenhouse gas emissions (in CO_2 eq.) came from fuel combustion in the transport sector, of which 78 % were due to road transport (ITF, 2010). These numbers show that road transport is to a large extent responsible for i) the transport sector's fuel demand (as indicated above), and ii) the country's total greenhouse gas emissions (notably for almost 22 % in 2008). Similar emission breakdowns can be identified on the EU level (ITF, 2010).

The European Commission has recognised the magnitude of the transport sector's contribution to greenhouse gas emissions (EC, 2011b). It is determined to achieve by 2050 a reduction of at least 60 % in greenhouse gas emissions with respect to 1990 levels (corresponding to emission cuts of around 70 % below 2008 levels) – the necessary contribution of the transport sector for limiting climate change to 2ºC. Corresponding measures are simultaneously seen as means for breaking the transport system's dependence on oil. The Commission however recognises the importance of transport for allowing economic progress: "Curbing mobility is not an option"; rather, "New transport patterns must emerge, according to which larger volumes of freight and greater numbers of travellers are carried jointly to their destination by the most efficient (combination of) modes." From this perspective, one of the identified goals focusing on road transport is to "Halve the use of 'conventionally-fuelled' cars in urban transport by 2030; phase them out in cities by 2050; [and] achieve essentially CO_2-free city logistics in major urban centres by 2030". It is further recognised that "Growing out of oil will not be possible relying on a single technological solution" (EC, 2011b). For achieving this road-transport-specific goal, corresponding policy measures have already been put in place. For example, passenger vehicles are subject to the EU's emission performance standards (EC, 2009a), which support the development of EVs being considered as zero-emission vehicles (as already described in 3.1). Moreover, the transport sector is subject to objectives defined in the European national renewable energy action plan, released in 2009 (EC, 2009b). This plan calls for more energy efficiency in transport and sees the increase of electric cars as one principal means for reducing transport's energy consumption, which is, furthermore, to attain a 10 % renewable energy share by 2020.

Exploring whether EVs are indeed more CO_2-efficient vehicles than their conventional counterparts requires a more holistic evaluation approach though. Frequently, emissions of different vehicle types are assessed from well-to-wheel (WTW). WTW emissions comprise emissions from well-to-tank (WTT, "upstream" emissions from the production of electricity or fossil fuels and their distribution to a vehicle's tank) and emissions from tank-to-wheel (TTW, "downstream" emissions emitted by the vehicle). Emissions resulting from the production or the disposal of the vehicle are not accounted for.

In the EV's case, a WTW analysis entails that the CO_2 intensity of the electricity generation is accounted for. Here, average emission factors of the prevailing electricity mix give an impression of the actual CO_2 emissions of an EV when in use. However, the approach neglects temporal and spatial variations of the energy supply, as well as the impact of potentially increasing EV penetration rates, their effect on the vehicles' and country's electricity supply, and, consequently, the prevailing CO_2 intensity of electricity generation. If comparing different vehicle technologies with each other, the results of the chosen approach also depend on the vehicle characteristics assumed – values that frequently remain unrevealed. Results of such studies can therefore only give an approximate impression of actual well-to-tank CO_2 emissions.

Figure 1.11 presents the results of such a well-to-wheel CO_2 emission analysis carried out by ADEME (2009). The EV's emissions are shown for different assumptions on the CO_2 intensity of the underlying electricity generation (in g CO_2/kWh) resulting in different well-to-tank emission assumptions. The CV's emissions are shown for different assumptions on the vehicle's tank-to-wheel emissions (in g CO_2/km): the average emission level of newly registered passenger cars in France in 2008. The EU 2020 target described earlier is shown for comparison. The resulting well-to-wheel emission level of an EV running on 'average' French electricity appears to be clearly lower to the one of the French passenger CV fleet registered in 2008. It is also clearly inferior to the EU's 2020 target for the average emission level of newly registered passenger cars. The situation where an EV is powered by electricity stemming from fuel or coal combustion is shown to be clearly unfavourable for the EV. The study does not reveal the assumed efficiency of the underlying EV.



EV: Well-to-tank (WTT) emissions; CV: Tank-to-wheel (TTW) emissions

Figure 1.11: Well-to-wheel CO_2 emissions according to well-to-tank and tank-to-wheel emission assumptions (ADEME, 2009)

Michelin (2011b) presents the results of a similar type of analysis shown in Figure 1.12. The relation between well-to-tank and well-to-wheel CO_2 emissions assuming different EV energy efficiencies becomes clear. The results underpin how the CO_2 intensity of the French electricity generation favours the EV's well-to-wheel CO_2 efficiency. In all other nations included in the study, the EV turns out to be significantly less CO_2 efficient. In case an EV energy efficiency of 15 kWh/100km is achieved, also the average European Union's electricity mix results in EV well-to-wheel emissions that are with 69 gCO_2/100km below the EU's 2020 average fleet emission goal of 95 gCO_2/100km.

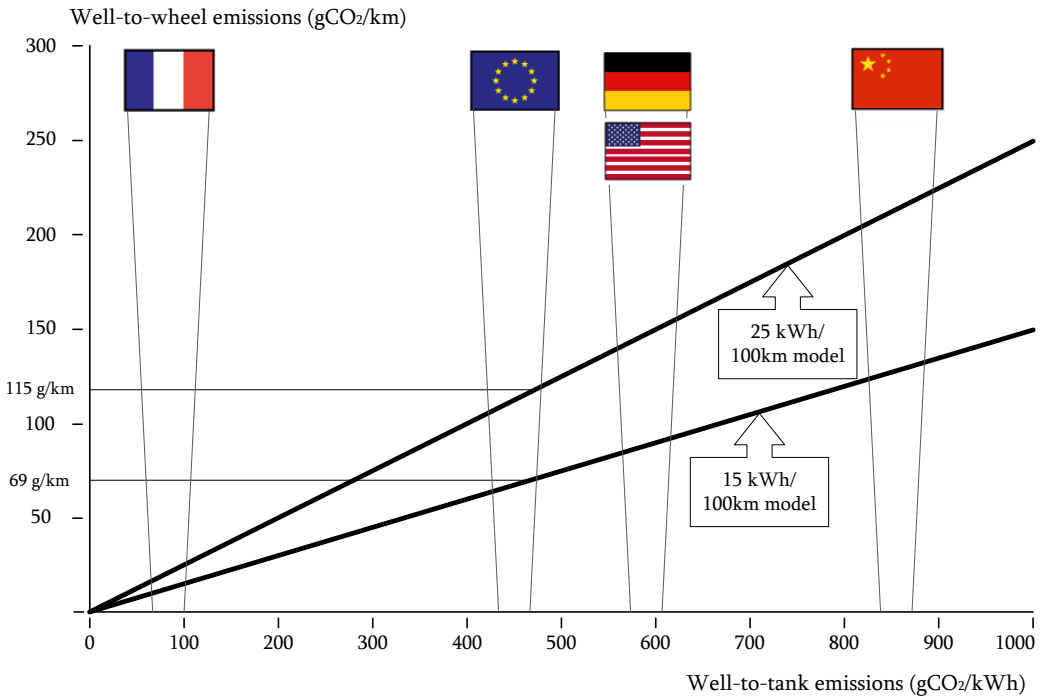


Figure 1.12: CO_2 emissions of electric drive cars by country (from Michelin, 2011b)

There is large consensus that France is a potentially favourable EV market place with regards to the vehicles' CO_2 emissions when relying on the results of such well-to-wheel analyses[7]. In case the average CO_2 intensity of the French electricity generation reflects the one of the electricity generated and used for recharging EVs – even in the case of an increasing EV market penetration – France is likely to observe decreasing total greenhouse gas emissions thanks to the introduction of EVs. It will be the energy sector's responsibility, and, above

[7] as other European nations, whose electricity generation mainly relies on renewable energy sources, will be (such as Norway, Denmark)

all, the responsibility of national and international policy makers to guarantee that these potential decreases can actually materialise. On an international level, this will only work if additional EV-caused electricity demand does not result in increased supply from carbon-intense energy sources – be it in or outside of France.

An even more holistic and adequate approach for comparing the carbon footprint of different vehicle technologies with each other is a life-cycle-analysis (LCA), that covers CO_2 emissions resulting from a vehicle's production, use, and disposal as well as CO_2 emissions from fuel production and all related delivery processes. Such analyses are naturally based on a very large number of input parameters and assumptions, which make the comparisons of results even more difficult than in the case of well-to-wheel analyses. They are specifically dependent on the assumptions of the location of vehicle production and disposal, which can be seen by comparing the following two examples. First, a recent LCA analysis contracted by the Californian Resource board (UCLA, 2012) estimates that (under all given assumptions) the total life-cycle of a battery EV causes 31 tCO_2e in GHG emissions, while the one of a petrol-driven CV causes 62 tCO_2e in GHG emissions. The "use phase" accounts for around 70 % of total CO_2e emissions in the EV's case, and for above 95 % in the CV's case. Second, the estimates of Ricardo (2012) are based on UK-specific assumptions (e.g. a CO_2 intensity of 500 gCO_2/kWh is assumed) and result in 20 % lower life-cycle CO_2 emissions for a mid-size battery EV when compared to a mid-size CV (i.e. 19 tCO_2e for the EV, of which 52 % in use and 46 % in production phase; 24 tCO_2e for the CV, of which 73 % in use and 23 % in production phase). Results of these two studies are quite different. Nevertheless, both point to life-cycle CO_2e advantages for the battery EV over its CV counterpart.

…with regards to local air pollution

Air pollution is a major environmental risk to health. It causes, for instance, skin and eye irritation, respiratory and cardiovascular problems, bears carcinogenic and mutagenic risks, and can cause premature death. The main pollutants from the transport sector responsible for adverse health effects include lead, various types of particulate matter [PM], ozone [O_3] (formed from atmospheric reactions of nitrous oxides [NOx] and volatile organic compounds [VOCs]), various toxic VOCs, nitrogen dioxide [NO_2], carbon monoxide [CO], ammonia [NH_3] and sulphur dioxide [SO_2]. However, the proportion of these various pollutants attributable to the transport sector varies significantly across different geographic areas (UN, 2002).

The World Health Organisation estimates that urban outdoor air pollution causes 1.3 million deaths per year worldwide (WHO, 2011a). The 2005 WHO air quality guideline (WHO, 2005) gives revised recommended limits for the concentration of selected air pollutants (PM, O_3, NO_2, and SO_2) applicable across all WHO regions. "Serious health risks from exposure to PM and O_3 [can be

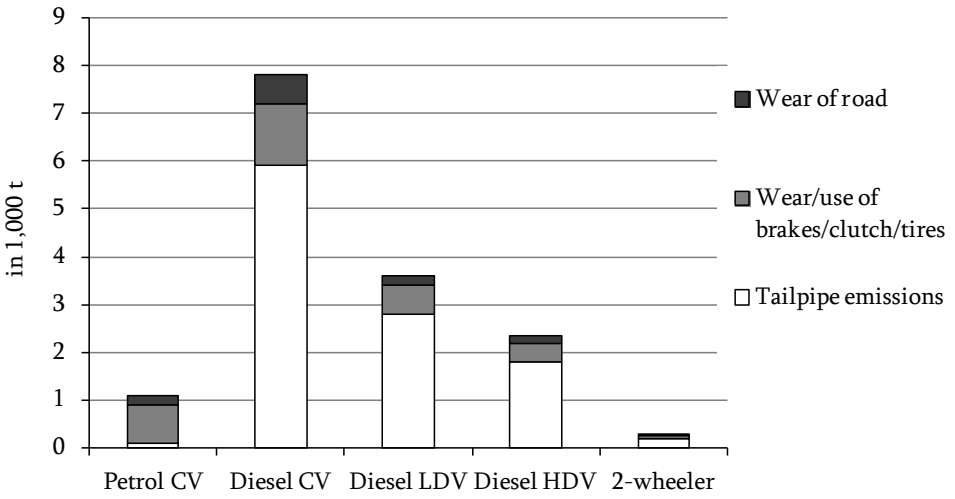
identified] in many cities", where a "significant reduction of exposure to air pollution can be achieved through lowering the concentrations of several of the most common air pollutants emitted during the combustion of fossil fuels" (WHO, 2011a). Thanks to EU legislation on pollutant emissions from road vehicles[8], pollutant emissions from road transport have been decreasing since the 1990s on the EU-27 level (CAS, 2011). Nevertheless, in 2005, approximately 20 % of the EU-27's population was still exposed to too high levels of PM (on more than 35 days), O_3 (on more than 25 days), and NO_2 (with regards to the year's average concentration) (*ibid.*). Increasing urbanisation, which is still observed and expected in the EU area (UN, 2012), entails the risk of a rising number of individuals exposed to air pollution levels that are too high.

In France, the concentration of PM has led the European Commission to take legal action against France in 2011: EU PM_{10} threshold values in more than 15 zones (of which 12 were agglomerations with more than 100,000 inhabitants) were surpassed (ADEME, 2012a). Following those observations, ADEME (2012a) states that a reduced life expectancy of 8.2 months due to anthropological $PM_{2,5}$, and 19,200 to 44,400 premature deaths per year (approx. 6 % of the total number of deaths) due to PM_{10} are estimated in France. Road transport, being the cause of 14 % of France's total $PM_{2,5}$ emissions[9], contributes to PM pollution through i) road vehicles' tailpipe emissions (especially so in the case of diesel-driven CVs), ii) the braking, changing gears, and wearing out of tires, iii) the road's wear, iv) the re-suspension of PM off the road surface due to passing vehicles, and v) secondary PM that is formed in the air due to other vehicle pollutants (*ibid.*). Obviously, zero tailpipe emission vehicles, such as EVs, will therefore not be a total cure to vehicle use-related PM pollution. Figure 1.13 gives information on vehicles' PM_{10} *emissions* (here defined as being PM pollution caused by reasons i-iii)[10]. More precisely, the figure shows the *total* PM emissions in urban areas (broken down by vehicle type and emission cause) in France in 2010.

[8] The Euro 5 and 5a norms for newly-registered petrol and diesel passenger vehicles are in act since 1 January 2011. They set binding threshold values for vehicles' tailpipe CO, NOx, NMVOC, HC, and PM emissions. For petrol vehicles they amount to (in mg/km) 1,000 CO, 68 NMVOC, 60 NOx, 100 HC, and 4.5 PM; for diesel vehicles they amount to (in mg/km) 500 CO, 230 HC + NOx, 180 NOx, and 5 PM. See regulation (EC) No 715/2007 (EC, 2007a). A Euro 6 norm for petrol and diesel vehicles has already been defined and will be in act from 1 September 2015 onwards (EC, 2011a).

[9] No value for PM_{10} is stated

[10] We could not identify sources that quantify the effect of PM re-suspension off the road, or on secondary PM caused by vehicle pollutants in France. However, the impact is likely to be significant if not paramount, as certain UK studies show (Charron, 2012).



LDV – light duty vehicle; HDV – heavy duty vehicle

Figure 1.13: Primary vehicle PM_{10} emissions in the urban area in France in 2010 (ADEME, 2012a)

Figure 1.13 shows the high PM contribution of diesel vehicles, which constitute approximately 60 % of the country's total vehicle fleet (ADEME, 2012a). EVs, that avoid all tailpipe PM, are best to replace diesel-driven CVs. Here the quantity of PM avoided is higher than if replacing a petrol-driven CV. Reductions of other PM thanks to the replacement of a CV with an EV are not apparent: while PM caused by the use of clutch will also be entirely avoided, PM stemming from the wear of tires and the road might increase due to the EV's increased weight[11].

While this discussion shows that EVs can only be a partial solution to vehicle use-related PM, it remains uncontested that EVs do not cause any other vehicle use-related local air pollution. In this respect, their benefit compared to CVs is unanimously recognised. Even if assuming that the EVs' electricity demand is covered by electricity stemming from fossil fuelled thermal power plants, the EV's benefits with regards to local air pollution remain apparent: While CVs cause local air pollution right there, where the vehicle is used (often in dense, urban areas), the air pollution stemming from fossil fuelled power plants will remain outside of (densely) populated areas. This way, the way contributes still in reducing the direct exposure of individuals to air pollution.

…with regards to local sound pollution

Road traffic noise has shown to increase the risk of ischaemic heart disease, hypertension, cognitive impairment of children, sleep disturbance, tinnitus, and

[11] E.g., Due to the vehicle's battery, the Renault ZOE Z.E. weighs 1,428 kg, or almost 50 % more than its conventional counterpart, the Renault CLIO (values obtained from Renault's website, accessed on 27 January 2013).

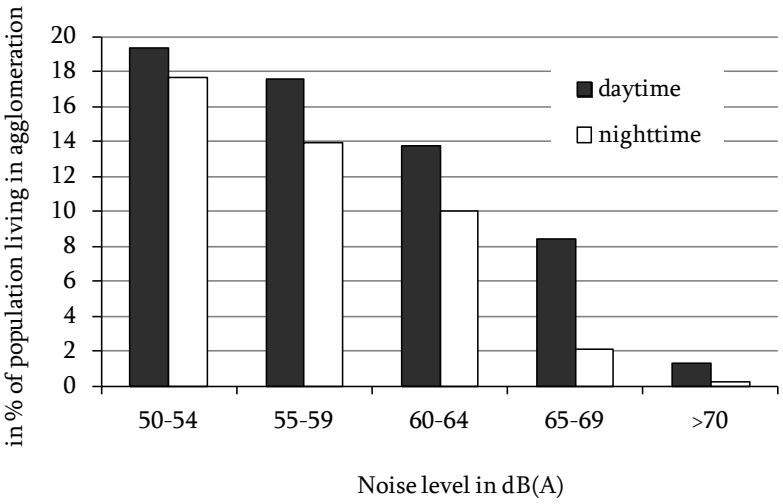
annoyance (WHO, 2011b). It is estimated that disability-adjusted life years[12] (DALYs) from traffic-related environmental noise in the western part of Europe are 1.0-1.6 million. This means that at least 1 million life years are lost every year from traffic-related noise in these countries. Sleep disturbance and annoyance related to road traffic noise constitute most of this burden (*ibid.*). The World Health Organisation recommends noise levels lower than 35 dB for a comfortable sleep during the night. It sets the threshold of dangerous noise to 90 dB, and states that noise levels of 105 dB (ADEME, 2012b) and above can lead to irreparable consequences to hearing. The European Union acts on these lines by defining permissible sound levels for motor vehicles[13].

In France, where 43 % of the population states to be harmed by noise, 80 % of environmental noise is caused by transport, of which 68 % stems from road transport. 3,000 zones with critical road noise levels are counted – built-up areas exposed to a noise level above 70 dB. 55,000 built-up areas are exposed to intolerable noise levels that affect the inhabitants' sleep (ADEME, 2012b). The European Environmental Noise Directive (Directive 2002/49/EC) obliges each Member State to carry out "strategic noise mapping" for specific sources. Figures 1.14 and 1.15 are established based on the resulting data sources (NOISE, 2012)[14].

[12] being "the potential years of life lost due to premature death and the equivalent years of "healthy" life lost by virtue of being in states of poor health or disability" (WHO, 2011)

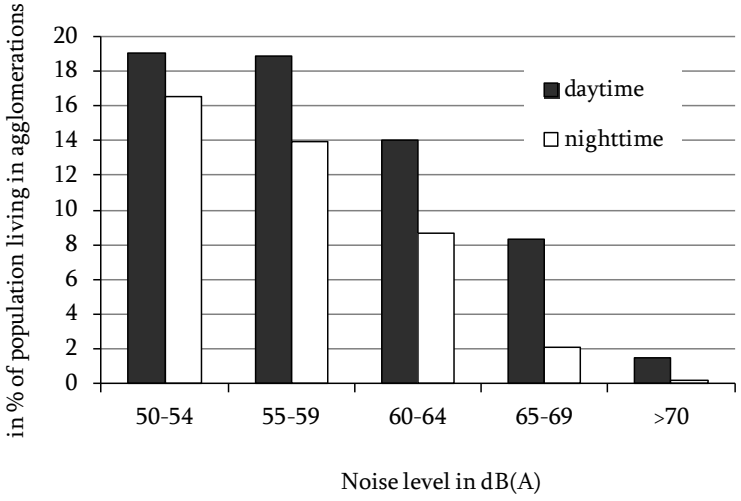
[13] The "EC-type approval" for, e.g., a "vehicle intended for the carriage of passengers, and comprising not more than nine seats including the driver's seat" is obtained if its sound level does not exceed 74 dB(A). See Directive 2007/34/EC (EC, 2007b).

[14] The data displayed in NOISE (2012) was collected between 2005 and 2007. The specific date of data collection/submittal in the case of France cannot be verified.



Source: NOISE (2012)

Figure 1.14: Individuals exposed to different road noise levels in agglomerations (Paris)



Source: NOISE (2012)

Figure 1.15: Individuals exposed to different road noise levels in agglomerations (France)

They show the level of noise exposure in the agglomeration of Paris (Figure 1.14) and in the whole of France (Figure 1.15). Paris reflects the average situation of French agglomerations well. Almost 20 % of the population living in an agglomeration is exposed to elevated noise levels, even during the night.

At high speeds, vehicle-related noise mainly stems from tires and wind resistance, which dominates the noise caused by the combustion engine motor. In such conditions, an EV cannot contribute to lower sound levels. At lower speeds, which prevail in dense areas, the noise of a combustion engine is greater

than the sound of tires or due to wind resistance (CAS, 2011). In such low-speed environments (of up to 50 km/h), the EV can help alleviate prevalent noise pollution thanks to the silence of the electric motor. A significant enough share of EVs in the traffic flow is, however, a necessary condition for attaining a noticeable effect (Pallas, 2012).

Especially in the introduction phase of EVs, the EV's silence at low speeds might entail certain risks though: pedestrians and other traffic participants who rely on sound for approaching traffic might be subject to higher risks of road accidents. For this reason, certain vehicle manufacturers offer sound emitters that automatically produce discrete artificial sound in case the EV is used at low speeds (CAS, 2011).

1.4.3 An opportunity for the French energy sector

The sector's challenges with regards to renewable energy

As the above discussion showed, an adequate development of the (French) energy sector is of utmost importance in order to exploit the full potential benefits of EVs in France. The energy dependence on foreign nations can only decrease if the French energy sector is capable of providing sufficient domestically produced electricity for the EVs' demand. The full potential of EVs' environmental benefits can only materialise if the reductions in vehicles' exhaust emissions do not entail increased emissions stemming from power generation[15]. The energy sector is therefore urged to provide electricity coming from sustainable energy sources – at least at times when EVs are being charged. This brings about certain challenges: Even though the French electricity base load relies on CO_2-efficient nuclear energy, peak electricity demands have to be partly covered by electricity originating from CO_2-intensive domestic thermal power generation or from imports (ADEME, 2011).

Regardless of the development of EVs, the French energy sector is already confronted with a challenging task: it is to achieve demanding targets set by the EU[16] that define the share of renewable energy sources in the gross final energy consumption to be attained by 2020. The "action plan" specifies the contribution of each renewable energy source to i) the production of electricity, ii) the production of heat, and iii) the transport sector's energy consumption – expressed in final consumption values. The 2020 renewable energy target set for

[15] If this was the case, EVs' environmental benefits would boil down to the delocalisation of local pollution from denser populated zones (i.e. the zones where the CV is usually used) to less dense populated zones (i.e. the zones where power plants are usually situated), with the effect of a decreasing human exposure to local air pollution.

[16] Defined in the European national renewable energy action plan, Directive 2009/28/EC (EC, 2009b).

France is 23 %, which signifies a considerable increase compared to the year 2005 value of 10 %. For the electricity sector specifically, this means that the total renewable electricity consumption is to increase from its 2005 (2011) level of 57.9 TWh (66.4 TWh) to 152.3 TWh in 2020. Put differently, this means that the share of the total electricity consumption attributable to renewable electricity is to increase form 11 % (13 %) to 26 % in 2020[17]. (NB: According to the sources used, these numbers translate to an expected increase in electricity consumption of approximately 13 % in the period from 2011 to 2020.)

	2005		2011		2020 objective	
Renewable energy source	*in TWh (1)*	*in % of tot. el.*	*in TWh (1)*	*in % of tot. el.*	*in TWh*	*in % of tot. el. (2)*
Hydro	53.1	10	46.5	9	64.4*	11
Wind	1.0	0	12.3	2	57.9*	10
Photovoltaic	0.0	0	2.3	0	6.9	1
Tidal and wave	n.s.	-	n.s.	-	1.2	0
Geothermal	0.1	0	0.1	0	4.8	1
Biomass	3.7	1	5.3	1	17.2	3
Total renewable electricity	**57.9**	**11**	**66.4**	**13**	**152.3**	**26**

Sources: CGDD (2012a), where stated: CGDD (2012b), ADEME (2011)

Notes: see sources for further specifications; value units partly adapted by the author (using 1 kgoe = 11.628 kWh); n.s. - not stated in source;

* normalised values (according to EU Directive 2009/28/EC, (EC, 2009b));

(1) split on energy sources according to CGDD (2012b);

(2) based on wind energy contribution according to ADEME (2011)

Table 1.1: Final electricity consumption by renewable energy source in France

Table 1.1 shows the contribution of each energy source to the total past and future electricity consumption is shown.

The share of hydro energy as an energy source for renewable electricity is expected to decrease significantly on a relative basis (from 70 % in 2011 to 42 %

[17] The 2020 total is based "normalised" values for hydro and wind energy: these are obtained by multiplying the production capacity of the year in question with the average of the ratio *real production/installed capacity* of the last 10 years, in the case of hydro power, or 5 years, in case of wind power (according to EU directive 2009/28/EC (see EC, 2009b)). For the year 2005 (2011) the *normalised* values of hydro energy are 67.0 (63.3) TWh, the ones for wind energy are 1.2 (12.8) TWh – all of these are higher than the real production values. This indicates that, on average, the utilisation rate of installed capacities decreased.

in 2020[18]). The expected increase of the wind energy share is significant: its 2005 (2011) share of 2 % (19 %) is required by EU standards to rise to 38.0 % in 2020. Also the photovoltaic share is to increase from 0 % (3 %) in 2005 (2011) to 5 % in 2020. The contribution of these two "intermittent"[19] electricity sources to final renewable electricity consumption sum to a total increase of 63.8 (50.2) TWh compared to the respective 2005 (2011) level. If this level is attained, wind electricity will contribute 10 % and photovoltaic 1 % to the total French electricity consumption in 2020 (ADEME, 2011).

How and under which conditions can EVs contribute to meet the targets

In case appropriate infrastructure is put in place, EVs can contribute to achieving the electricity sector's challenging EU targets. They do so by making use of electricity stemming from intermittent renewable energy sources (i.e. from wind energy) at times when demand for electricity does not meet the full supply potential from renewable sources. An increased usage rate will make the exploitation of renewable energy sources more efficient and profitable. This stimulates their development, which will come to the benefit of the sector's total renewable electricity output. Hence, the overall consumption of renewable electricity can be enhanced.

To make sure that EVs make use of intermittent renewable energy sources and do not contribute to an increasing peak load, well-functioning load management that is supported by adequate information and infrastructure is crucial. Indeed, EVs, that will be frequently parked and connected to the electricity net over long periods of time (e.g. during the night at home, or during work hours at the workplace), can benefit from wind energy that regularly finds no taker in off-peak hours.

Figure 1.16 shows how, on average, in France, in 2007, "carbon-free" power supply (here understood to be power from nuclear, wind, or hydro energy) met total power demand throughout the day. Between midnight and 7h in the morning, oversupply can be observed[20]. This oversupply could be used for overnight EV charging: It is estimated that 3 GW would suffice the simultaneous charging of 1 million EVs in a "standard" charge mode (by the means of a standard electricity outlet that provides 3 kVA) (ADEME, 2009).

Figure 1.17 depicts the expected picture for the year 2020: Overall power demand as well as "carbon-free" power supply increases. In case French goals with regards to additional "carbon-free" power supply are met (primarily due to supplementary installations of wind power plants), a power-oversupply of over 8

[18] The observed decrease in nominal values between 2005 and 2011 was due to drought

[19] meaning that electricity production based on these sources can vary with the prevailing wind and sunlight conditions, respectively

[20] Currently, this oversupply is exported.

GW during the night is estimated. In case appropriate load management was in place, the foreseen power installations could suffice for over 4 million EVs that are recharged during the night.

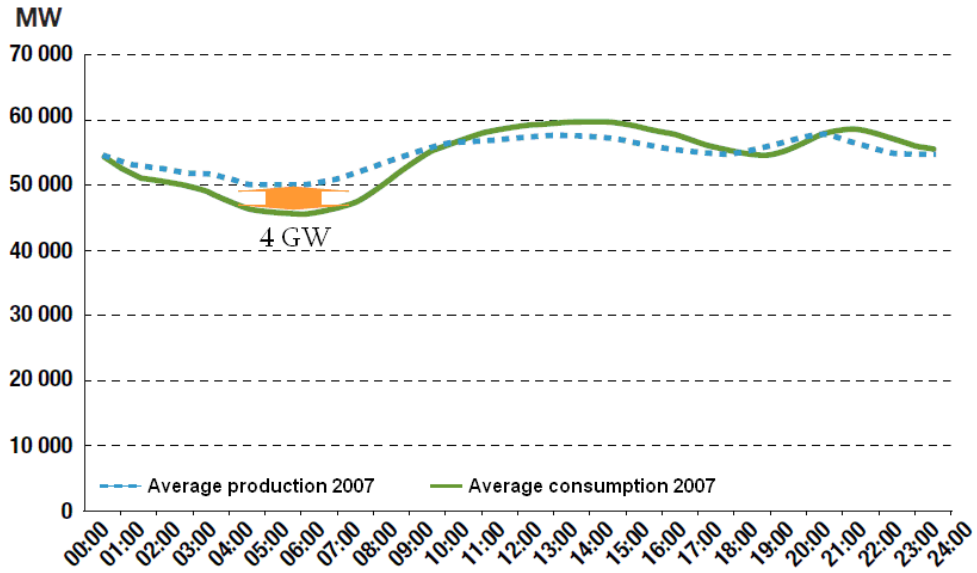


Figure 1.16: Average "carbon-free" electricity production and consumption in France in 2007 throughout the day (ADEME, 2009)

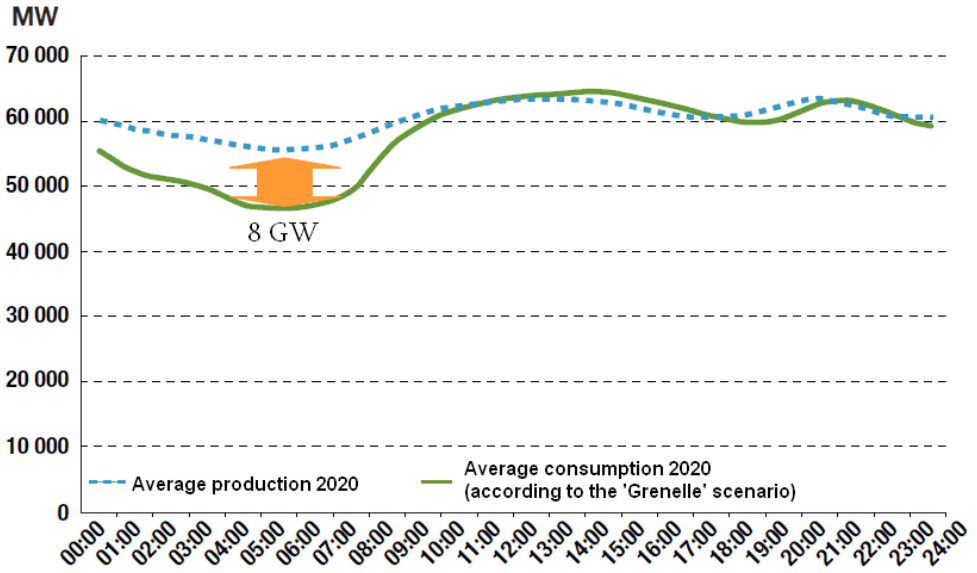


Figure 1.17: Expected average "carbon-free" electricity production and consumption in France in 2020 throughout the day (ADEME, 2009)

For such a scenario to work, vehicle users will have to be encouraged to charge their vehicle in such off-peak hours. Dynamic pricing, that varies electricity tariffs according to prevailing electricity demand, can create adequate

incentives and could avoid the excessive use of "fast" or "rapid" charging modes requiring more power. Smart-grids combined with appropriate communication and information technology (such as smart meters and smart phones) will support the most adequate charging behaviour. They can provide the EV user with real-time information on the battery charge level and on electricity tariffs, and allow the launch and cut of charging processes from a distance. Eventually, charging processes could even be managed automatically (e.g. during a time frame predefined by the user).

Such load management systems will finally come to the advantage of the whole electricity grid's functioning. Excessive peak-load demand that destabilises the net can be avoided. The system's overall efficiency and use of domestic energy sources can be enhanced, which will result in decreasing imports of electricity stemming from carbon-intense energy sources.

In a more distant future, EV batteries could also serve as intermittent electricity storage that can feed electricity back into the electricity grid. This can be enabled by so-called vehicle-to-grid technology. It allows electricity supply and demand to be matched in a more beneficial way, which could entail financial benefits for EV users. Depending on the system that is put in place, the EV users can be in a position to make profit from selling the service of intermittent electricity storage to electricity providers.

The above discussion shows that ensuring that the electricity sector is in a position to support and benefit from the take-up of EVs requires adequate load management supported by smart-grids. The importance of data services providing users with vehicle- and electricity-net-related information increases; communication technology and decision support that allow users to conveniently manage their charging processes will be essential for the well-functioning of the electromobility system. These new demands on real time data exchange and communication technology are likely to allow data providers to enter the newly evolving electromobility system and to take on essential roles in the provision of mobility services. The role of the electricity sector in contributing to the provision of mobility services can become of increasing importance if new business opportunities are identified and seized.

1.5 The role of public policies

Public policies to initiate and guide the system's development

In order to seize the opportunities sketched above that come with the deployment of EVs and to make sure that maximum benefit can be retrieved, public policies play a crucial role. The system's development needs to be *initiated and guided* in order to ensure that the opportunities are seized adequately and contribute to the well-being of society as a whole.

The need for *initiating* the system's development comes from the inertia of the prevailing CV system – a well-established system that has evolved throughout the last century, and that meanwhile enjoys large customer acceptance and the support of strong industry sectors. It is a system that gained momentum when considerations of the system's environmental impact were nonexistent or in its infancy, and when oil appeared to be an abundant source of energy. Up until today, CV use is not subject to the total costs of its externalities. Consequently, the CV system's demand-side actors have only little incentive to change their (auto-)mobility behaviour and expectations. In turn, supply-side stakeholders are not urged to provide new or alternative mobility offers. Without adequate policy measures, which make sure that the current transport system's externalities are accounted for – in whichever form that may be –, evolutions of the well-developed system cannot be expected.

The need for the policy measures' *guiding* (or "steering") function comes from the fact that the societal opportunities sketched above do not represent an immediate opportunity for any of the system's "tangible" stakeholders – those stakeholders that will form the system due to a certain objective they follow out of their own interest. These opportunities therefore run the risk to be neglected and to remain un-seized if no steering force assures an adequate development. Public policies' job is to ensure that the reduction of CO_2 emissions actually materialise and are not only transferred to a different sector or to another nation.

Public policies as enablers

While numerous public policy measures provide a means for allowing a system development or privileging a certain development option, there are certain public policy initiatives that constitute an essential cornerstone to the system's development. Without these initiatives, the system will either be bound to fail, will remain in its infancy, or will bring about unwanted effects. More specifically, the task of the public authority is to create an adequate legal framework that will avoid these latter scenarios by enabling the sustainable development of electromobility. Such a legal framework primordial to the evolution of the electromobility system is to

1. *Allow for and promote the deployment of recharge infrastructure*
   Infrastructure deployment will be a crucial cornerstone in the process of taking up electric vehicles. Public policy makers' responsibility is to provide an adequate legal framework under which the deployment of recharge infrastructure at public and private premises can happen. Public space is to be made available and accessible, especially in urban areas where it is scarce and congested. Also, the deployment of recharge spots at condominiums is to become legally supported: This way, not only owners of private parking

spaces who install their own recharge infrastructure, but also users of parking places at co-owned dwellings will increasingly have access to overnight recharge possibilities.

2. *Ensure the interoperability of recharge infrastructure*
   Interoperability of recharge and supportive communication infrastructure will play a crucial role in the evolution of the electromobility system. It will create consumer confidence by allowing seamless operation of EVs across borders and service areas of different infrastructure and/or electricity providers. Ensuring such seamless operation necessitates the creation of technical standards. These should harmonise the physical connection between vehicles and recharge infrastructure, and the way vehicles can communicate with the electricity provider and/or grid operator to enable billing or more sophisticated interactions such as necessary for load management.

3. *Ensure CO_2 reduction via imperative load management*
   In order to avoid any unwanted effects and profit the most from the development of electromobility, public authorities must make sure that potential reductions in CO_2 emissions actually materialise. Emissions avoided in the transport should not result in increasing emissions in electricity generation. As discussed, this necessitates functioning load management and its respective infrastructure, such as smart grids. It is in the public authority's hands to ensure that EV development is imperatively bound to an adequate development of grid load management.

While 1 and 2 can be seen as the public authorities' imperative tasks to *initiate* and further boost the electromobility system's development, task 3 can be seen as a *steering* task of the authority. This steering task ensures the system's *sustainable* development from the beginning, which is to the advantage of society as a whole.

Public policies as supporters and facilitators

Next to the above defined enabler role that allows for a sustainable development of the electromobility system, public authorities have a portfolio of policy options to actively support and facilitate the system's evolution.

Policy measures can focus on demand- and/or supply-side stakeholders, support more explicit (sets of) stakeholders, or enhance the system's overall development by both financial and non-financial means. They can act on the whole EV value chain: from the very beginning, e.g. when it comes down to financing and supporting research activities or ensuring sufficient qualified labour, to the far-end, e.g. when it comes to supporting EV demand or financing adequate infrastructure. Awareness campaigns on all levels, or efficient

stakeholder network management, are examples for measures that actively support the evolution of the system as a whole.

How and in which magnitude a given country decides to actively support the uptake of EVs will mainly depend on the country's industrial and environmental objectives, on the structure of, and challenges for its energy and transport sector, and on its financial capabilities.

Public policies on all administrative levels

The desire for mobility cannot be geographically delimited. Neither can the borders of our mobility system, of its environmental impact, or of the energy sources it relies on. Mobility and, prospectively, electromobility takes place on local, regional, national, and international level, and will consequently evolve under the influence of policy measures that are defined on all corresponding administrative levels.

Policy makers are to be aware of this multitude of impacts under which the system is to develop. Synergies of all policies measures put in place should be searched for. For this purpose, cooperation between public authorities at different levels will be of utmost importance, as also cooperation between nations will be.

Issues with regards to the interoperability of infrastructure, energy provision, and environmental effects are to be treated by international policy measures and agreements. Infrastructure usage rights or parking policies will be best treated on local or regional levels. This illustrates the importance and necessary implication of all levels of jurisdiction when enabling, supporting and facilitating the evolution of the electromobility system.

1.6 Drivers and barriers to EV uptake

The previous discussion showed the potential advantages of EVs. In order to benefit from these, public authorities play a crucial role. A legal framework is to be created that allows the evolution of EVs in a sustainable way. Furthermore, public authorities can decide to actively support and facilitate the uptake of electromobility. In the following, we address to what extent EV-supportive and facilitating activities of public authorities, in other words – market "push" measures, will be of importance in order to ensure the development of the electromobility system. For doing so, we take the perspective of the single (private) vehicle purchaser and user, who we put in the centre of this work. We see the single user to play the central and most decisive role in the electromobility system - the role which will "make or break" its development. We discuss the most important market barriers and market drivers potentially discouraging or, respectively, encouraging the consumer to decide for an EV when being in a vehicle purchase process. Having identified barriers (5.1) and

drivers (5.2) to EV purchase and usage for the private user, we also discuss most probable first EV market niches (5.3).

1.6.1 Market barriers

In the following, two types of market barriers are distinguished. First, we discuss the market barriers that result from technical limitations or economic aspects related to EVs, the "technical and economic" barriers. Second, we take a look at market barriers that originate from individuals' behaviour and individuals' perceptions or misperceptions of electromobility. We call these the "human" barriers.

Technical and economic barriers

High upfront costs

An issue often mentioned with regards to the introduction of EVs is their elevated upfront costs. Currently available BEV or PHEV models on the French market show indeed elevated purchase costs[21]. These elevated costs are mainly due to the high costs of the vehicles' battery. Depending on the model, the capacity of these batteries lies at around 15-30 kWh. The costs per kWh are estimated to be in the range of EUR 375-1,500 per kWh (as of 2010; Zero Emission Vehicles, 2010). Even though EVs will frequently entail lower vehicle usage costs (see below), upfront costs remain to be a main decision criterion for vehicle buyers (e.g. Kley *et al.*, 2010). In an attempt to lower these, vehicle manufacturers have been developing new business models that allow the customer to acquire an EV at a more affordable upfront price: purchase prices are lowered by the means of a battery hire business model that foresees the hiring of the vehicle's battery for a mileage-based monthly subscription fee.[22]

Uncertainty of resale value

Related to the issue of high upfront costs, is the concern about the uncertain future resale value of an EV. Whereas the resale value of petrol- or diesel-driven

[21] Purchase prices of selected electric passenger cars available on the French market by the end of 2012 (prices incl. battery purchase, incl. all taxes, excl. the French purchase subsidy): BEVs: Mitsubishi I-MiEV/Citroen C-Zero/Peugeot iOn – EUR 29,500; Nissan Leaf – EUR 32,990; Smart Fortwo Electric Drive – EUR 24,500; PHEVs: Chevrolet Volt – EUR 43,500; Opel Ampera – EUR 43,900; Toyota Prius Plug-In – EUR 37,000 (AVEM, 2013a).

[22] As of the end of 2012, the following selected passenger EVs are available with a battery hire option (only BEVs; prices incl. all taxes, excl. battery purchase, excl. the French purchase subsidy): Renault Fluence ZE – EUR 26,900, battery hire from EUR 82 per month; Smart Fortwo Electric Drive – EUR 19,450, battery hire from EUR 65 per month (AVEM, 2013a).

vehicles can be approximated thanks to their well-established second-hand market, resale values of EVs and their batteries will be subject to the still uncertain future offer of, and demand for, these vehicles. The battery hire business model contributes in reducing the customer's risk with regards to uncertain resale values: it is the vehicle manufacturer who retains ownership of the EV's battery.

Limited range

Depending on the battery's capacity, BEVs offer varying theoretic driving ranges[23], mostly within the limits of 100-200 km. The range of PHEVs, being approximately the sum of a battery electric and a petrol range, does not need to be considered as limited.[24] Actual driving ranges will heavily depend on the actual driving behaviour (such as the pattern of acceleration or deceleration), the driving circumstances (such as changing altitudes or differences in urban or long distance trips), the effective use of the vehicle's regenerative braking capabilities, and the auxiliary energy usage in the vehicle (e.g. for air conditioning and heating). Actual driving ranges are therefore expected to be well below advertised driving ranges. Limited, uncertain ranges cause "range anxiety" (continual concern and fear of becoming stranded with a discharged battery in a limited range vehicle) among vehicle users (SAE, 2008).

Duration of recharging

The issue of limited range is aggravated by the time needed for recharging a battery. Charging an EV by connecting its battery to a simple electricity outlet (of 3 kVA), such as available in French households, entails battery charging times of approximately 5 to 8 hours for a depleted battery. The exact duration will largely depend on the battery's capacity. More powerful electricity outlets allow for "fast" or "rapid" battery charging, e.g. 22 kVA outlets allow for a charging time of approx. 1 hour; 43 kVA outlets allow for a charging time of approx. 30 min (Legrand, 2011). Such accelerated charging options are envisaged for battery charging at public premises, such as on the public street or at shopping centres. Only so-called battery swap stations (such as designed and offered by the company Better Place[25]) which exchange depleted batteries with

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[23] Based on the standardised New European Driving Cycle (NEDC) – a driving cycle designed to assess the emission levels of car engines and fuel economy in passenger cars simulating urban and extra-urban driving situations.

[24] Advertised driving ranges of selected electric passenger cars available on the French market by the end of 2012: *BEVs*: Mitsubishi I-MiEV/Citroen C-Zero – 150 km; Peugeot iOn – 130 km, Nissan Leaf – 175 km; Smart Fortwo Electric Drive – 145 km; *PHEVs* (electric/total range): Chevrolet Volt/Opel Ampera – 40-80 km/500 km; Toyota Prius Plug-In – 25 km/1,200 km (AVEM, 2013a).

[25] See www.betterplace.com (accessed 3 February 2013)

fully charged ones within a couple of minutes, make the time needed for "refuelling" an EV competitive to that needed for refuelling a CV.

Limited availability of recharge infrastructure

The limited battery capacity of BEVs entails the frequent need for recharging, which, consequently, puts high importance on the access to recharge infrastructure. While it is expected that EVs will be mostly charged at the primary parking space of the EV (such as the EV user's residence)[26], the access to public recharge infrastructure will serve as reassurance for the usability of an EV and to reduce EV drivers' range anxieties. As of the beginning of 2013, the deployment of such public recharge infrastructure is in its infancy (*AVEM*, 2013b). The density of current recharge infrastructure, especially with regards to fast and rapid charging points (let alone battery swap stations), is insufficient to be perceived as reassuring. This low density is likely to refrain potential EV buyers from an actual EV purchase.

Human barriers

Consumer preferences

Even though the market offer of EVs is steadily increasing[27], the availability of EVs is not comparable to the availability of CVs. Certainly not every CV finds its electric homologue on the French market. Customers that show a specific preference for a vehicle type, a certain specification, or a certain look of their prospective vehicle, are more likely to find satisfaction with one of the numerous CVs on the market.

Misconception of range requirements

Even though BEVs can only offer limited driving ranges, these do not necessarily lead to driving constraints for every-day vehicle usage: CGDD (2011) finds that in France, the total daily vehicle kilometres per vehicle are more than 90 % (80 %) of the time below 100 km (60 km). This shows that actual daily range requirements are often well below the range limitations of a BEV. "Range anxiety" with regards to every-day usage of the BEV can therefore be seen to be mostly unfounded. The frequent misconception of actual vehicle usage behaviour of private vehicle users gives, however, reason to this range anxiety in practice (e.g. already identified by Kurani *et al.*, 1996)

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[26] first experimentations show that 90 % to 95 % of EV charging takes place at such parking spaces (Legrand, 2011)

[27] E.g., in France, the launch of the following (quite diverse) passenger electric cars, available to the public, can be expected in 2013: *BEVs:* BMW-i3, Lumeneo – Neoma, BYD – e6, Ford – Focus Electric, Hyndai – Blueon, Renault – Zoe Z.E., Volkswagen – Golf Blue emotion; *PHEVs*: BYD - F3DM, Mitsubishi - Outlander hybride rechargeable, Volvo - V60 Hybride Rechargeable (AVEM, 2013a).

"One-for-all" attitude

Even in case vehicle purchasers are aware of their daily range requirements and do not identify any range constraints for their every-day vehicle usage, the limited range will still hold many individuals off buying a BEV. Especially in mono-motorised households (households with only one car), but also in multi-motorised households (households with more than one car), the vehicle will most often be seen as a means to cover all possible mobility needs. The vehicle has to be able to cover every-day short distance trips, but also infrequent long-distance journeys, for example, during the vacation season. Given the recharging duration of BEVs and the need for respective recharge infrastructure, many individuals will not consider a BEV as a possible transport means for a long-distance trip. More integrated EV offers that, e.g. allow EV purchasers to have easy and flexible access to a CV short-term rental service in case the EV does not meet the range requirements of an exceptional trip, could help overcome this barrier (Renault, 2010).

Unawareness of, or insensitivity to, future savings

Although EVs offer the benefit of future savings, especially with regards to energy costs and maintenance costs, consumers tend to put a low value on such future savings and do not, or are unable to, value future benefits (e.g. Turrentine and Kurani, 2007; Kley *et al.*, 2010). It is expected that implicit discount rates with respect to EVs are high, implying that consumers expect short payback periods for their investment in an EV (Rand, 2012, based on studies from the 1970s and 80s). This would frequently necessitate high annual mileage in order to recover the high upfront costs of an EV. A more recent study finds only little evidence of consumer myopia: Busse *et al.* (2012) analyse new and used car purchases and find implicit discount rates similar to the range of interest rates paid by car buyers who borrow. This could be a first sign for increasing sensitivities to future savings among car buyers.

Unfamiliarity with, and misconception of, EVs

Given the relatively recent market launch of the last generation of EVs, and the vehicles' insignificant market penetration as of the beginning of 2013, it is certain that many individuals are still unfamiliar with EVs and/or misperceive their potential advantages and disadvantages. Not only the performance of most recent EV models, but also their look, size, and safety are certainly frequently misjudged. People often associate prejudices, such as described by "small", "slow", or "cheap-looking", with EVs (Etrans, 2009; Accenture, 2011; Rand, 2012), that are not necessarily valid for many of the recently launched EVs. An irrational preference for the status-quo, a status-quo bias, that keeps individuals from even considering an EV, is a likely effect (see Kahneman et al., 1991).

1.6.2 Market drivers

The EV market will be driven by various influences that we do not consider as market drivers *per se*. Such driving forces are i) all actions taken to overcome the EV market barriers, and ii) the consequences of a developing electromobility system.

The actions taken to overcome EV barriers were partly already sketched above. They refer to the development of business models that help surmount the upfront cost barrier or uncertainties with regards to the EV's range limitation. Also, all possible EV-supportive measures taken by public authorities – whether they are of financial or non-financial nature – are considered to be *re*actions to market barriers rather than actual market drivers.

What we see to be the *consequences of a developing electromobility system* are all endogenous phenomena resulting from increasing EV penetration rates. These are, for example, decreasing battery and/or vehicle purchase costs due to economies of scale and learning effects in production processes; increasing recharge infrastructure density resulting from increasing usage rates leading to the infrastructure's higher profitability; and increasing battery and infrastructure performance due to learning effects and/or increased investments in research and development.

What we do consider to be actual EV market drivers are i) the features of EVs (or of its accompanying system) that create added value for the private EV purchaser and user – added value that a typical CV cannot offer, and ii) attitudinal or behavioural changes that support the uptake of EVs. In line with the categorisation of market barriers as introduced above, we make also here the distinction between so-called *technical and economic drivers*, and *human drivers*.

Technical and economic drivers

Home recharging

A highly valuable advantage of EVs, which is frequently neglected in public discussions, is the home, overnight recharging possibility of EVs. As long as the EV has a dedicated parking place equipped with battery recharge infrastructure at the EV user's residence, the EV's battery can be recharged while being at home. Often this will be the case during the night. Trips to petrol stations can be avoided. Especially in rural areas, where the net of petrol stations can be sparse, such trips can frequently turn out to be tedious. The possibility of retrieving a fully charged EV, that can serve an individual's mobility needs of a whole day, is a valuable feature of private EV use.

Vehicle usage costs

Even though individuals might not be as sensitive to vehicle usage costs as to vehicle purchase costs when being in a vehicle purchase process, it can be

expected that lower energy costs of EVs, thanks to their efficiency and comparatively low electricity prices, will become more and more of an asset for EVs. Already in the last decade, fuel costs have been rising significantly[28], hereby putting increasing financial burden on the vehicle user. Current outlooks on oil price developments suggest that fuel prices will be subject to further increases (e.g. IEA, 2012). Whereas vehicle users in the past might not have been confronted with viable different alternatives to choose from, EVs could now be seen as the long-awaited cure to inescapably increasing vehicle usage costs. Also lower maintenance costs of EVs (for example due to the significantly smaller number of moving parts as compared to a CV in the vehicles much simpler motor) are likely to motivate vehicle buyers to purchase an EV.

Electricity storage

Once vehicle-to-grid technology has been developed and deployed, the electricity storage capacity of EVs' batteries can be seen as a valuable asset of EVs. Depending on the system put in place, EV users might be able to sell electricity storage capacity to electricity providers or grid operators. Alternatively, they could directly benefit from this electricity storage in case of electricity shortages.

Human drivers

Societal values

An EV does not only provide its owner with a means of transport, but also with a symbolic meaning which the vehicle owner can use to describe and present himself (Heffner *et al.*, 2007). Heffner *et al.* (2007) show that the symbolic meaning associated with hybrid electric vehicles includes ideas like preserving the environment, opposing war, saving money, reducing support for oil producers, and owning the latest technology. Some EV owners use this symbolic content of their vehicle to communicate that they are (for example) intelligent, moral people – individuals that make sensible, mature choices. Others see themselves as part of a technological vanguard.

These kinds of societal values, prone to become of increasing importance with rising environmental consciousness and acceptance of information and communication technologies of individuals, are likely to be a driver behind EV uptake (Axsen and Kurani, 2013).

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[28] In France, in the time period from 2000 to 2012, average diesel (petrol) prices, incl. all taxes, increased from 0.847 EUR/l (1.092 EUR/l) to 1.354 EUR/l (1.396 EUR/l). This signifies a total price increase of 60 % (29 %), or an annual price increase of 4.0 % (2.1 %) within this 12-year period (DGEC, 2012).

"Wind of change" in mobility attitudes and expectations

Numerous recent developments have been demonstrated to have an effect on consumers' attitudes towards, and perceptions of, their mobility behaviour and needs. The increasing *"servisation"* of products, which puts a product's function rather than the product itself in the centre of a vendor-client relation, is becoming increasingly popular and accepted. It is recognised that selling the service of a product rather than the product can be of advantage and convenience for both the supplier and the client.

Next, the market penetration, acceptance and use of new means and forms of communication and information technology for organising and optimising every day life have been increasing: for example, e-commerce and the use of smart phones appear to be becoming increasingly popular.

Combined with the trend of increasing environmental awareness of consumers, future mobility will not be left untouched by these developments. This will bring about opportunities for alternative transport modes, new business models and EVs:

For example, the increasing acceptance of vehicle hire services might result in more cost-effective vehicle purchases among private households. Small and energy-efficient cars, such as EVs, could become more and more popular with the increased offer and use of flexible, short-time vehicle hire services that allows access to a different vehicle type in case of need. Next, the private car could be increasingly used for private car sharing systems[29] which allow the owner to make financial profit from the otherwise unused vehicle. As a consequence, up-front costs might become a less important vehicle purchase criterion compared to the vehicle usage costs. Also new business models, as offered with the EVs (e.g. the hiring of the EV's battery), are likely to face less acceptance problems. Finally, "traditional" shared vehicle services, such as deployed in inner cities (a potential market niche for EVs – see below), are likely to become increasingly popular. This potentially growing shift from privately-owned "all-for-one" vehicles to shared, small, and energy-efficient vehicles might turn out to be an important driver for EV uptake – mainly with the help of adequate communication and information technology that allows users to optimise their vehicle use, share and hire.

1.6.3 Potential first market niches

The above discussion shows that current framework conditions, consumer behaviour, and BEV characteristics are likely to give only insufficient incitation

[29] Also called "peer-to-peer" car sharing; e.g. http://www.buzzcar.com/fr/ offers an according internet platform in France, http://www.autonetzer.de/car2share (by Daimler) does so for Germany (accessed 13 February 2013).

for triggering an EV mass deployment. Unlike other new products or services which frequently bridge a gap in the market or offer evident advantages compared to their predecessor models, electric vehicles face fierce competition from conventional vehicles, whose features are partly superior to those of an EV (e.g. with regards to the vehicle's purchase price or refuelling practicability). Compared to the CV, the EV does not (yet) offer enough unique selling points. Public policies will play an important role in boosting the EV's development. But they will not ensure an immediate EV mass market. Indeed, this will only emerge once private customers are convinced by this vehicle technology.

Especially the BEV is likely to evolve first in niche markets – markets that are well-adapted to the limitations and needs of BEVs and that can benefit already today from their advantages. Thanks to the BEVs' establishment in such niche markets, network effects can be expected (such as decreasing costs, increasing visibility and awareness, increasingly established technologies, increasing infrastructure density, etc.), which will eventually result in increasing uptake rates among the general public and, finally, in the creation of an EV mass market.

Corporate and public fleets

The potential niche for BEVs is corporate and public vehicle fleets (The Climate Group, 2012). Fleet vehicles frequently show BEV-favourable usage patterns (such as predetermined and/or repetitive trips in urban or semi-urban areas), and are often parked on a company's own parking facilities which can be adapted to accommodate necessary battery charging infrastructure. Further, fleet managers are in a position to evaluate the potential profitability of an EV compared to a CV. By developing tools that allow apprehending and rationalising the vehicles' purchase and usage costs, fleet managers can aim at identifying upfront which vehicle technology will be best adapted for which fleet vehicle (Boutueil and Leurent, 2013). Finally, the symbolic content of EVs, as discussed above, could provide branding benefits for a company or a public authority: consumers' growing demand for brands with stronger environmental credentials could be increasingly satisfied. The EV could even become a marketing instrument (The Climate Group, 2012).

Shared vehicles

Another potential market niche for BEVs is shared vehicle services, an increasingly popular mobility service especially in dense urban areas[30]. In these

[30] Such as the service *Car2Go* that has been deployed in almost 20 inner city areas in Europe and North America (in San Diego, Amsterdam and Stuttgart the service's fleet

areas, owning and using one's own vehicle becomes more and more fastidious. Due to increasingly restrictive parking policies, shared vehicle services that allow individual mobility at affordable prices without the need to own the transport means, increasingly appeal to customers.

Vehicles deployed in car-sharing schemes are usually parked on dedicated parking infrastructure, where recharge infrastructure could be installed. Also, they are frequently used for inner-city short-distance trips, which lie well within the range of BEVs. Given that local pollution in dense urban areas is an increasing concern, the deployment of BEVs in car-sharing fleets finds favour with public authorities. Car manufacturers are likely to see in shared vehicle services a promising means for testing and marketing their new vehicles as well as for effectively creating awareness for the new vehicle technology among the greater public. They could therefore have interest in actively supporting the uptake of their BEVs in shared vehicle services.

1.7 Approaches to EV market analyses

Given the complexity of the electromobility system, the uncertain future of the system's framework conditions and the resulting uncertainty with regards to system stakeholders' actions, forecasting the uptake of EV is a very challenging task. Forecasts on growth trends of the EV market have so far been extremely vague: Wallner (2011), who reviews 15 studies on the European market[31] for their 2020 forecasts, finds that the expected share of new vehicle registrations attributable to EVs ranges from 5 % to 20 %. ETC/ACC (2009) reviews 8 studies on global EV penetration rates and shows that expectations concerning EVs' share in new car sales range from 8 % to 50 % in 2030 or 20 % to 90 % in 2050.

These numbers make it clear that EV uptake rates remain uncertain – even more so if the geographic scale and/or time scale become larger.

In the following, we briefly introduce main approaches to EV market analyses and discuss their limitations. Approaches from industry, as well as approaches more frequently found in academic literature, are sketched.

1.7.1 Aggregate analyses

Aggregate demand analyses mainly serve to identify likely long-term trends in vehicle purchase behaviour on a large geographic scale. Sales market shares of different vehicle technologies are forecasted. Often these forecasts predict sales

consists of 300 solely *electric* vehicles) (Car2Go, 2013); or the project *Autolib'* in Paris that deploys 1,740 EVs (as of 8 January 2013) (AVEM, 2013c).

[31] Mainly these studies stem from industry stakeholders (such as management consultancies, banks, or vehicle manufacturers)

potential for the vehicle technologies in question up until the year 2020, 2030 or 2050. Specific characteristics or preferences of potential (first) EV buyers cannot be identified.

Diffusion models

The theory of the diffusion of innovations was spread by Rogers (1962). It aims at explaining how, why and at what rate innovations diffuse from a given level to its full market potential across populations. The five defined categories of adopters of new ideas are called *innovators*, *early adopters*, *early majority*, *late majority*, and *laggards*. Each of these is subject to its specific *rate of adoption* giving the length of time required for a certain percentage of the social system's members to adopt the innovation. *Critical mass* is reached when the adoption of the innovation is self-sustaining. Typically, an S-shaped curve, a logistic function, is used to illustrate the progress of the diffusion of an innovation (see Figure 1.18 that gives the shapes of S-curves for three different innovations).

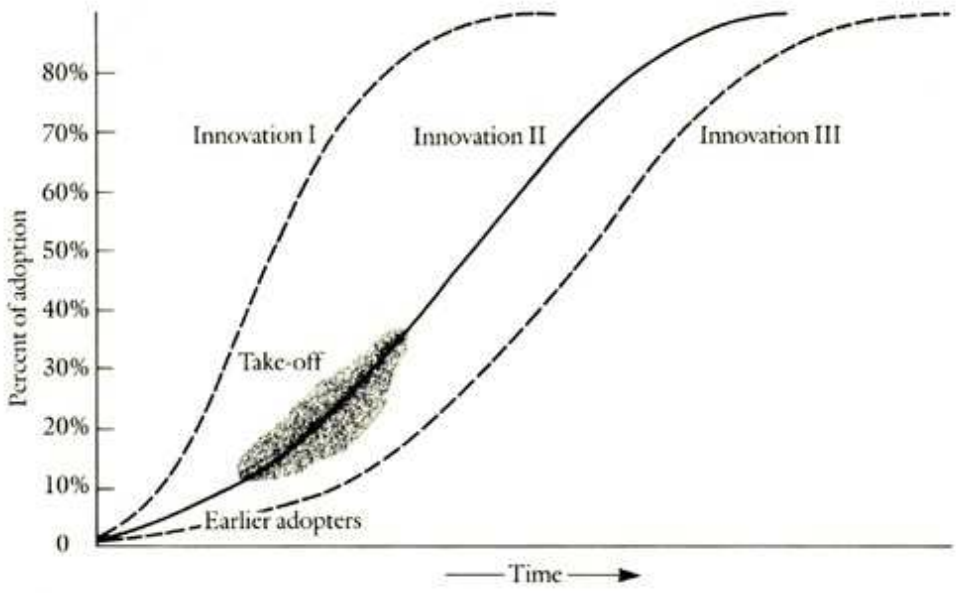

Figure 1.18: The diffusion process (Rogers, 1962)

The Bass diffusion model (Bass, 1969) provides the following formulation for the diffusion theory:

$$x_t = \left(p + q \cdot \frac{Q_{t-1}}{M} \right) \cdot \left(M - Q_{t-1} \right)$$

where x_t is the product sales in period t; Q_{t-1} is the cumulative product sales by time period t-1; M gives the total market potential; and p and q are the coefficients of innovation and imitation. The diffusion process is thus

determined by the adoption of the new product and the imitation of already carried out product purchases (meaning the purchase decisions that emerged thanks to the already attained level of diffusion of the innovation). The Bass diffusion model is widely used in marketing and management science (Becker *et al.*, 2009). Examples of studies that apply a Bass diffusion model for forecasting the penetration of EVs are Becker *et al.* (2009), Cao and Mokhtarian (2004), and Lamberson (2008). Draper *et al.* (2008) uses a different formulation for applying diffusion theory.

Massiani (2012) provides more examples and a discussion on the Bass diffusion model's limitations for making market forecasts. These mainly refer to the difficulty and uncertainty with regards to the determination of a product's total market potential M which is frequently defined "as irrelevant to the attractiveness of competing alternatives" (Massiani, 2012). Especially concerning the introduction of EVs which will be in high competition with CVs or other alternative drive train technologies, the application of the Bass diffusion model for forecasting future sales remains therefore a contestable undertaking. Further, any disaggregate specifications on vehicle users' preferences, on households' infrastructure availability (in order to detect issues with regards to parking and overnight battery recharge infrastructure accessibility), or on vehicle usage behaviours (in order to detect range problems) etc. are neglected. Conclusions on where, under which conditions or among who first EV demand will evolve cannot be derived.

Payback analyses

Another widely applied approach to aggregate forecasts on EV penetration is payback analyses. They are frequently used in industry studies or studies from renowned consultancies (e.g Deutsche Bank, 2008; McKinsey, 2009). Payback analyses compare the purchase and vehicle usage costs of different vehicle technologies with each other in order to define the payback time of an EV (which frequently entails higher purchase costs but lower vehicle usage costs compared to its conventional counterpart). On the basis of these payback times, it is decided whether and under which circumstances consumers are likely to decide for either an EV or a CV. Payback times vary with the assumptions on purchase and energy price developments.

McKinsey (2009) uses estimations of average annual mileage and average daily driving distances per US region. This helps account for potential dissimilarities of EV uptake rates over regions. Average daily driving distances further allow identify the percentage of households that are likely not to face any range problems with a limited-range EV.

A comparison based on holistic total cost of ownership (TCO) calculations that take into account, on top of energy costs, other vehicle operating costs such as maintenance, insurance, or parking costs, cannot be identified in any of the

studies mentioned above (although BCG (2009) claims to follow such an approach). It also remains unclear how identified payback periods, or identified EV cost (or TCO) advantages emerging from a certain time instant onwards, exactly influence the EV uptake rate over time.[32]

CE Delft (2011) does base its financial comparisons of different vehicle technologies on holistic TCO calculations. These are carried out for various cost and price development scenarios. Also the relation between identified cost advantages and resulting EV uptake rates is more apparent: pre-defined demand cross-elasticities with regards to TCO changes (among other parameters) help derive likely EV uptake rates[33].

Also aggregate payback analyses do not attempt to take into account specifications of single vehicle users, their vehicle usage behaviour, or their preferences. Partly, they do differentiate various user groups (McKinsey, 2009) to reflect likely differences in preferences. However, such specifications remain on an aggregate level. Massiani (2012) further discusses the limitations of analyses solely based on financial considerations (specifically, on TCO). These mainly pertain to the underlying assumptions that vehicle purchase decisions are financially rational, and that different vehicle purchasers act equally when being confronted with the same choice. Both of these assumptions do not reflect actual vehicle purchase behaviour well.

1.7.2 Disaggregate analyses

Disaggregate demand forecasts are more frequently found in academic literature. Rather than forecasting long-tem uptake rates, the objective is to identify characteristics of potential EV buyers and/or their localisation. This necessitates a disaggregate approach that takes into account the characteristics of single individuals (or households), their potential preferences and their purchase motivations. The following classification of disaggregate market analyses is based on Axsen and Kurani (2013).

Choice models

Choice models are used to predict market shares of different vehicle technologies based on information on i) the characteristics of the different vehicle technology choice options, ii) the socio-economic characteristics of

[32] I.e. it is not clear what percentage of the underlying "aggregate" population is supposed to buy an EV in case the payback period has reached a certain level or in case a certain cost advantage (under specific conditions) has been identified.

[33] I.e. a certain %-decrease of the TCO of vehicle technology A entails a certain %-decrease in the demand of vehicle technology B (in line with the pre-defined cross-elasticity A/B).

decision makers, and iii) the choice a decision maker made in a specific choice situation. Decision makers are hereby assumed to be rational: they choose the choice option that has the highest *utility* to them. The utility is defined by the choice option's monetary and non-monetary characteristics (such as purchase costs and range respectively) and the decision maker's perception of these attributes.

The data used for establishing choice models stems either from hypothetical (stated) consumer data or from actual (revealed) market data. Given the lack of existing market data with regards to new products or services, studies exploring the market potential of alternative fuel vehicles, notably of BEVs and PHEVs, are usually based on *stated preference* data. This data is collected in *stated preference surveys* that put individuals in hypothetical choice situations. Individuals are confronted with various choice games which vary vehicle choice options and their attributes. Choice data obtained then allows the estimation of the customers' willingness to pay for certain vehicle attributes, i.e. their observed preferences for certain vehicle attributes are valued in monetary terms.

Vehicle attributes that are usually explored comprise of vehicle purchase costs, operating costs, vehicle size and performance. Some studies also include parameters like policy incentives (Hess *et al.*, 2009), vehicle refuelling/recharging times (Golob *et al.*, 1997; Hidrue *et al.*, 2011), refuel/recharge station availability (Brownstone and Train, 1999; Brownstone *et al.*, 2000), vehicle range (Brownstone and Train, 1999; Dagsvik *et al.*, 2002; Brownstone *et al.*, 2000; Hidrue *et al.*, 2011), or vehicle pollution levels (Brownstone *et al.*, 2000; Hidrue *et al.*, 2011). Ewing and Sarigollu (2000) also introduce environmental and technology attitudes of decision makers as explanatory variables; van Rijnsoever (2009) introduces a variable that describes information sharing; Axsen, Mountain and Jaccard (2009) incorporate information on market penetration and the acceptance of the new vehicle technology.

Massiani (2012) provides various other examples of choice models based on stated preference data and discusses the methodology's advantages (such as the possibility of including non-monetary attributes) as well as its drawbacks (such as the distortion that are likely to occur in hypothetical choice games). Such distortions are especially significant when decision makers are not sufficiently aware and used to new choice options or their attributes, such as those of limited-range vehicles. This is likely to lead to unreasonably high penalties for such vehicles for which, consequently, estimated potential market shares go towards zero (Kurani *et al.*, 1994). Further, choice models can only inaccurately estimate the impact of intangible factors on consumer purchase decisions, e.g. such as symbolism (Axsen and Kurani, 2013).

A more complete critique on the use of choice models based on stated preference data with regards to alternative fuel vehicles is provided in Turrentine and Sperling (1992).

Constraints analyses

Constraints analyses define the market potential of EVs by identifying car buyer's resource and functional constraints to an EV purchase. Often these constraints refer to the access to home recharging infrastructure or driving patterns that might not be compatible with limited-range vehicles. The underlying data to such analysis usually stems from nationwide household and/or transport surveys.

The assessment of potential access to home recharge infrastructure is usually defined by using information on a household's access to parking infrastructure, on the age of the household's residence, on the residence's building type, or on a combination of these information elements (e.g. Nesbitt *et al.*, 1992; Williams and Kurani, 2006; Biere *et al.*, 2009; CGDD, 2011; Kihm *et al.*, 2013[34]). Axsen and Kurani (2012) base their analysis on data stemming from two surveys that explicitly investigated the access to home recharge infrastructure in the US. This avoids any ambiguity about a certain household's access to recharge infrastructure.

Constraints analyses focusing on travel behaviour explore the proportion of vehicles that could be replaced by a limited-range vehicle. The condition for a vehicle to enter into the pool of potentially replaceable vehicles is that lengths of observed trips do not (or only infrequently) lie outside the range of the limited range vehicle (e.g. Greene, 1985; Pearre *et al.*, 2011). Alternatively, such analyses work on a household level and explore whether a household is (according to its currently observed vehicle usage behaviour) capable of accommodating a limited-range vehicle in their vehicle fleet without consequently facing any range problems (e.g. Nesbitt *et al.*, 1992; Kurani *et al.*, 1994 and 1996[35]; Chlond *et al.*, 2012). Pearre *et al.* (2011) is an example for a study that furthermore explores the EVs' potential under the condition that vehicle users are willing to adjust their travel behaviour on one or more days per year in order to accommodate a limited-range vehicle in their fleet.

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[34] Kihm et al. (2013) combines a constraints analysis with a TCO analysis (this latter one falling into the category of payback analyses, as defined above) to forecast EV demand up until 2030.

[35] *Stricto sensu*, these two studies are *not* considered to be constraints (or travel bevhaviour) analyses, but rather an extension (see the following subsection). The applied approach and the studies' presentation of results allow, however, their classification as such as well.

Analyses that take household infrastructure *and* travel behaviour constraints into account (and therefore necessarily work on a household level), are less frequent (however, Nesbitt *et al.* (1992) provides an example). A frequent, simplifying approach is that only multi-motorised households (households that own more than one car) are considered as potential purchasers of limited-range vehicles: the assumption is made that any out-of-range trip can be pursued with the household's conventional vehicle (e.g. Williams and Kurani, 2006; Biere *et al.*, 2009; CGDD, 2011).

In constraints analysis, no effort is taken to assess the actual consumer preferences or purchase intentions. *Stricto sensu* constraints analyses rather investigate only the "practical" potential for EVs. Whether individuals (or households) that are identified to belong to potential EV buyers would *actually* consider buying an EV remains unexplored. It also remains unexplored whether, and if so, when, such individuals or households would actually be in the process of purchasing a new vehicle.

Simulations of customers' choice experiences

Approaches that are based on data stemming from surveys that simulate the vehicle choice process have the potential to overcome the main limitations of choice models or constraints analyses. Survey respondents go through a whole survey *process* (or a survey game) that allows them to learn about and reflect upon different vehicle technologies, their advantages and drawbacks, their personal constraints as well as their personal willingness to pay for or adapt to certain vehicle attributes over a certain period of time. Such survey techniques aim at simulating the actual vehicle purchase process, the "choice experience" as observed in reality – a process that entails learning curves, interpersonal influences, reflection and the evolution of personal preferences. This is in contrast to stated preference surveys that treat the vehicle choice process as a static, single action which is consequently prone to lead to uninformed, immature responses of survey respondents. Given the complexity and cost of such surveys, studies that follow such a choice-process simulation approach are limited. Examples are Kurani et al. (1994), Turrentine and Kurani (1998), and Axsen and Kurani (2013).

1.8 Summary and outlook

Electric vehicles (EVs) do not only entail the launch of a new product on the market. Rather, they call for the development of a whole new mobility sub-system, an electromobility system. Existing CV system stakeholders will be in the position to take advantage of the EV's development in case their strategies, fields of activity, and forms of cooperation with other system stakeholders evolve and are adjusted to the developing needs. New or untraditional

stakeholders will have the opportunity to enter and/or to gain importance in the evolving system. This way, the development of the electromobility system – which is in the best case provided with domestic products and services – will be an opportunity for many stakeholders. Effects such as the reduction of energy dependency or of the prevailing transport system's environmental impact will even inure to the benefit of society as a whole. For such effects to actually materialise, an energy sector that is capable of providing EVs with "green" electricity is a primordial condition. It will be mainly in the hands of public authorities to ensure that this condition is met.

Eventually, it will be the final consumer who decides on the success of electric vehicles. The consumer's vehicle purchase decision will be the driving force, or alternatively, the barrier to the EV system's development. Public policies will play an important role here in stimulating first consumer demand until a critical mass is reached that assures self-sustaining market. Public authorities have the great responsibility of dosing policy measures appropriately: a system optimum, hereby accounting for all system's externalities, should be achieved.

Various approaches to market forecasts and market analyses have been introduced in the last part of this chapter. These provide a means to understand potential vehicle purchase behaviour and consequently to estimate the EVs' future potential. Policy makers can and should make use of such market analyses in order to dose their demand-side policy measures that incentivise the private and corporate sector as well as the public body in the best possible way to the most reasonable vehicle purchase decision – from their own, but also from a public welfare perspective.

The following chapter provides an international policy review that introduces the vast variety of possible policy measures that can be put in place in order to support EV uptake. Subsequent chapters build up on insights obtained and develop an EV market forecast methodology for private households in France that takes the impact of policy measures into account.

Chapter 2
International EV-policy review

2.1 Introduction

2.1.1 Context and objectives

In Chapter 1 the potential reasons for government support for the development and uptake of electric vehicles (EVs) were sketched. These can be of different nature and will mostly depend on a country's transport system, strategic energy dependency, environmental targets, as well as on the structure and importance of its automobile and energy industry.

This chapter now analyses policy initiatives and interests with regards to plug-in EVs[36]. First, a comprehensive overview of possible EV-supportive (or, in general, alternative-vehicle-supportive) policy measures is given. This overview allows the reader to learn about the vast portfolio of possible fields of action for policy makers. Next, a policy review based on nations' official policy briefs and EV implementation plans identifies (i) policy interests behind the support of EVs, (ii) nations' vehicle and infrastructure deployment objectives, and (iii) national demand-side measures that are mainly focused on the single vehicle user. Country comparisons reveal the main differences and similarities between the governments' initiatives and objectives with regards to the development and uptake of EVs. The most ambitious EV plans, as well as the most supportive

[36] Comprising plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs) – in the following collectively referred to as electric vehicles (EVs).

demand-side measures are identified; current EV deployment progress is analysed.

2.1.2 Geographic scope of the review

The policy review is carried out first for a number of European countries that are expected to become the most important EV marketplaces during the upcoming decade. Countries with supportive policy measures and/or ambitious goals haare identified as Austria, Denmark, France, Germany, Ireland, Italy, The Netherlands, Norway, Portugal, Spain, and the United Kingdom. The case of Switzerland is explored as an example of a country where EV support is solely driven from industry players and local initiatives. Further, a number of non-European countries that show strong interest in the development of EVs are reviewed. These are China, India, Japan, South Korea, and the United States. Also if we consider the selected countries as significant contributors to the initial EV market, we do not claim these to be the only ones. The geographic coverage of the review can certainly not be considered as exhaustive.

2.1.3 Outline of the chapter

The chapter is structured in 6 sections. Section 2.2 provides a typology of policy instruments that have the potential to support EV development and uptake. The proposed typology helps to then define the political scope of the underlying international policy review. Section 2.3 provides the actual review by looking at EV policies and deployment objectives of the European Union as a whole, of 12 European countries, and China, India, Japan, South Korea and the US. Section 2.4 is a synthesis of the country review by the means of country comparisons. Further, an analysis of current EV deployment progress is carried out. Section 2.5 gives two selected examples of EV initiatives taking place at a local level. An impression of possible (additional) measures that can be put in place on a local level is obtained. Section 2.6 gives a summary of main findings and draws conclusions about the most important observations.

2.2 Typology and scope

2.2.1 Typology of policy instruments

The introduction of a new mobility product, such as the electric vehicle, faces a variety of obstacles. Governments playing a key role in the development of an electromobility system can actively influence the whole market on demand and supply sides. The essence of an International Energy Agency report on deployment strategies for new technology vehicles (IEA, 2004) is that the scope of policy instruments that influence market development should go far beyond

the traditional direct State regulations and financial incentives. Priority should be given to network management, where the State acts as facilitator. Platforms that include all actors in the mobility system should be established to develop a joint, economically viable strategy for EV deployment. Such an approach is likely to be more time consuming but also more successful than massive programs aimed at selected, stand-alone targets. Of course a network management approach requires the setting of legislative regulations. Financial incentives that target the customer can play an important, but only complementary role.

In the following section, a synthetic typology of possible government measures supporting the introduction of EVs is given. These range from direct state interventions to measures supporting the network management role of a government. The categorisation is taken from IEA (2004) and is in line with Sustainable Energy Ireland (2008).

Command and control instruments are usually in the hands of public authorities and applied at a countrywide level. Traditionally, they represent the core of a government's strategy that is then complemented by other types of instruments. Command and control instruments are neither costly for the public budget, nor very time consuming for the government to implement. Their effectiveness stems from their legally binding character, which obligates EV-system supplying stakeholders to provide products that conform to quality or safety standards. Also, emission regulations or licensing procedures including environmental criteria can force developers and manufacturers to adopt cleaner technologies and create a trend towards EVs. The consumer side can be encouraged by including environmental criteria on issuing contracts for the purchase of public service vehicles; by creating mandates that enforce the inclusion of EVs into public sector fleets (or enforce vehicle retailers to sell a fixed percentage of EVs per year); by exempting EV users from restrictive regulations (as, e.g. parking and driving restrictions). Command and control instruments are usually adapted to market and technological developments throughout time.

Economic instruments are purported to overcome the cost barrier to EV development. These instruments support the development of EV technology or provide financial incentives for potential buyers. Instances include direct investment in R&D or infrastructure, preferential pricing policies (e.g. road pricing based on emissions or preferential parking fees), subsidies for EV purchase, or EV infrastructure construction and tax incentives for EVs (e.g. concerning fuel taxes, circulation taxes/motor taxes, registration/purchase taxes). Also, special financing schemes that help alleviate high investment costs can be offered. Economic instruments should not be implemented as stand-alone measures, since the diffusion of an innovative technology requires behavioural changes that involve a set of conditions broader than financial incentives.

Procurement instruments aim to drive up the demand for clean vehicles, hence to increase their numbers and enable economies of scale in production. A government or a consortium of stakeholders decides to buy clean vehicles in bulk, hereby benefitting from reduced prices. Also, initiators of an EV program can decide to use EVs and lead by example by spreading information about their experiences. 'Green' procurement for public and industrial fleets can be introduced on a voluntary or mandatory basis.

Collaborative instruments pertain to the network management approach by a government, based on the principle that the State should play a collaborative and managing role in the society and the markets. The government takes a coordinating role between manufacturers, researchers, authorities, and customers. Certifications and labels can be introduced to improve transparency and information dissemination in the market; voluntary agreements between manufacturers and public authorities are decided; public-private partnerships favouring new mobility practices are established.

Communication and diffusion instruments inform and educate the public in order to develop their interest in, and acceptance of, EVs. Simultaneously, new mobility practices are encouraged amongst the public. Measures include establishing information and awareness campaigns, marketing activities, providing buyer guides and vehicle labelling, education and training activities for vehicle-salespeople, mechanics, and conversion-shop-employees. Lobbying activities, demonstration projects, development of target-group-specific EV offers, and marketing and showcasing the potential for changing mobility behaviour also play an important role.

2.2.2 Policy implementation

Policy instruments can be implemented at various levels: by national, regional or local authorities, each covering a certain geographic area within a given nation. Whereas command and control instruments are traditionally implemented on a national level, the geographic scope (or rather the administrative level at which all other types of policy measures are implemented) can vary significantly. In particular, economic instruments can be implemented on a national scale (e.g. when it comes to emission based fee and rebate systems), a regional scale (e.g. considering registration or circulation taxes), but also on a local scale (e.g. when locally-specific parking fees are to be decided). Depending on the objective and the nature of the policy instrument, either one or the other administrative level might be more or less adequate for the implementation of a certain measure.

Governments are likely to select a certain package of instruments with respect to the existing framework, the capability and financial capacity of the country. The capability depends on specific country characteristics, including

the geographic and economic situation. To be effective, a policy package should combine all kinds of instruments in a comprehensive and balanced way: network management, framework conditions, economic incentives, fleet procurement, communication and information diffusion, and policy supporting multimodal transport.

2.2.3 Political scope of the review

The main aim of the policy review is to reveal countries' predominant reasons and policy instruments for the support of EVs, and to identify defined vehicle and infrastructure deployment objectives. The analysis of policy measures that were implemented in order to achieve these objectives is mainly restrained to *demand-side economic instruments* targeting private vehicle users (as classified above and shown in Figure 2.1). They affect the natural market development of EVs by altering an EV's or a CV's purchase or usage costs. These measures are therefore of major interest for all subsequent analysis of the underlying work. As Figure 2.1 shows, the existence of scrapping schemes is not explored in the review. While such schemes might influence the take-up rate of a new vehicle technology, they usually do not alter purchase or usage costs of newly bought vehicles. Vehicle type choices that are of interest for this work are, therefore, unlikely to be influenced by such measures. Figure 2.1 shows that alongside the generic economic instruments, measures such as preferential access rights (e.g. for high-occupancy lanes, bus lanes, or congestion charging zones) and initiatives concerning the supply of recharge infrastructure on public grounds are also explored. In addition, these latter two types of measures are seen as main drivers behind private EV take-up – even though they do not translate into a quantifiable financial impact on the single vehicle user. This review is focused on *national* policies; an extensive overview of existing policy measures defined on the local level is out of scope. For this reason, the review also only highlights the existence of local EV demonstration or pilot projects. However, despite their limited geographic scope and impact area such local projects are seen as important drivers for EV uptake thanks to increasing EV awareness in the specific region where they are carried out. Consequently, Section 2.5 describes two explicit examples of local initiatives in more detail. Policy packages that are often only sustainable or effective on a local scale are presented.

The reviewed countries largely overlap the 17 members of the International Energy Agency's implementing agreement for co-operation on Hybrid and Electric Vehicle Technologies and Programmes (IA-HEV).[37] The working

[37] Austria, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States (IA-HEV, 2012)

group's annual report gives exhaustive information on each member country's policy measures – also with regards to industry and R&D support. A more exhaustive policy review is available in IEA (2011b).

Figure 2.1: Typology of policy instruments and scope of the underlying review (freely adapted from Kley et al., 2010)

2.3 Review of countries' policies

2.3.1 The European Union

EU policy

The European Economic Recovery Plan (EC, 2008) identifies "Developing clean technologies for cars and construction" as one of ten key actions to pursue in order to recover from the economic crisis. Acknowledging that the automobile sector "face[s] significant challenges in the transition to the green economy", a "European green cars initiative", being one out of the three proposed public private partnerships (PPP), was announced. Thanks to this initiative, EUR 5 billion were made available (EUR 4 billion as loans through the European Investment Bank; EUR 1 billion through joint funding programmes of the European Commission, the industry and the member states). These means serve as support for R&D into technology and infrastructure that are essential for achieving "breakthroughs" in the use of renewable and non-polluting energy sources, in safety, and in traffic fluidity (Green Cars Initiative, 2012). In addition, the Recovery Plan declares the Commission's support for "the development of a procurement network of regional and local authorities to pool demand for clean buses and other vehicles". In 2009, this announced support was implemented by the Directive "on the promotion of clean and energy-efficient road transport vehicles" (EC, 2009b). It "requires contracting authorities, contracting entities as well as certain operators to take into account lifetime energy and environmental impacts, including energy consumption and emissions of CO_2 and of certain pollutants, when purchasing road transport vehicles with the objectives of promoting and stimulating the market for clean and energy-efficient vehicles and improving the contribution of the transport sector to the environment, climate and energy policies of the Community." Further, the Commission commits in the Recovery Plan "to speed up the implementation of the CARS21 initiative" (see below).

At the end of April 2010, the European Commission communicated the "European strategy on clean and energy efficient vehicles" (EC, 2010). The strategy is purported to encourage the development and uptake of clean and energy efficient vehicles. Europe declares its aim to become market leader and technological champion for clean and energy-efficient vehicles, while promoting sustainable growth, and reducing the EU's dependency on fossil fuels and emissions resulting from the transport sector. The strategy envisages (i) continuing and revising the current regulatory framework that lays down standards and regulations for vehicle emissions, (ii) supporting R&D into green technologies, (iii) supporting consumer information and market uptake by introducing EU-wide electromobility projects, and (iv) engaging in international standardisation activities and dialogues. Concerning EVs specifically, the

Commission's aim is to assure Europe-wide standards for communication and recharging infrastructure. Funding for EV infrastructure development on national and regional levels is made available, and ways to stimulate investment in infrastructure and EV services are defined. Life cycle analyses of different new vehicle technologies are to be carried out in order to evaluate the effect of the increased requirement for low-carbon electricity on the electricity supply system. The EU takes initiatives for assuring sustainable secondary use of batteries. Research programmes concerning recycling and reusing of batteries in particular are promoted.

Since 2009, passenger vehicles are subject to the EU's emission performance standards (EC, 2009a) which support the development of EVs. EVs are considered to be zero-emission vehicles and can therefore significantly reduce the average CO_2 emissions of a vehicle manufacturer's vehicle sales.

The European national renewable energy action plan (EC, 2009a), released in 2009, calls for more energy efficiency in transport and sees the increase of electric cars as one principal means for reducing the energy consumption in the transport sector. The transport's energy consumption is furthermore to attain a 10 % renewable energy share by 2020.

The European Commission's White Paper "Roadmap to a Single European Transport Areas", released in March 2011 (EC, 2011b), expresses the EU's determination to achieve a reduction of at least 60 % of the transport sector's greenhouse gas emissions by 2050 with respect to 1990 levels (corresponding to emission cuts of around 70 % below 2008 levels) – the necessary contribution of the transport sector for limiting climate change to 2°C. One of the identified goals focusing on road transport is to "Halve the use of 'conventionally-fuelled' cars in urban transport by 2030; phase them out in cities by 2050; [and] achieve essentially CO_2-free city logistics in major urban centres by 2030." It is further recognised that "Growing out of oil will not be possible relying on a single technological solution."

In January 2013, the European Commission released a proposal for a directive on the deployment of alternative fuels infrastructure (EC, 2013). With regards to EVs, it is proposed that Member States insure recharging points for EVs with sufficient coverage, being at least twice the number of vehicles. 10 % of these charging points are to be publicly accessible.[38] The focus for infrastructure deployment is to be put on urban agglomerations. All publicly accessible recharging points shall be equipped with intelligent metering systems. Further, EV users are not to be prohibited from buying electricity from any electricity supplier regardless of the Member State in which the supplier is registered. Further, consumers are to have the right to simultaneously engage

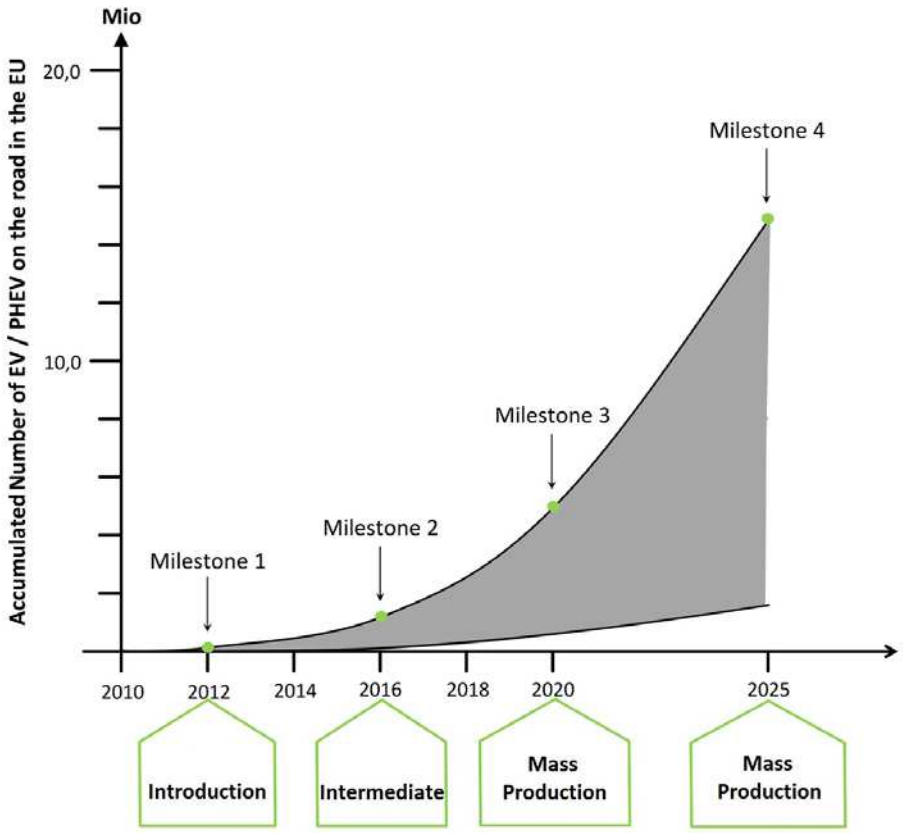
[38] The proposed 2020 objective for France is to deploy 969,000 charging points, of which 97,000 are to be publicly accessible.

with several suppliers so that electricity supply for an EV can be contracted separately. Also, Member States shall insure that any person can establish or operate publicly accessible recharging points and that distribution system operators cooperate on a non-discriminatory basis with any such person. Prices charged at publicly accessible recharging are not to include any penalty or prohibitive fees for recharging an EV by a user not having contractual relations with the operator of the recharging point.

EU stakeholder's view

One of the specific actions listed in the EU's strategy on clean and efficient vehicles (EC, 2010) is the re-launch of the *CARS 21 High Level Group*, which was originally set-up in 2005. The group comprises representatives from national governments, the European Commission, the European Parliament, the automobile industry, environmental NGOs, trade unions, consumers, and the oil industry. The objective of the CARS 21 process is "to make policy recommendations to support the competitiveness and sustainable growth of the European automotive industry" (CARS 21, 2012). In its final report (CARS 21, 2012), the group defines a common view on desirable key characteristics of a "strong and competitive automotive industry". These also refer to the existence of "a portfolio of propulsion technologies, dominated by advanced combustion engine technology, although increasingly electrified", to the significantly growing "deployment of vehicles with alternative powertrain concepts (such as electric and fuel cell vehicles)", and to an "appropriate refilling and recharging infrastructure for alternative fuel vehicles […] in line with their market potential". One of 24 key messages is that "A portfolio of alternative fuels, covering electricity, hydrogen, biofuels, methane, LPG and others, is necessary to meet policy objectives [of diversifying energy sources used for transport]".

The second edition of the "European Roadmap – Electrification of Road Transport" (ERTRAC et al., 2012), released in June 2012, unifies the opinion of the *European Technology* Platforms *ERTRAC, EPoSS and Smart Grids* on the milestone planning of the electrification of road transport. The roadmap is the result of a taskforce established to support the European Green Cars Initiative (Green Cars Initiative, 2012). The second edition reviews goals and objectives of the first milestone defined as "introduction phase" in the report's first edition, it maps current Green Cars Initiative projects against defined actions, and outlines a new 4th milestone that extends the timeframe of the roadmap to 2025. Sub-milestones are defined for each milestone, referring to the six technology fields of (1) energy storage systems, (2) drive train technologies, (3) system integration, (4) grid integration, (5) transport systems, and (6) safety (see Annex 2.1 for a description of these milestones). Figure 2.2 shows the milestones in terms of the expected resulting accumulated number of (PH)EVs on the road.



Lower curve: Evolutionary development; Upper curve: Expected development under assumption of reaching the major technological breakthroughs as described for the six technology fields in Annex 2.1

Figure 2.2: Milestones of the European Roadmap for Electrification of Road Transport (ERTRAC et al., 2012)

Selected EU projects

The CIVITAS (CIVITAS, 2012) programme for cleaner and better transport in cities defines the support for "clean fuels and vehicles" as one of eight categories of measures. 25 projects throughout various European cities have been launched under this programme.

A project focusing specifically on (PH)EVs that operates on a large scale is the 4-year *Green Emotion Project,* launched in March 2011 (Green Emotion Project, 2012). It brings together 42 partners from industry and the energy sector, as well as EV manufacturers, municipalities, universities and research institutions. The aim is to exchange and expand know-how about the introduction of (PH)EVs in selected European regions. Smart grid developments, ICT solutions, different types of EVs, and urban mobility concepts are taken into account. The total project budget is EUR 42 million, of which EUR 24 million are funded by the European Commission.

2.3.2 Selected European countries

Austria

In March 2010, the Ministry of Agriculture, Environment and Water, together with the Ministry of Economy, published the "Austrian Energy Strategy" ("Energiestrategie Österreich"; BMLFUW, 2010). This document foresees the promotion of the stepwise and nationwide introduction of electromobility, which is considered to be an important lever to achieve the 10 % renewable share of the transport sector's total energy consumption by 2020 (as defined by the EU). The proposed target is 250,000 electric cars on Austrian's roads by that year. This number corresponds to almost 5 % of the forecasted total passenger fleet by then. The most recent document on how this objective is to be met is the implementation plan "Electromobility IN and FROM Austria" ("Elektromobiliaet IN und AUS Österreich"; BMLFUW, 2012) published by the aforementioned two ministries, as well as by the Ministry of Transport. Electric mobility is seen as a means to support Austria's industrial, environmental and climate policy by:

- demonstrating Austria's competencies in innovation and technology
- reinforcing the competitiveness of Austria's production sites and creating employment
- enhancing efficient mobility due to the creation of an intermodal, public transport-based, integrated, and optimised transport system
- enhancing affordable mobility in the future
- enhancing clean and environmentally sound mobility by providing economically efficient and renewable energy

In order to insure that electromobility develops *in* Austria, measures around the 5 themes of (1) electromobility in an integrated transport system, (2) energy system and recharge infrastructure, (3) market preparation and demand stimulation, (4) awareness raising and information dissemination, and (5) environmental consciousness are defined and allocated to one of the three ministries involved. The same is done around the three themes of (1) business location and location of innovation, (2) internationalisation, and (3) education and qualification in order to insure that electromobility comes *from* Austria (BMLFUW, 2012). The implementation plan that was established with input from industry, research, local and national authorities, and transport agencies appears to be a comprehensive and well-conceived approach to electromobility.

So far, eight EV demonstration projects have been defined around the cities of Vienna (two projects), Graz, Salzburg, Eisenstadt, and in the regions of Vorarlberg, Corinthia and Lower Austria (E-connected, 2012).

EVs are excluded from a consumption-based, one-time vehicle tax (the "Normverbrauchsabgabe") that is levied upon the first registration of a passenger

car. It can reach a maximum level of 16 % of the value of the vehicle. Under an emission based bonus/malus system, alternative fuel vehicles took advantage of a EUR 500 maximum reduction of this tax up until August 2012. There are financial subsidies for enterprises and authorities for EV acquisition, as well as several municipal and state-wide financial incentives for the purchase of EVs mainly for private individuals (ACEA, 2012a).

Denmark[39]

The Danish government acknowledges that EVs can significantly contribute to a reduction in the use of fossil fuels. Energy security is, next to environmental reasons, the main reason for the Danish government support of EV market penetration in Denmark. EVs are expected to enhance (Danish Ministry of Climate and Energy, 2009):

- a reduced usage of fossil fuels in a sector
- an energy-efficient transport system
- the production of renewable energy, such as wind power (being one of the country's key competences)

Denmark's initial goal was to replace 200,000 CVs by EVs by 2020 (IEA, 2009a). This 2020-goal appears to have been revised to 50,000 vehicles (2011a). Denmark is conceiving an EV infrastructure system that allows vehicle-to-grid connection in order to use batteries as electricity storage devices for the whole electricity net.

In February 2008, the Danish government signed an energy agreement that features a test scheme for EVs (Danish Energy Agency, 2012). This scheme explores the opportunities for integrating EVs as a flexible storage facility into the Danish electricity system. DKK 35 million (approx. EUR 4.5 million) were set aside for the test scheme in the period 2008-2012.

EDISON, an EV infrastructure project, develops the intelligent electrical power infrastructure, which makes possible the integration of increasing amounts of wind power into the grid and its use for charging EVs. At the same time, the system will enable V2G (vehicle-to-grid) functionality. The project is partly funded by the Danish transmission system operator's research programme FORSKEL. The total budget amounts to approximately DKK 49 million (approx. EUR 6.6 million) (EDISON, 2012).

In 2009, Denmark became the second country, after Israel, to fully cooperate with Better Place, a clean-tech venture capital company promoting electric vehicle infrastructure. Together with its partner DONG Energy (Danish Oil and

[39] In the following, all monetary values that are converted to Euro values are approximate based on the conversion rate of the 1st of February 2013.

Natural Gas), the public limited company agreed to invest DKK 770 million (approx. EUR 100 million) to develop recharge infrastructure. An extensive recharge and battery swap system is being rolled out. 500,000 charging points and 150 battery swap stations are planned (Better Place, 2012; RAND, 2012).

EVs are exempt from the Danish registration tax (that can be up to 180 % of the value of a conventional vehicle) until 2015 (Noslone, 2012).

France

France's vision for EVs is ambitious. Until 2015 the market share of EVs of newly sold vehicles is to reach 7 % (16 % in 2020, 27 % in 2025). Two million vehicles are to be deployed by 2020; 4.5 million by 2025 (MEEDDM, 2009).

In October 2009, a national plan for EV development was released (MEEDDM, 2012). An updated version was released in April 2010. The document gives an overview of all initiatives supporting the broad-scale introduction of EVs that are seen as an opportunity to fight against climate change, while simultaneously restructuring the economy as a whole (MEEDDM, 2010).

The "Pacte Automobile" (released in February 2009) foresees a EUR 250 million loan for the industrialisation of decarbonised vehicles. The "Grand Emprunt" (announced in December 2009) plans investment of EUR 750 million to develop decarbonised vehicles. This sum goes to research and deployment projects under the patronage of the French Environment and Energy Agency (ADEME). Specific funding has also been made available for the construction and development of a battery production factory with a capacity of up to 350,000 batteries. Research priorities appear to be the eco-design of batteries and their recycling (MEEDDM, 2010).

To guarantee EV demand for the biggest French car manufacturers (Renault and PSA), a purchase group of 20 industry partners was formed constituting a demand of 50,000 vehicles over 5 years (*ibid.*). In October 2011, the first orders from this purchase group were placed: Renault received an order for 15,637 utility vehicles (Kangoo ZE electric) over four years – mainly for the vehicle fleet of La Poste. PSA received an order of 3,074 vehicles for its Peugeot Ion model (Le Figaro, 2011).

In order to insure the supply of appropriate recharging infrastructure, legislation has been introduced stipulating that all parking units of newly constructed buildings are to be equipped with an electricity outlet. Car parks at workplaces have to be equipped with electricity connections by 2015. Further, EUR 60 million was made available for the installation of 1,250 public recharging points around 20 urban areas until the end of 2012. By 2025, a recharging infrastructure of 9.9 million points will be installed around France (of which, 9 million private points, 750,000 public normal charging points, and 150,000 public rapid charging points) (MEEDDM, 2010).

In France, numerous EV demonstration and test projects have been launched. They test infrastructure and vehicle technologies as well as customer behaviour and business models. Some examples are:

- *Project Kléber* by EDF and Toyota – the Toyota Prius is tested in real life situations in the city of Strasbourg;
- *Project Mini E* by BMW, EDF and Véolia – tests around 50 MINI E vehicles in Paris by renting them to enterprises and private individuals (twice during the 6-month period);
- *Project SAVE* – a large scale deployment project in the Yvelines region (West of Paris) involving Renault-Nissan, EDF, the Yvelines local authority, EPAMSA (Etablissement Public d'Aménagement du Mantois Seine Aval), the authorities of the Île-de-France region, Total and Schneider Electric. It deploys 100 EVs and 300 recharging points on public and private premises;
- *Project Carsharing* in Nice by Veolia Transport and EDF (SODETREL) – deploys 210 shared EVs of different types among 70 car sharing stations and provides 140 charging stations;
- *Project Mopeasy* – an electric car sharing service launched in January 2010 in Neuilly-Sur-Seine;
- *Project Yelomobile* by Proxiway (a daughter of Veolia Transport) – the follow-up of the Liselec project, an electric car sharing service in the urban district of La Rochelle that started in 1999 and that today deploys 50 EVs and 15 recharge and parking facilities;
- *Project Autolib* – an EV car-sharing system in the Île-de-France region launched in 2011, that deploys 1,120 charging stations (predominantly located in Paris) and more than 3,000 EVs (the Bolloré Bluecar).

In France, EVs benefit from the highest bonus in an emission based fee and rebate (bonus/malus) system. Until July 2012, this bonus amounted to EUR 5,000 per vehicle (or maximum 20 % of the purchase price). Since August 2012, the bonus amounts to EUR 7,000 (MRP, 2012).

Germany

In January 2009, the German government approved the "Economic Stimulus Package II", where one out of 14 resolutions specifically addresses electric mobility. Within this framework, EUR 500 million were made available for investment in R&D between 2009 and 2011. In 2011, it was decided that another EUR 1 billion would be made available until the end of the current legislative period (in 2013) (German Federal Government, 2011).

In August 2009, a "National Development Plan for Electric Mobility" (the "NEPE") was adopted. It lays down the goal of deploying 1 million EVs by 2020 (German Federal Government, 2009). By 2030, more than 5 million EVs are to

be deployed; by 2050, most urban transport will not use fossil fuels. Up until 2020, the development plan identifies the following three stages of EV deployment:

- *A market preparation phase* to 2011 was dedicated to advancing research. Focus areas were energy storage systems, vehicle technology, and system and grid integration. First recharge stations were deployed and several demonstration projects were launched.
- For a subsequent *market escalation phase* to 2016, the introduction of EVs into the market and a broader infrastructure installation that covers numerous towns is planned.
- From 2017 onwards, a *mass market* for EVs is to be created. Mass production of EVs and (probably) lithium-ion batteries within Germany are envisaged.

The main goals outlined for Germany are: meeting energy and climate policy targets, developing a lead market for electric mobility, maintaining and expanding the country's competitiveness, and fostering new mobility practices in order to achieve a considerable improvement in living standards.

In May 2010, a national platform for electromobility (NPE) was established. Its goal is to deliver concrete proposals that help achieve the targets set out in the NEPE. The federal government released a national government programme (German Federal Government, 2011) based on the NPE's second interim report in May 2011 (NPE, 2011). It defines solid measures to support (i) R&D activities, (ii) EV-system development, (iii) educational programmes, (iv) standardisation procedures, and (v) the development of infrastructure and electricity generation. In April 2012, four showcase electric mobility regions[40] were announced. They are set to receive EUR 180 million of central government funding, which is expected to generate a substantial leverage effect in terms of private sector investments and co-financing from regional governments. They offer "the opportunity to gain first-hand experience" of the electromobility system (NEP, 2012).

Besides an exemption from circulation tax for five years from the date of the vehicle's registration, no other fiscal EV-supportive measures have been stipulated so far (ACEA, 2012a). The plan is that all EVs registered before the end of 2015 are eligible for tax exemptions for a period of 10 years. Also, the taxation regime of fleet vehicles (or vehicles with professional usage) will be adapted to favour EVs (German Federal Government, 2011).

[40] Baden-Wuerttemberg, Bavaria/Saxony, Berlin/Brandenburg and Lower Saxony

Ireland

Ireland sees EVs as a means to offer an efficient, sustainable and clean alternative to fossil fuels, as well as an opportunity to take a global leadership role in technology, research and innovation. It sees itself to be as a natural fit for EVs due to (i) the size of the country's island (naturally limiting the necessary range of EVs – there are no excessively long distances between urban centres), (ii) the country's high engagement in wind power (offering a renewable energy source that requires intermediate storage capacity), (iii) the country's mild climate (limiting the auxiliary usage of electricity stored in the vehicles' batteries), and (iv) the country's high level of home ownership (allowing significant accessibility to private parking infrastructure as well as easier installation of residential recharge infrastructure) (ESB, 2012).

Ireland's Sustainable Energy Authority (SEAI) provides government support for the introduction of EVs. The objective is to have 6,000 EVs (BEVs or PHEVs) in operation by the end of 2012. This market should produce a critical mass that allows the country to achieve its overall goal of ensuring that 10 % of all vehicles (equivalent to 230,000 vehicles) are electric by 2020. For this purpose, an Irish electricity utility, the Electricity Supply Board (ESB), was appointed as the single responsible agency for recharge infrastructure deployment. A unified network is being built up that is accessible for all supply companies and types of electric cars. ESB ecars' targets are: the installation of 2,000 home charging points (free of charge for the first 2,000 vehicles bought), 1,500 public charging points (of which 500 in Dublin and at least one per community with over 1,500 inhabitants), and 30 fast charging points (on inter-urban routes at 60 km intervals) (SEAI, 2012).

EV and PHEV grant support has been available since 2011. For PHEVs with a list price greater than EUR 18,000, a grant of EUR 2,500 is available. For BEVs with a list price greater than EUR 20,000, a grant of EUR 5,000 is available. For BEVs with a price less than or equal to EUR 20,000, the grant will be in proportion to the vehicle's costs. The lowest subsidy of EUR 2,000 is granted to vehicles costing between EUR 15,000 and EUR 15,000. The scheme is "cash limited": it runs on a first come/first serve basis until the end of 2012, or until the funds are exhausted. So far, the EV models[41] that are available and eligible for grants are the Nissan Leaf, Renault's Kangoo and Fluence Z.E. models, and the Peugeot C-Zero (the Mitsubishi iMiEV). Further, EVs are subject to a

[41] Conditions for BEVs: (i) range > 100 km, (ii) top speed > 100 km/h, (iii) warranty of at least 3 years or 100 000 km, (iv) tail-pipe emissions of 0 gCO2/km, and (v) Euro NCAP star rating of at least 3. Conditions for PHEVs: (i) all-electric range > 20 km, (ii) top speed > 100 km/h, (iii) warranty of at least 3 years or 100,000 km, (iv) tail-pipe emissions less than 75 gCO2/km, and (v) Euro NCAP star rating of at least 3.

vehicle registration tax exemption that is worth of up to EUR 2,500 for PHEVs and up to EUR 5,000 for BEVs (SEAI, 2012).

Several EV trial initiatives have been launched: an electric car sharing project (by ESB), an electric car rental project (by ESB), e-bus trials (by ESB), an e-taxi service in Dublin, and a "Green Hotel Drive" programme (by ESB, Failte Ireland, and the Environmental Protection Agency's "Green Hospitality Programme") that provides charge points to green accredited hotels across Ireland.

Italy

Until 2012, support for EV uptake and infrastructure provision was mainly limited to local and regional initiatives in Italy. The economic crisis impacted national clean vehicle initiatives more than those in regions, provinces, and many municipalities. Local governments were able to support clean vehicles through European, national, and industrial funding for projects, often in conjunction with the definition of promotional and protective measures to limit or ban the circulation of more polluting vehicles, especially in historic urban centres. (IEA, 2011b) The range of EV models offered has been very limited until 2012 since no Italian car manufacturer offered EVs (Cars21, 2012e).

As of mid 2011, an estimated 1,500 charging points were installed in Italy. These mainly stem from one out of the following two EV demonstration projects that started in 2010. Under the *E-Mobility project* of the electric utility ENEL and Daimler, 400 (home and public) charging points and 100 electric Smarts were put on the street in Milan, Pisa and Rome. The *E-Moving project* is an initiative of A2A (an electric utility based in the Lombardy Region that installs 270 charging points in Milan (64 public, 136 private) and 70 charging points in Brescia), and Renault (which put 60 EVs of various types – passenger cars and vans – on the roads). Further, Rome has installed 96 charging points at 11 locations (and created a green zone which limits access to EVs during certain periods); Florence has built up a network of about 130 charging points; Parma has approved a plan to install 300 charging points in the city by 2015; Bologna has 60 charging stations; Genoa has about 24 points. The Municipality of Reggio Emilia fully electrified its fleet of around 400 vehicles that carries out a variety of services in the centre city. Further local initiatives exist (IEA, 2011b).

On 25 July 2012, a decree supporting electromobility was approved in the Chamber of Deputies. It guarantees funding of EUR 50 million in 2013, and EUR 45 million in 2014 and 2015 to support the uptake of EVs via (Cars21, 2012e):

- purchase subsidies: vehicles emitting less than 50 gCO_2/km qualify for a subsidy of 20 % (up to EUR 5,000) in 2013 and 2014 and 15 % (up to EUR 3,500) in 2015;

- legislation that guarantees a minimum level of service of recharge infrastructure in main cities and defines standards and interoperability among energy utilities and providers (EUR 20 million per year for 2013 – 2015 is available);
- a law obliging that all new (and restored) non-residential sites more than 500 m^2 must install EV recharge infrastructure (local laws must be updated to make sure that the installation of EV charging points becomes a routine installation within public and private buildings);
- special electricity tariffs for EVs that promote the domestic and commercial use of the vehicles;
- funds for research and development especially regarding the recharge network and board equipment for smart grid applications.

The Netherlands

In 2009, the Dutch Ministry of Transport proposed an action plan to support EV uptake (Dutch Ministry of Transport, 2009). EV uptake is seen to help improve the nation's energy security, stimulate the economic development, and achieve CO_2 reduction goals. During a build-up phase to 2011, demonstration projects were carried out. From 2012 to 2015, a market built-up phase is planned that will put around 15,000-20,000 EVs on the road. 200,000 and one million EVs are planed to be in circulation by 2020 and 2025 respectively.

Three main actions, altogether worth EUR 65 million, were defined in the action plan:

- Establishment of a *Formula E-Team* that comprises individuals from industries that are essential to deploy EVs. By using a collaborative approach with all parties, the necessary interplay for a successful introduction of EVs is guaranteed.
- Definition of a *Programme of measures 2009-2011* to turn the Netherlands into a testing centre for electromobility by (a) developing EV test areas and model regions, (b) making public authorities "launching EV customers", (c) creating EV-necessary recharge infrastructure, (d) supporting research and development adequately, (d) establishing purchasing consortia, and (e) defining fiscal measures such as purchase or vehicle tax exemptions.
- Coordinated and phased development of an EV market to insure that the right actions are taken at the right time, while retaining highest possible level of flexibility.

On 3rd October 2011, the Ministry of Economy published a subsequent 2011-2015 action plan for the market build-up phase (Dutch Ministry of Economy, 2011). The action plan foresees putting the most effort into *focus areas* – areas where electromobility is seen to have most viability. Such areas are seen to be

larger towns, places with clear links to research and education, or zones that show increasing economic activities. Further, focus is to put on, *viable EV market segments.* These are identified to be in the areas of logistics and distribution, commercial mobility and commuter traffic, mass transit (public transport, taxis, hire cars, pooling cars), and vehicles of company fleets and public authorities. A supporting policy package is put in place that ranges from measures supporting communication and international collaboration, and measures supporting research activities, to the definition of lead customers (the government), and safety standards. The following fiscal measures are put in place (IEA, 2011b):

- exemption from additional purchase tax on new passenger cars and motorcycles until 2018;
- exemption from road tax until 2018;
- exemption from income tax surcharge for leased cars until 2014;
- fiscal grants for companies that invest in EVs for commercial transport;
- fiscal grants for companies that invest in charging stations.

The E-laad Foundation was initiated by regional electricity grid operators and is to be seen as a temporary EV recharge infrastructure implementing organisation. Costs of charging points (budget EUR 25 million) are covered by the cooperating grid managers. The objective is to establish 10,000 charging points for public spaces, comprising 2,000 charging spots requested by municipalities (one charging point per 10,000 inhabitants) and 8,000 charging spots requested by EV drivers (through a dealer organisation) by 2012 (IEA, 2011b).

The most important local initiatives supporting the uptake of EVs are found in Amsterdam, s' Hertogenbosch, Rotterdam and Utrecht (IEA, 2011b).

Norway

An action plan for the electrification of road transport that was commissioned by the Ministry of Transport and Communication in 2009 set out the goal of attaining 200,000 EVs on Norwegian roads by 2020 (approximately 10 % of the current car fleet). The need for an accompanying public recharge infrastructure that allows normal, fast, and quick charging was identified and is estimated to lie at around 30,000 public charging points (Solvi and Norbech, 2011).

In 2011, Norway attained the worldwide highest EV share of newly sold vehicles with 1.6 %, or 2,038 vehicles (ahead of Denmark at 0.21 %; Austria, 0.18 %; and the Netherlands, 0.16 %; Norbech, 2012). As of June 2012, EVs accounted for 2.5 % of monthly new-vehicle sales. As of the same date, the country counts over 7,000 EVs for its 5 million population – this signifies the worldwide highest EV penetration rate. Oslo, showing the highest EV density of any capital city, is considered to be the EV capital of the world (The Green Car,

2012). Norway's EVs are predominantly sold to private customers; only a third go to public or enterprise fleets (Norbech, 2012).

Norway's EV success is certainly due to comparatively strong and comprehensive fiscal and non-fiscal purchase incentives that have both been stipulated on a national level: EVs have access to bus lanes, benefit from free public parking, and are exempt from 25 % VAT, registration taxes, and road and ferry tolling (Solvi and Norbech, 2011). These measures have been secured until the next government election in 2018, or when the country has 50,000 EVs on its roads (The Green Car, 2012).

By the end of 2011, the installed infrastructure comprised 3,123 ordinary charging spots and 33 rapid charging points. In April 2012, a strategic plan for rapid recharge infrastructure installation was published. The number and location of rapid charging stations required for the needs of 90 % of the population is identified using the hypothesis of 60,000 to 120,000 EVs in circulation by 2020 (NB: note the difference between this hypothesis and the official 2009 objective of 200,000 EVs by 2020), and accounting for the country's population densities and climate. Already today, the state-owned, specifically developed software NOBIL delivers all useful data on the location, status, technical characteristics, usage and availability of fast charging points by internet, smartphone or GPS (Norbech, 2012).

Portugal [42]

Portugal, a country without domestic coal, natural gas, or oil resources, produces 43 % of its energy from domestic renewable sources (such as hydro, wind, and solar power). The growing reliance upon domestic renewable energy has led to an increased interest in electric mobility as a storage facility for this energy. The government estimates that Portugal could have roughly 200,000 EVs on the roads by 2020, with approximately 25,000 public (standard and fast) charging stations in its network. The long-term aim is a road transport system solely powered by electricity. Pursuing these objectives will lead to significant CO_2 emission reductions, as well as to reducing the country's dependence on imported fossil fuels. Electromobility is perceived as a strategic lever for the country's medium-term economic success and sustained economic growth.

In 2008, a national programme for electromobility was launched. The resulting MOBI.E[43] is an integrated, comprehensive and nationwide e-mobility model. It is based on an open-access, fully interoperable approach that enables the integration of electricity retailers and charging service operators into one single system, hereby stimulating competition. MOBI.E allows the user to

[42] Source: IEA (2011b)

[43] See http://www.mobie.pt/en/homepage (viewed 1 October 2012)

charge his vehicle in any location by using a single subscription service and authentication mechanism. The user pays one fee that comprises the costs for electricity, for the charging service, and for the MOBI.E central system. MOBI.E sets the business relations between the different stakeholders.

A nationwide public recharge network (comprising 1,350 pilot charging points that were installed by June 2011 in 25 major cities), is being deployed. The network is supposed to be complemented by a demand-driven approach by private operators. They will contribute to building a wider and more comprehensive network for streets, public car parks, shopping centres, service stations, hotels, airports and private garages.

The following (mostly fiscal) demand-side measures have been put in place to enhance the uptake of EVs (they apply to battery electric vehicles only):

- exemption from the vehicle acquisition tax and the circulation tax;
- consumer incentives for EV purchase up to a maximum of EUR 6,500 for the first 5,000 electric vehicles sold before the end of 2012;
- corporate tax deduction for fleets that include EVs;
- mandatory installation of electric mobility charging infrastructure in the parking areas of new buildings;
- special EV access to priority lanes and exclusive circulation areas;
- preferential parking areas for EVs in urban centres;
- annual renewal of State and municipality fleets with 20 % EVs, from 2011 onwards;
- financing of pilot network infrastructure.

Spain

In April 2010, Spain set out an integrated strategy promoting the growth of electric mobility. A related action plan, released in November 2010, points out the priority for electromobility in the near future. The goal was to have 250,000 EVs on the road by 2014. 85 % of these are expected to be in large public and company fleets, the remaining 15 % will be privately owned. Together with gasoline-electric (plug-in) hybrid cars, 1 million low-emission cars are to be deployed by 2014. The main reasons for these goals are to reduce carbon emissions and Spain's dependency on imported energy. Further, introducing EVs is seen as an important stimulus for innovation, and as a necessary contribution to the sustainability of the transport system (DowJones, 2010; Guardian, 2009). 145 cities with more than 50,000 inhabitants are to create an e-mobility environment ("Ciudades con Movilidad eléctrica, CME"). The overall budget for the strategy was fixed at EUR 2.9 billion between 2011 and 2015 (Cleanvehicle, 2012). The hereby financed "Movele" project with a budget of EUR 10 million kick-started EV initiatives. It aimed at introducing 2,000 EVs of various categories across a broad range of companies, institutions and private

individuals, for use in urban environments, and at least 500 public recharging points by 2011. Besides the pilot cities of the Movele project (Seville, Madrid and Barcelona), numerous other regions and local authorities have established individual plans for establishing recharging infrastructure (Soria, 2010). By 2014, altogether 62,000 recharging points for private homes, 263,000 points in car parks, 12,150 points in public car parks and 6,200 points on public roads are to be established (Cleanvehicle, 2012).

Various regional governments give grant incentives of EUR 2,000 to EUR 7,000 for the purchase of electric, hybrid, fuel cell, CNG and LPG vehicles. (ACEA, 2012a)

Switzerland

The Swiss national government believes that the introduction of EVs should primarily be driven by market forces. The focus of national policy initiatives are, therefore, on the development of adequate framework conditions that take into account all e-mobility system stakeholders. Direct policy intervention to support EVs or their associated infrastructure is avoided. The uptake of green vehicles is supported by CO_2 emission regulations for newly purchased vehicles. The regulations are expected to become more stringent in the future (a threshold of 130 gCO_2/km in 2015 is planned). Information dissemination concerning EVs is primarily in the hands of non-governmental organisations. These are mainly focused on electric two-wheeled vehicles that were subject to significant demand in recent years (IEA, 2011b).

Public charging infrastructure has been most actively promoted by the Electric Vehicle Club Switzerland, a private association of EV users. The payment of an annual contribution that includes overhead and electricity costs gives EV users access to the 120 so-called "park & charge" charging stations. Private individuals and certain companies partly put their sockets at the disposal of charging subscribers. This adds up to a total of more than 650 listed charging points across Switzerland. Local utilities frequently do not charge for the amount of electricity drawn from these park & charge stations (*ibid.*).

Local fiscal policy measures, such as the exemption from vehicle taxes, exist in numerous Swiss Cantons (*ibid.*).

In October 2011, a consortium of Swiss industry players and representatives from the Swiss authorities established a roadmap for electromobility (Forum Elektromobilitaet, 2011). This roadmap identifies three priorities for the Swiss E-mobility policy in the upcoming years:

- *A nation-wide recharge infrastructure is to be created* by all concerned stakeholders (local and national authorities, utilities and car manufacturers). The goal is that by 2020, EVs will comprise 10-30 % share of the total Swiss vehicle fleet. This will be achieved by providing 600,000

home charging ("sleep+charge") units, 60,000 charging ("work+charge") units at businesses and offices, 30,000 public charging ("shop+charge") units, and 150 fast charging ("coffee+charge") stations.
- *Enterprise and public fleets are to be electrified* in order to achieve an EV share within those fleets of 25-50 % by 2020. Fleet vehicles are seen to be an important leverage for the uptake of EVs.
- *The number of available EV models is to be enlarged* by vehicle manufacturers and importers.

United Kingdom

The United Kingdom leaves technological development open to the market. Favouring of specific technologies is avoided. The Office for Low Emission Vehicles (OLEV) is a cross-governmental team that brings together existing policy. Its objective is to manage funding and to streamline policy delivery from the Department of Transport, the Department for Business, Innovation and Skills, and the Department of Energy and Climate Change. OLEV released a policy paper on "Ultra-Low Carbon Vehicles in the UK" (DfT, 2009) that largely refers to (PH)EVs. The policy paper defines the following three-step strategy:

- *Short term* (to 2015): Support for demonstration projects and for transforming urban centres into EV cities. Consumer incentives are implemented to stimulate demand.
- *Medium term* (2015-2020): Continued improvements to the efficiency of new cars are planned. Coverage of charging infrastructure is to be increased. (PH)EVs are produced on a large scale.
- *Long term* (2020+): A continued rollout of charging infrastructure. This shall allow for a mass market for ultra-low carbon vehicles, that will result in a complete decarbonisation of the road transport by 2050.

The main reasons for the UK government to invest in the development of (PH)EVs are environmental and economic. The transportation sector will be decarbonised, national economic competitiveness and growth will be supported, and the country's standard of living, health, and transport safety will be improved.

The government announced that over £ 400 million (approx. EUR 460 million) will be provided to support measures designed to promote the next generation's ultra-low emission vehicle technologies (OLEV, 2012). Over the life of the current parliament (until April 2015), a share of this funding is ring-fenced for the "Plug-in Car Grant" (Plug-in Car Grant, 2012) programme that supports ultra-low carbon vehicle drivers with a subsidy of 25 % of the vehicle's costs (up to a maximum of £ 5,000 or approx. EUR 5,800). Both, private consumers and businesses can benefit from the grant when purchasing a qualifying ultra-low emission car. As of September 2012, there are 10 eligible

vehicle models. To qualify, vehicles must conform to a set of criteria released by the OLEV[44]. As of 30 June 2012, 1,706 claims have been made through the Plug-in Car Grant scheme. Since February 2012, a "Plug-in Van Grant" (Plug-in Van Grant, 2012), which functions in the same way as the car grant, is also available for seven models (as of September 2012). The grant accounts for 20 % of the vehicle purchase price (up to the maximum of £ 8,000, or approx. EUR 9,300).

A "Low Carbon Vehicle Procurement Programme" (CENEX, 2012) put in place in 2007 is supported by an initial funding of £ 20 million (approx. EUR 23 million) and aims to use the public sector's purchasing power to accelerate the introduction of lower carbon vehicle technologies onto the market.

With regards to recharge infrastructure, the current government published a strategy in 2011 (DfT, 2011) that sets out how to (i) facilitate vehicle charging for individuals at home and at night, (ii) locate and use public charging points, (iii) faclitate the installation of recharge infrastructure by removing regulatory barriers, and (iii) include adequate policy in the National Planning Policy Framework in order to encourage local authorities to implement local policies that help install recharge infrastructure at new domestic, workplace and retail developments. Within this framework, the "Plugged-In Places" programme aims at creating a critical mass of infrastructure in eight regions[45]. 8,500 charge points are to be installed. £ 30 million (approx., EUR 35 million) was made available for this purpose (The Charging Point, 2012).

Electric vehicles are exempt from the annual circulation tax and the company car tax until April 2015. Electric vans are exempt from the van benefit charge until the same date (ACEA, 2012a).

2.3.3 Selected non-European countries

China

The electrification of vehicles is of strategic importance to China. It contributes to the country's future development with regards to (i) global climate change (China is committed to 40-45 % lower CO_2 emissions per unit of GDP by 2020 compared to a 2005 baseline), (ii) energy security (half of China's oil is imported; its consumption is expected to increase by more than 50 % by 2020 compared to

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[44] The vehicle eligibility criteria for the consumer incentive: (1) *vehicle type*: passenger cars, (2) *tailpipe emissions*: 0 g CO_2/km for BEV, and 75 g CO_2/km for PHEV, (3) *minimum electric drive range*: 70 miles for BEV and 10 miles for PHEV, (4) *safety*: rated as at least 4 stars under the EUroNCAP scheme, (5) *minimum top speed*: 60 mph, (6) *warranty*: 7 years or 100,000 miles for electric power train (incl. battery), 3 years or 600,000 miles for other conventional elements of the vehicle

[45] East of England, Greater Manchester, London, Midlands, Milton Keynes, North East, Northern Ireland and Scotland

2007 levels), (iii) urban pollution (e.g. the share of Beijing's CO and HC emissions attributed to transport (70 %) is expected to increase with the predicted rise in the number of vehicles on the road), and (iv) auto industry growth (while China is not expected to transform into a large-scale CV exporter due to the significant technological advantages that the established auto manufacturers have in ICE engines, electric propulsion systems are likely to introduce a value chain shift that could favour China thanks to its capabilities in electric motor and battery manufacturing, and its dominant position as provider of rare earths) (World Bank, 2011).

In its 11th five-year plan (2007-2011), the Chinese Ministry of Science and Technology set out a detailed roadmap for EV technology development, entitled the "863 Programme". Originally, this programme was focused on FCEV technologies and was supported by a government investment of RMB 800 million (approx. EUR 95 million). In the meantime, it developed into a programme directed towards all FCEV, HEV, PHEV and BEV technologies (UN, 2011). An objective was outlined of attaining a manufacturing capacity of 500,000 new energy vehicles (pure electric, hybrid and other alternative energy vehicles) by 2011. The new cars will represent 5 % of annual new passenger car sales (Wand and Kimble, 2010).

In its 12th five-year plan (2011-2015) the Chinese government recognises that the creation of a Chinese car industry may take longer than expected (Cars21, 2012a), but states that battery electric vehicles will be the top priority of China's new energy automobile industry development goal (ACORE, 2012). A three step strategy was released. It foresees (i) the commercialisation of hybrid technologies by 2015, (ii) the increase in development efforts for all-electric and plug-in hybrid technology between 2015 and 2020, and (iii) a dominant role of the all-electric drive technology from 2020 onwards (Cars21, 2012a). The State Council, China's highest administrative agency, published its comprehensive development plan for the new energy automotive industry in June 2012. It sets the following targets: by 2015, a target production and sales volume of 500,000 pure electric and plug-in hybrid electric vehicles per year. By 2020, the cumulative sales should have reached 5 million vehicles, and a production and sales capacity should have reached two million vehicles per year (ACORE, 2012). Regarding infrastructure, China aims to have 400,000 charging spots and 2,000 charging stations in more than 20 cities by 2020 (Cars21, 2012a).

In 2008, the government announced a package of measures in 13 pilot cities[46] that belong to the first batch of the "10 Cities, 1,000 Vehicles – New Energy Vehicle Demonstration Project". Over a three year period (starting January 2009) the nominated cities aimed to have at least 1 000 hybrid or pure

[46] Beijing, Shanghai, Chongqing, Changchun, Dalian, Hangzhou, Jinan, Wuhan, Shenzhen, Hefei, Changsha, Kunming, and Nanchang

EVs on the road. In June 2010, 7 more cities were added[47], and finally, in July 2011, the programme was expanded to 25 cities[48]. In these 25 cities, public service vehicles receive significant national government subsidies of up to RMB 50,000 (approx. EUR 6,000) for qualifying EVs. Infrastructure installation was left to the local authorities. Since June 2010, 5 cities (Shanghai, Changchun, Shenzhen, Hangzhou, and Hefei) have offered subsidies for private buyers of plug-in electric vehicles in the range of RMB 50,000 for PHEVs, and RMB 60,000 for BEVs (approximately EUR 6,000, and EUR 7,300) for a period of 2 years. When combined with local subsidy programmes in some cities, the combined EV purchase subsidies could be as high as RMB 120,000 (approx. EUR 14,000; UN, 2012; ACORE, 2012). From 2011 onwards, some of the demonstration cities exempted EVs from license plate auctions and six days per week driving limitations, granted preferential parking, waived toll road fees, and provided electricity for EVs at a reduced price (ACORE, 2012). Results of the project (as of October 2011) showed that the city-individual EV deployment targets were too ambitious. The 25 participating cities reached only about 38 % of their deployment goals (China Decoder, 2012).

In 2011, the Ministry of Finance (MOF) decided to waive sales taxes on certain domestically manufactured EVs (ACORE, 2012).

On 9 July 2012, the Chinese government released the "2012 Chinese Auto Industry Development Report" that reaffirms the government's support of EVs. Continuous tax incentives and financial support is promised. Further, the report emphasises that hybrids are only transition technologies, and that the industry should focus on electric vehicles (Cars21, 2012b).

India

The study "Growth of an electric vehicle industry in India: Selected Policy Imperatives" (USAID, 1999) underlines the findings of an even earlier study that concludes that EVs are a "natural option" for India given (i) the country's high level of urban air pollution that is primarily caused by vehicular emission, (ii) the nature of transportation needs and the population's driving habits (basically all forms of personal transport occur within a single urban area; inter-city travel by car is low), (iii) the resource balance of the country under different technology options (on the one hand, India's dependence on imported oil (currently at 50 %) is steadily increasing with the growth of the conventional automobile industry; on the other hand, India has a large potential for hydro power production), and (iv) the country's warm climate (electric motors are expected to run more efficiently). The report proposes policy measures that are

[47] Tianjin, Haikou, Zhengzhou, Xiamen, Suzhou, Tangshan, and Guangzhou

[48] Shenyang, Chengdu, Nantong, Xiangfan and Hohhot

seen to help overcome barriers to EV development and uptake. Measures dealing with the "knowledge barrier" of users, as well as financial, fiscal, and legislative barriers, and the support of pilot projects are suggested.

In December 2006, the Ministry of Heavy Industries and Public Enterprises, released the "Automotive Mission Plan 2006-2016" (Indian Ministry of Heavy Industries, 2006), which lays out the roadmap for future development in the automobile industry. The manufacturing and assembling of fuel efficient and hybrid vehicles appropriate for the Indian market is a recommended measure. Conversion of vehicles to alternative fuels is to be encouraged and innovative R&D projects are to be supported.

In late 2010, the Ministry of New and Renewable Energy decided to offer EV incentives in order to boost their sales. The ministry paid up to 20 % of the EVs price, which the manufacturers were expected to pass onto buyers. In return, the manufacturers had to assure that at least 30 % of the parts originate from Indian enterprises (Panchabuta, 2011). The subsidy expired in March 2012. Since then, sales of the country's only electric car, Reva, plummeted by two thirds to an average of about 25 units a month (Cars21, 2012c). On 30th August 2012, India's national Council for Electric Mobility announced a EUR 3.1 billion plan that calls for the deployment of 6 million electric vehicles by 2020 (including two-wheelers, four-wheelers and commercial vehicles) over the next 8 years under the National Electric Mobility Mission Plan 2020. Two million of these are forecast to be electric four-wheeled vehicles (Cars21, 2012c and 2012d).

According to IEA (2011a), states and municipalities have begun to provide EV incentives. Some states brought down VAT rates from 12 % to 4 % for EVs. Some cities refund road tax and registration charges.

India has the ambitious electric car manufacturer REVA Electric Car Company (RECC), which designs, develops, manufactures and sells EVs. According to RECC, EVs have not yet gained popularity owing to lack of adequate and timely support from central and state governments. However, RECC aims to have 100,000 EVs in circulation by 2020 (Maini, 2007).

Japan

In April 2010, Japan released the *Next Generation Vehicle Strategy 2010*. New vehicle technologies are to be supported collectively until 2030 (METI, 2010a). The main objectives for creating a next-generation vehicle strategy are to improve fuel efficiency (and hereby energy security), to reduce CO_2 emissions, and to diversify the country's energy mix. Further, the production and deployment of next generation vehicles is expected to drive the country's economy and maintain the competitiveness of its automobile industry (METI, 2010a).

The objective for 2050 is full-scale diffusion of EVs (METI, 2009). It is expected that the range of EVs will reach up to 500 km, and that battery costs will be lowered to 1/40 of the current price. By 2030, the governmental diffusion target is to achieve a 50-70 % penetration rate of clean vehicles for newly sold vehicles. It is estimated that up to 50 % of clean vehicles could be EVs. The remainder should be covered by hybrid, fuel cell or clean diesel vehicles (METI, 2010a).

The "EV & pHV Towns" concept (Hosaka, 2010; METI, 2010b) is an implementation framework that demonstrates the fully-fledged dissemination of EVs. In cooperation with municipalities, automobile manufacturers, power companies and local enterprises, infrastructure for EVs is intensively developed in 11 different urban regions[49]. Demand is initiated by the government, the municipalities and corporations; it is then extended to taxis or car-sharing systems; and finally to private users by fiscal incentives.

The Japanese government introduced temporary tax reductions/exemptions for fuel-efficient vehicles lasting until the end of 2012. EVs are completely exempt from taxes. However, since the government budget for purchase subsidies is coming to an end, it is expected that this financial support will end earlier than predicted (Hosaka, 2010; CleanBiz, 2012). In 2010, an electric vehicle taxi pilot project was launched in Tokyo in cooperation with the venture capital company Better Place[50], providing battery switch stations (IEA, 2011b).

South Korea

Up until 2009, South Korea concentrated on hybrid electric vehicles. This triggered the commercialisation and an increasing uptake of this type of vehicle (200,000 HEVs are expected to be on the roads by 2013). Since the introduction of the "Low Carbon Green Growth" policy in 2009, the government's focus is now turned towards plug-in electric vehicles (PEVs). PEVs are mainly seen as a means to support "low carbon green growth". They are in line with global environmental conservation trends and help overcome the country's dependency on oil. The Ministry of Knowledge Economy has been made responsible for the expansion of the PEV supply, and the development and commercialisation of green cars in general. The objective is to replace up to 10 % of the nation's small-sized passenger cars with PEVs, to form 10 % of the global PEV market by 2015, and to be among the top four green vehicle-producing nations. The aim is to increase the production capacity of green

[49] Niigata, Fukui, Kyoto, Okayama, Nagasaki, Aomori, Tokyo, Kanagawa, Aichi, Kochi, Okinawa

[50] See http://www.betterplace.com/Japan

vehicles to 1.2 million units, of which an estimated 0.9 million will be destined for export (FinPro, 2010).

The green car roadmap (Green Car Roadmap, 2010), released on 6 December 2010, defines explicit deployment goals for each of the vehicle types considered. By 2020, (approximately) 1 million BEVs, 250,000 PHEVs, 400,000 HEVs, 100,000 FCEVs, and 1.9 million clean diesel vehicles are to be deployed (a total of approximately 3.7 million green cars). The roadmap further defines EV research and development targets until 2015 (e.g. compared to 2011 levels, the efficiency of the motor is to be increased from 85 to 92 %, the total size is to be reduced to 80 %, the range of the vehicle is to be increased from 140 to 200 km, the dollar price of the battery is to come down from 1,000 $/kWh to 500 $/kWh). With regards to charging infrastructure, a total of 2.4 million charging spots are to be deployed by 2020 (1.2 million home charging units, 8,000 public slow charging spots, 2,600 public quick charging spots, 1.3 million commercial slow charging spots, 19,600 commercial quick charging spots). The expected effects by 2020 are (among others) employment creation (150,000 jobs), and a greenhouse gas reduction of 18 million tons/year.

Korea's first full speed electric vehicle, Hyundai Motor's Blue On, was launched in September 2010. In March 2010, the world's first "online" electric vehicle was presented that "picks up" electricity magnetically from electric strips (buried below the road's surface) as it travels (FinPro, 2010).

USA

The American Recovery and Reinvestment Act of 2009 (ARRA, 2009) is the most recent legislative act that specifically supports the development and use of a variety of alternative fuel and advanced vehicle technologies. It funds research into and the industrialisation of alternative vehicles in order to put 1 million environmentally friendly vehicles on US roads by 2015.

The main motives for the US government to support the development of alternative fuelled vehicles lie in the country's energy security concerns. Further, it is stated that the US wants to (i) compete with foreign nations in the race to be world leader in renewable energy, (ii) create jobs and thereby lay the foundation for lasting prosperity, (iii) advance economic recovery, and (iv) improve the country's environmental sustainability (DOE, 2009a).

In 2009, President Obama announced that $ 2.4 billion out of the ARRA budget was to be dedicated specifically to accelerating manufacturing and deployment of batteries and EVs. 48 new advanced battery and electric drive component manufacturing, and electric drive vehicle deployment projects are funded (DOE, 2009a; DOE, 2009b).

The ARRA dedicates funds to further programs/incentives that (partly) contribute to the development of EVs. Some important measures concerning EVs are (ARRA, 2009):

- The *Qualified Plug-In Electric Drive Motor Vehicle Tax Credit* that contributes between $ 2,500 and $ 7,500 to the purchase of a new qualified (PH)EV, depending on battery capacity and the gross vehicle weight.
- The *Alternative Fuel Infrastructure Tax Credit* that subsidises expenditure on installing alternative fuelling equipment. The credit amount goes up to 50 % of the equipment costs (and does not exceed $ 50,000). Private consumers receive a tax credit of $ 2,000.
- The *Manufacturing Recovery Provisions Tax Credit* – a 30 % tax credit for investment in advanced energy property manufacturing facilities.
- The *Support for fuel-efficient vehicles in the federal fleet* – a $ 3 billion fund for the acquisition of more fuel-efficient vehicles for the federal fleet.

Many measures concerning alternative fuel vehicles are defined on the state level. The Department of Energy provides an online database of policy measures supporting the take-up of alternative fuel vehicles (see DOE, 2012). All measures are retrievable per state. It shows that 31 (out of the 50) US states provide grants (including grants toward eligible project costs), 41 states offer tax incentives (including tax credits and exemptions), 24 states offer loans and leases (including direct loans, loan guarantees, and leases), 24 states offer rebates (including rebates for the purchase of vehicles, sale of fuel, etc.), 42 states provide exemptions (including exemptions from restrictions and requirements such as roadway weight limitations, parking fees, high-occupancy vehicle lane access, and vehicle inspections), and 38 states offer "other" incentives (including discounts/rate reductions, technical assistance, etc). California has the highest number of measures supporting the uptake of alternative fuel vehicles, with 39 different incentive schemes. The second highest number is found in the state of Washington that provides 22 different incentives. It is important to note though, that these measures do not only concern EVs, but also all other types of alternative vehicle technologies[51].

After an growing market for hybrid EVs, interest in BEVs in the US automobile industry has taken off, with manufacturers beginning to introduce new generations of BEVs (IEA, 2011b).

A federal initiative that was launched on 1 October 2009 is the EV project (EV project, 2012). It is funded with over $ 100 million from the Department of Energy, and a supplementary $ 230 million from project partners (notably Chevrolet and Nissan). Recharge infrastructure is deployed in major cities and metropolitan areas across the US. EV drivers who qualify for the programme receive a residential charger at no cost and are partly refunded for installation

[51] Biodiesel, ethanol, natural gas, propane (LPG), hydrogen fuel cells, BEVs, HEVs, PHEVs, NEVs (neighborhood EVs, typically limited to speeds of less than 35 miles per hour)

costs. In exchange, vehicle and charge information is collected in order to characterise vehicle use in diverse topographic and climatic conditions.

2.4 Synthesis and discussion

This section synthesises the policy approaches outlined above in view of (2.4.1) identified national interests and engaged authorities, (2.4.2) EV deployment objectives, (2.4.3) action plans, and (2.4.4) demand-side measures focused on the private vehicle user. Section 2.4.5 then gives an overview of the vehicle deployment progress as of the end of 2012. Most sections provide a country comparison based on the findings of the review per country.

2.4.1 National interests and engaged public authorities

The policy overview shows that basically all reviewed countries recognise the numerous potential advantages of EVs to CVs. Most policy papers state environmental objectives, on going industrial and economic downturn, or concerns with regards to increasing energy dependence as the main reasons for increasing interest in the development and uptake of electric vehicles, and in electromobility in general. The importance of each of these reasons naturally depends on a given country's transport system and energy supply, its industry focus and industrial capacities and interests. While the customer is frequently subject to the environmental publicity surrounding the introduction of EVs – probably seen to be an effective marketing strategy – the initial policy interests in EVs might be of a different nature.

Although these initial, or maybe even 'primary' interests, of a given country are difficult to identify, an attempt is made to do so. For this purpose, public authorities that are the main administrative and sponsoring bodies of EV-directed policy measures are identified. This might shed light on the origins of the initial interest in EVs. Engaged public authorities are often ministries. Partly, inter-ministerial bodies have also been specifically set-up to work either under the direct patronage of the government (e.g. Germany's National Platform for Electromobility that is financed by the federal government) or under the patronage of selected ministries in order to streamline all EV-focused policy measures of different instances (e.g. the UK's Office for Low Carbon Vehicles that receives funding from the Department for Transport, the Department for Business, Enterprise and Regulatory Reform, and the Department for Innovation, Universities and Skills).

Table 2.1 shows the activity field(s) of countries' first engaged authority(ies). These fields were categorised into (i) environment/transport, (2) energy, and (3) economy/industry. This categorisation frequently corresponds with the countries' government departments. The table reveals that EV-supportive public

authorities hardly ever coincide with only one of the defined fields. The countries for which this is the case are briefly discussed in the following.

In **Norway,** EV support seems to exclusively stem from a public body focusing on environmental or transport policy (namely the Ministry of Transport and Communication). EVs are mainly seen as means to actively support and further extend the large hydro-power capacities that essentially cover all of the country's electricity needs (EIA, 2012a). EV support from authorities that are concerned with energy policies only is more frequent. More specifically, this is the case in Ireland, Spain, and the United States. In **Ireland** the progressive increase of renewable electricity from onshore and offshore wind farms or domestic and export markets was declared as a strategic goal. With this comes the strategic goal of a more sustainable transport sector through electrification and an increased focus on growing electricity storage capacity (DCENR, 2012). Funding for policy measures and incentives comes from the Sustainable Energy Authority, established as Ireland's national energy authority under the Sustainable Energy Act 2002. **Spain** has a similar energy-related interest in EVs: 77 % of Spain's energy consumption relies on external sources, (61 % of which comprise net oil imports). The transportation sector accounts for almost 40 % of total energy consumption, and for 65 % of all oil imports. Within the transportation sector, road transport accounts for 80 % of energy consumed, with virtually all of this energy coming from oil. For this reason, the extension of national renewable energy sources in Spain has gained importance. A focus has been put on wind energy, which will necessitate a larger electricity storage capacity, something that EVs' batteries can deliver (IEA, 2011b; IEA, 2009b). Spain's main EV-supportive public body is the national government's Institute for Energy Diversification and Saving (IDAE). In the **US**, the Department of Energy (DOE) provides most of the public funding for research, development and deployment of innovative vehicle technologies. The DOE's mission is to advance energy technology and promote related innovation. In the US, the transport sector is responsible for 28 % of the country's total energy consumption, and relies to 93 % on oil, which stems for two-thirds from imports (IEA, 2012b). Also the US' interest in becoming more energy independent in the transport sector becomes apparent. With more support for renewable energy sources, backing EVs that can help exploit their full potential appears like a logical consequence. In **China**, it is the Ministry of Science and Technology that appears to be the main carrier of EV-supportive measures and initiatives. Table 2.1 indicates that China's public body is concerned with industry issues, since EVs appear to be primarily seen as a means to contribute to the automobile industry's development goals. China specifically defines goals related to EV production capacities: in 2020, EV production capacities will reach 2 million vehicles per year, of which many will be bound for export. In **Japan**, the main EV-supportive public authority is the Ministry of Economy, Trade and Industry.

In **Portugal**, the Office for Electric Mobility (GAMEP), established within the Ministry of Economy, coordinates all EV-supportive policy packages.

In all other countries, no single public authority of a certain field stands out as being specifically EV-supportive. Either, there are various authorities involved, or the authority's activity field overlaps with more than one of the here defined categories. One such example is **Denmark**, where the main active public body appears to be the Danish Energy Agency that operates under the Ministry of Climate, Energy and Building. The Danish interest in EVs seems to be driven primarily by the goal to double the current share of renewable energy to at least 30 % by 2025 (where 50 % is expected to come from wind energy). Managing such a higher share of intermittent electricity will be a major challenge. Within this context, EVs are expected to provide the storage of such energy (IEA, 2011b).

Table 2.1 further shows that the activity field of "Economy/Industry" is – if only slightly – the most recurrent one. It is interesting to note here that it is not only countries that are heavily engaged in the automotive industry that appoint industry-related public bodies to support EVs. Countries such as Ireland or the Netherlands, whose automotive industries take less important roles in the countries' economies, also appear to see economic/industrial development opportunities arise following the introduction and uptake of EVs.

		Activity field of country's most engaged authorities		
		Environment/ Transport	Energy	Economy/ Industry
Austria	AUT	●		●
China	CHN			●
Denmark	DNK	●	●	
EU	EU	●	●	●
France	FRA	●		●
Germany	DEU	●	●	●
India	IND		○	●
Ireland	IRL		●	
Italy	ITA	●		●
Japan	JPN			●
Netherlands	NLD	●		●
Norway	NOR	●		
Portugal	PRT			●
South Korea	KOR	○	○	●
Spain	ESP		●	
United Kingdom	UK	●	●	●
United States	USA		●	
●	activity field of the primarily engaged authority			
○	activity field of a further engaged authority			

Table 2.1: Activity fields of most EV-supportive authorities

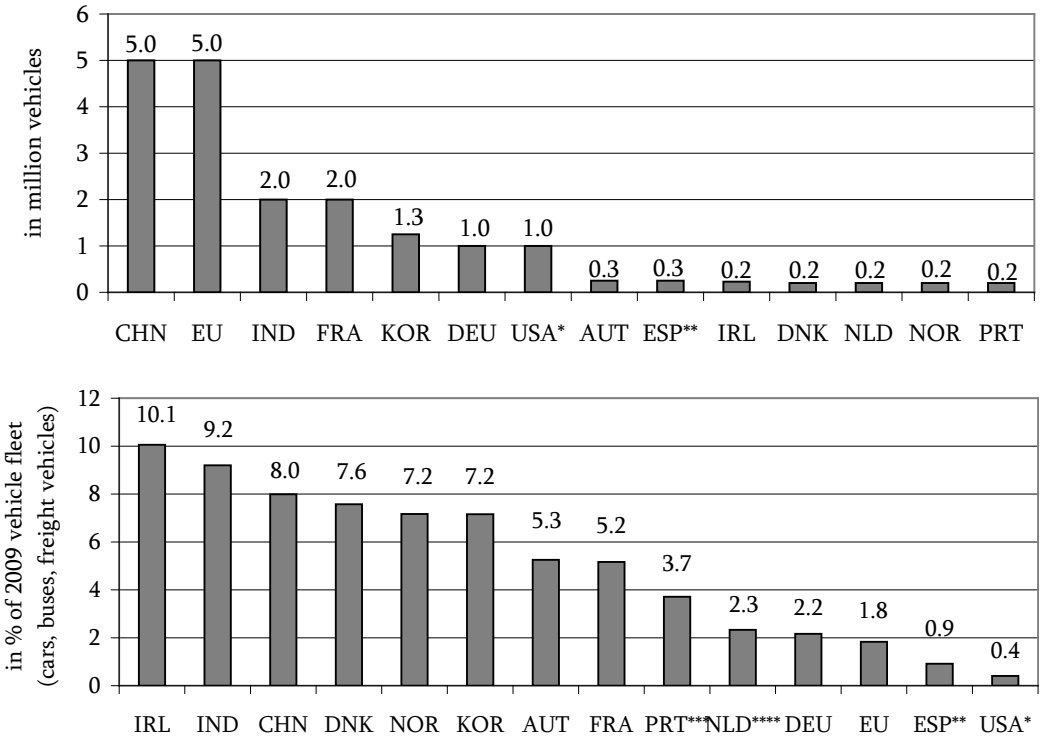
2.4.2 Deployment objectives

Concerning EV deployment objectives, countries show more or less ambitious goals. Figure 2.3 gives an overview of deployment objectives defined for 2020 (or 2015 for some exceptions) in total numbers and percentage of the respective country's 2009 4-wheel motor vehicle stock (including cars, buses, and freight vehicles).

It can be seen that China and the EU have the most ambitious EV deployment goals in total numbers. With the objective of deploying 2 million EVs by 2020, France shows to be, by far, the most ambitious European country. Germany, with the objective of attaining 1 million EVs by 2020, ranks second. The American goal of deploying 1 millions EVs by 2015 appears to be modest

given the country's large market size. Spain's rather ambitious goal of 250,000 EVs ready by 2014 seems to be somewhat optimistic.

When looking at the deployment goals as a percentage of the 2009 vehicle fleet (including cars, buses, and freight vehicles), it can be seen that the most ambitious country is Ireland. It aims to replace 10 % of its vehicle fleet with EVs by 2020 (assuming a stable vehicle fleet until then). In addition, India and China, with the objectives of attaining an EV share of 9 % and, respectively, 8 % prove to be ambitious. However, the percentage values displayed for these countries' 2009 vehicle fleet have to be treated with caution. India's and especially China's motorisation rate has been increasing enormously during last decade and an imminent change in this trend is not expected.



*2015 objective ** 2014 objective *** in % of 2006 car fleet **** in % of 2008 car fleet
Source: the author's policy analysis and World Bank (2012a, 2012b)

Figure 2.3: EV deployment objectives per country

On the one hand, this leaves significant market potential for EVs and leaves hope for a quicker EV uptake rate than in developed countries where markets are already saturated. On the other hand, even if EV deployment objectives in total numbers are met, the EV fleet could prove to be negligible in comparison to the uptake of conventional vehicles. The importance of public policy measures in these countries, which should provide incentives that allow for leapfrogging these latter technologies, becomes apparent. After Ireland, it is

Denmark and Norway that show the most ambitious deployment goals in Europe when expressed as a percentage of the 2009 vehicle fleet. The US target of 1 million EVs by 2015 still proves to be comparably modest, given that it translates into only 0.4 % of the country's total vehicle fleet.

2.4.3 Defined action plans

Many national governments have released action plans that define how deployment objectives are to be reached. Often, such action plans define milestones until 2020 or 2030, the time when mass market (e.g. in Germany) or even completely decarbonised transport is to be attained (e.g. in the UK). Most often, 3 phases are defined that refer to (i) a market build-up or preparation phase until 2014 at the latest, (ii) a market growth or a maturation phase that lasts until 2020, and (iii) a mass market phase from 2020 or 2030 onwards. Exact time slots are defined differently in each country, as are the exact milestones for each phase. Often, milestones are defined separately for research activities, the deployment of (mainly public) infrastructure, and the uptake of vehicles. Figure 2.4 gives an impression of defined action plans by synthesising what has been found for specific countries. In particular, the EU as a whole, Germany, the UK, and the Netherlands were found to have defined such 3-step (or partly 4-step) action plans. Whether future milestones are realistic remains to be verified. Concerning the market penetration phase, 2012 milestones seem to have been largely reached: Demonstration projects have been deployed in most countries, the first public recharge infrastructure (mainly in metropolitan areas) deployed, and electric vehicles launched onto the market. On the contrary, sales numbers appear to partly lag behind expectations (see Section 2.4.5 on countries' current progress).

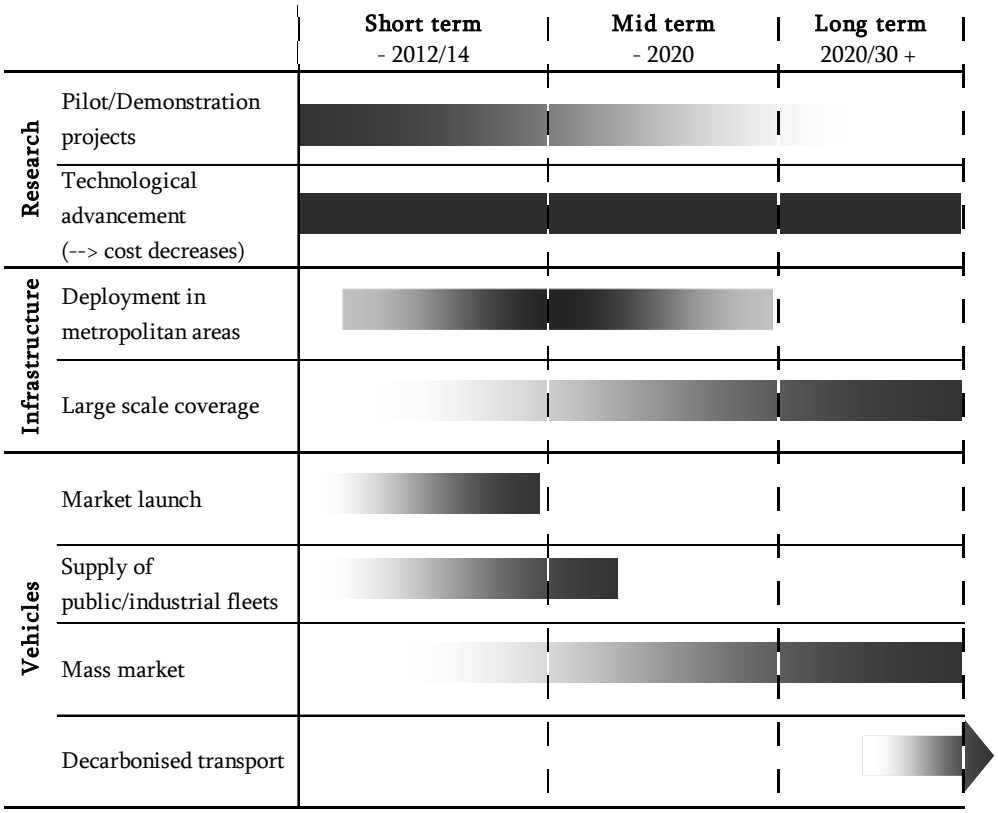


Figure 2.4: Synthesised action plan

2.4.4 Implemented measures

Table 2.2 illustrates the implemented policy measures that belong to the defined scope of the underlying review (see Figure 2.1). These measures refer mainly to demand-side economic instruments that alter vehicle purchase or vehicle usage cost for either an EV or a CV. They are of particular interest to the private vehicle purchaser. Next to these demand-side economic instruments, it is also shown whether EV users have preferential access rights to public parking or restricted traffic zones, and whether there are national efforts (financial and/or administrative) to provide public recharge infrastructure. Also, these two instruments are seen as the main drivers behind private EV uptake. Table 2.2 only accounts for measures that have been defined on a national level and that are in place at the end of 2012 (unless stated otherwise).

The policy instruments displayed are classified into measures focusing on vehicle uptake and those focusing on infrastructure deployment. Both of these can result in either a *one-time* benefit or, alternatively, in a *recurring* benefit for the single vehicle user. The benefit to users of national efforts that focus on providing public recharge infrastructure is considered to *increase* as the recharge network grows over time.

Table 2.2 only gives a qualitative overview of deployed measures. The actual effect on purchase costs or vehicle usage costs is not evaluated; the duration of policy measures is not stated; and the amount of purchase subsidies, existing tax rates and resulting tax reliefs are not verified. While an evaluation of one off benefits is conceivable, evaluating recurring benefits is much less straight-forward. Recurring benefits depend on the vehicle user and their assumed vehicle usage behaviour, and – in the case of preferential access rights – are not directly quantifiable in monetary terms. Neither the instruments' effect on a country's national budget nor the policy package's sustainability over time (both also dependent on the actual uptake rate of EVs) can be inferred. The table helps shed light on *which* policy measures have been deployed, but does not evaluate the exact financial effect of the measures on a single user or the public budget.

	Vehicle uptake							Infrastructure deployment	
	One-time benefit			*Recurring benefit*				*One-time b.*	*Increasing b.*
	Vehicle purchase subsidies/feebates	Preferential taxes on sale prices	Preferential registration taxes/fees	Preferential vehicle/circul. taxes	Preferential energy taxation/tariffs	Preferenial fees (e.g., for parking)	Preferential access (e.g., to bus lanes)	Home infra. installation subsidies	Coordination of/investments in public infra.
AUT			+						+****
CHN*	+	+**			+	+	+		
DEU				+					
DNK			+						+
ESP									+
FRA	+		+						+
IND									
IRL	+		+						+
ITA	+			+	+				+
JPN		+***							
NLD		+		+					+****
NOR		+	+			+	+		+
PRT	+	+		+		+*****	+		+
UK	+			+					+
USA	+							+	+

*measures in "demonstrator cities" **nation-wide; for certain domestically produced EVs ***funding available till 09/2012

****national initiative of stakeholds other then public authorities ***** in all urban centres

Table 2.2: Overview of implemented measures per country

One-time benefit measures for supporting vehicle uptake

Table 2.2 shows that there is no clear favourite policy instrument to support vehicle uptake. Vehicle purchase subsidies (sometimes in the form of CO_2-emission-based fee and rebate schemes, or 'feebate' schemes), and exemptions or reductions in recurring annual vehicle or circulation taxes appear to be the most common demand-side economic policy instruments. Those countries that do not offer purchase subsidies frequently reduce EV sales taxes or vehicle registration taxes in order to lower up-front costs for the vehicle user. In general, measures bringing down these up-front costs are seen as major policy levers to support EV uptake. These "direct reductions of the sales price have twice the effect of deferred support schemes" (Kley et al., 2010), given that the up-front costs of EVs pose a major obstacle for private EV uptake (see, e.g. Deloitte, 2010). More specifically, purchase subsidies in the framework of feebate systems appear to be more effective than sales tax reductions. Customers usually value the amount paid separately for a subsidy more than tax reductions, and are generally more averse to a possible malus associated with their vehicle purchase than to a potential bonus (see the concept of *loss aversion*; Kahneman and Tversky, 1979). The importance of up-front one-time benefits seems to be acknowledged by most countries.

Purchase subsidies often lie in the range of EUR 5,000 per vehicle (e.g. EUR 5,000 in Ireland and Italy, GBP 5,000 in the UK, EUR 6,500 in Portugal, and, since August 2012, EUR 7,000 in France). The effect of exemptions or reduced taxes on the purchase price of an EV depends on the prevailing vehicle tax system in place in each country.

In Europe, the most extreme examples with regards to taxation on vehicle prices appear to be Denmark and Germany. In Denmark, a value added tax of 25 % is added too the vehicle's price, before an additional registration tax of 105 % (for up to DKK 79,000, or approx. EUR 10,600) and 180 % (on the remainder of the vehicle's price incl. VAT) is applied. The effect of the vehicle registration tax exemption for EVs in Denmark becomes apparent. In Germany, the VAT amounts to 19 % of the vehicle's price. After that, there are no additional registration taxes charged. The UK's vehicle taxation system resembles that of Germany, where the VAT amounts to 20 % of the vehicle's price. These examples show that the possible scope of action for EV-supportive policy measures depends heavily on policies already put in place (ACEA, 2012b).

Recurring-benefit measures for supporting vehicle uptake

Preferential electricity tariffs or taxation for the amount of electricity used when recharging an EV were announced in Italy and have been put in place in some of the Chinese EV demonstration cities. In all the reviewed countries, EV users benefit from remote taxations on electricity as compared to the often significant fuel taxations. This gives a recurring cost advantage to the EV user, which grows

with increasing vehicle usage. Since such energy taxation schemes were originally not introduced with the objective of supporting EV uptake, they are not specifically shown in Table 2.2. Also, it should be kept in mind that the currently existing schemes are likely to be aligned to increasing EV market penetration: in the long term, increased electricity taxation might become the adequate policy measures for compensating reduced fuel tax incomes that result from a continuously decreasing and more fuel-efficient CV fleet. As is the case with fuel tax increases, such electricity taxation adjustments are expected to be an extremely unpopular measure. They not only affect other industries, but also come with a comparatively higher disadvantage to low-income households (see Kley et al. 2010).

Preferential fees, for example to public parking or congestion charging zones, and preferential access rights to the latter and high occupancy or bus lanes, are fairly easy to implement and are politically accepted (Kley et al., 2010). Typically, these measures are defined on a local level. Local authorities can best define where, to what extent, and when such measures are most reasonable given existing traffic volumes or parking scarcity. EV owners benefit from reduced fees, emptier streets and more parking availability. Table 2.2 shows that defining these measures on a national level is an exemption. China introduced such measures to its EV demonstration cities; Portugal did so for its urban centres. Norway is the only reviewed country that implemented preferential fees and access rights on a national level. More specifically, EVs are exempt from all road and ferry tolling, public parking fees, and have the right to access all bus lanes. Probably the earliest evidence for the effectiveness of congestion charge waivers and applying preferential parking fees for green vehicles comes from London. Here, such measures proved influential on EV uptake rate in 2007 (Gruenweg, 2007). For this reason, London continuously expanded such measures (see Section 2.5.1 for more information). However, these instruments are only sustainable until a certain EV penetration is reached. Stockholm is an example of where waiving congestion charges had to be ceased before the envisaged end of the measure: instead of maintaining it until 1 August 2012 (as initially planned), it was abandoned on 1 January 2009. Vehicle owners that had registered their green car before 1 January 2009 kept preferential access rights until August 2012 (Swedish Transport Agency, 2009).

Measures supporting the deployment of infrastructure

Table 2.2 gives an idea of national support for infrastructure uptake. The two measures explored give only an overview of *if* there is support on the national level for infrastructure uptake, but does not concretise how such a support is implemented. The last column shows that most reviewed countries engage in infrastructure deployment at public premises on a national level. Varying sized funds were made available (e.g. EUR 50 million in France according to Plan

Automobile, 2012; £ 30 million (approx. EUR 35 million) in the UK, through the Plug-In Places programme in the UK). Further, several countries have released laws that ease administrative hurdles concerning installation of infrastructure on public (and also private) premises (e.g. France, UK, and Italy). In the US, funds have been made available that also financially support the infrastructure installation at private premises. Here, private consumers receive a tax credit of $ 2,000. In case EV drivers qualify for the *EV project*, they receive a residential charger at no cost and are partly refunded for installation costs. Ireland offered free private recharging units at home for the first 2,000 EV owners. Such infrastructure-directed measures have not been identified in any other reviewed country. While the need for supporting the uptake of *public* recharge infrastructure appears to have been generally recognised by policy makers of EV deploying countries, the often faced difficulty surrounding the installation of recharge infrastructure at private premises seems to have been largely neglected.

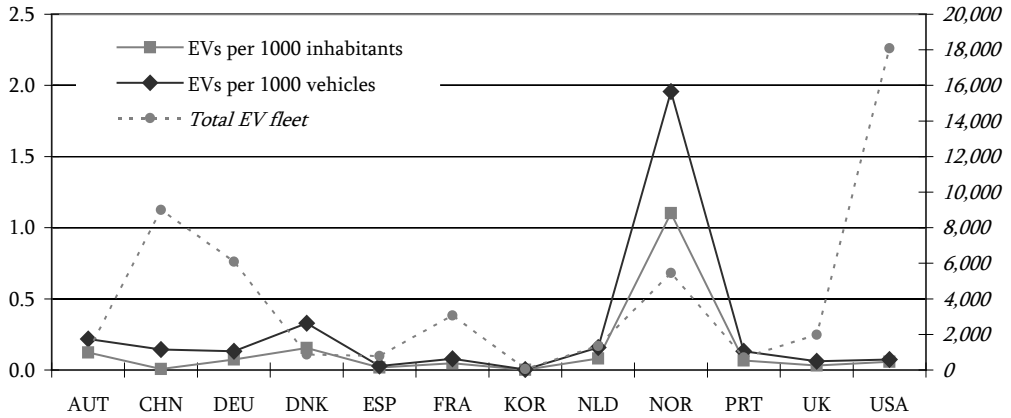
Most countries are aware of the importance of Smart Grid developments that allow the intelligent and efficient charging of vehicle batteries. Denmark, Portugal and Spain are countries that underline the importance of such developments in the view of the planned increasing wind power capacities in the upcoming years.

2.4.5 Deployment progress as of 2012

This section gives an overview of the EV deployment progress as of beginning 2012. Country comparisons shown in Figures 2.5 to 2.7 are based on various data sources stemming from the different countries' statistics offices or, alternatively, from secondary sources. Attention is therefore drawn to the fact that not all numbers refer to the same type(s) of electric vehicles. Whereas the term *EV* refers, in German or Austrian statistics, to battery electric vehicles (BEVs) only, in the US the same term refers to BEVs, plug-in hybrid electric vehicles (PHEVs), and range extended electric vehicles (EREVs). Attention is given to the fact that all presented numbers solely include plug-in electric cars that need to be registered. Classic hybrid vehicles that cannot be recharged by an external electricity source are not included in the analysis. According to the data sources, Dutch numbers also comprise fuel cell EVs (FCEVs). Their total number is most likely negligible. The notes in each figure give EV definitions and further important remarks to help correctly interpret the numbers displayed. Annex 2.2 and 2.3 give all shown numbers as well as used key indicators per country. Due to the lack of available data, not all of the countries reviewed are included in the following analysis.

Figure 2.5 gives the EV fleet per country as of beginning 2012. The EV fleet is also expressed in relation to the country's population (as of 2011 – the number of EVs is given per 1 000 inhabitants) and to its total vehicle (as of 2009 – the number of EVs is given per 1,000 registered vehicles – cars, buses, and freight

vehicles) in order to make country comparisons more valid. It can be seen that the highest number of EVs deployed is found in the US, where a bit more than 18,000 vehicles were deployed by the beginning of 2012. A large share of these vehicles is EREVs (in 2011 they constituted a bit more than 50 % of the total PEVs demand; Electricdrive, 2012).



Sources: EV stock 2011: DNK, ESP, KOR, NLD, PRT, USA: AgentschapNL (2012); AUT: Statistik Austria (2012) for PVs, AgentschapNL (2012) for all other types, CHN: The Australian (2012), DEU: KBA (2012) for PVs, AgentschapNL (2012) for all other types; FRA: *Automobile Propre* (2012) for PVs, AgentschapNL (2012) for all other types; Gronnbil (2012): NOR, DfT (2012): UK. Countries' total vehicle fleet and population: World Bank (2012a, 2012b)

Notes: The countries' total vehicle fleet comprises the car, bus, and freight vehicle fleet as of 2009; countries' populations are as of year 2011. EV stock in UK and FRA is the sum of 2010 and 2011 EV registrations only; EV stock in China is the sum of 2011 registrations only. Definition of 'EVs': AUT and DEU: BEV only, CHN: BEVs and PHEVs, UK: all 'ultra low carbon emission vehicles' eligible for the plug-in car grant; USA, NOR: PEVs; NL: PEV and FCEV; EV definitions for other countries unknown. EVs comprise electric 4-wheel passenger cars, buses, light-duty vehicles, and trucks (unless unknown). See Annex 2.2 for all values.

Figure 2.5: EV fleet per country (as of 1 January 2012)

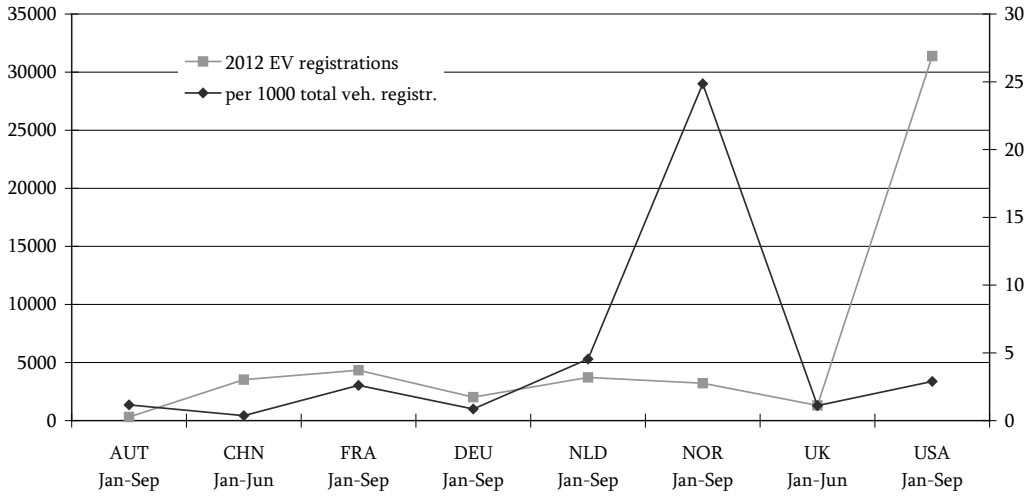
When putting the EV vehicle stock in relation with the country's total vehicle fleet (comprising cars, buses and freight vehicles), it can be seen that the total number of EVs is comparably negligible in the US (for every 1,000 registered vehicles, there are 0.074 EVs). Further, also China and Germany show comparatively large EV stocks (over 8,000 and, respectively, 6,000 vehicles). The highest share of EVs with regards to the total vehicle fleet is found in Norway. Here, almost 2 out of every 1,000 vehicles are electric. Norway is followed by Denmark where around 0.3 out of 1,000 vehicles are electric. Austria and Germany show values of around 0.2 and 0.1 EVs per 1,000 vehicles respectively. Also, China's value appears to be in the same order. It should be remembered, however, that the vehicle stock between 2009 and 2011 probably increased significantly, as it did already in previous years (in China, car motorisation had

increased from 24 to 32 cars per 1,000 inhabitants between 2009 and 2010[52]; ACEA, 2012c and ACEA, 2011). The numbers for China with regards to the 2009 vehicle stock therefore distort the picture to the advantage of the deployed EVs.

2012 signified the market launch of several EV models (e.g. the Renault Fluence Z.E. and the Opel Ampera on the European market, the Tesal Model S on the US market). Many other models were made available only in the second half of 2011 (e.g. the Nissan Leaf is available in Portugal and Ireland since 30 July 2011, in the UK since 1st September 2011). For this increased EV market availability, 2012 can be considered as the first year when a portfolio of mass-produced EVs was made accessible to the public[53]. Besides, infrastructure deployment at public premises has been advancing, several policy measures were reinforced or newly introduced (e.g. the French EV purchase bonus increased from EUR 5,000 to 7,000 in August 2012; the new UK Plug-in Van Grant of £ 8,000 available since February 2012; see Section 2.3.2), fuel prices have been increasing, and general awareness of low emission vehicles has certainly been increasing. Having a look at EV registration numbers for 2012 gives an impression if (and by what magnitude) such changes in framework conditions affected EV sales. Sales figures for 2012 were not easily accessible at the time of writing this report. Figures 2.6 and 2.7 give vehicle registration numbers retrieved for a selection of countries. These refer either to the time period of January to June 2012, or of January to September 2012. Again, all cited sources give more information on exact EV type definitions. Information on the country-specific vehicle category (on whether only passenger cars, or also other (light) duty vehicles and buses are considered) is found in the notes (and can be consulted in more detail in the given sources). Numbers are put in relation to i) the countries' total vehicle registrations for the same time period (Figure 2.6), and ii) the countries' 2011 EV stock (or to the according sub-selection of the EV stock in case only a specific vehicle category is regarded – see Figure 2.7).

[52] As compared to the EU, where it changed in the same time period from 473 to 477 cars per 1,000 inhabitants; the US, where it decreased from 437 to 424 cars per 1,000 inhabitants (not including sport utility vehicles), or India, where it increased from 8 to 10 cars per 1,000 inhabitants.

[53] Several more EV models, however, remain to be launched in the near future: e.g. the Renault ZOE Z.E. and the Tesla Model S are expected for early 2013 on the European Market.

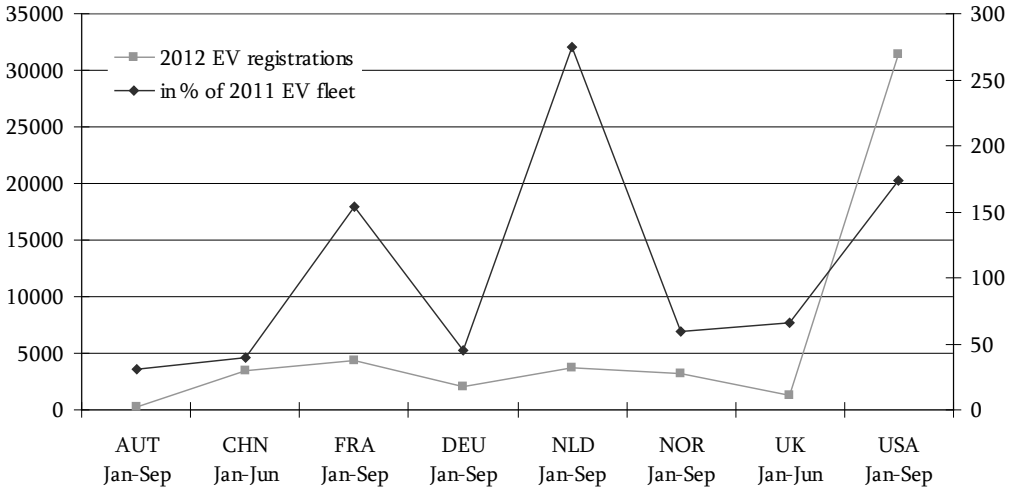


Sources: AUT: Statistik Austria (2012), CHN: CRI (2012), FRA: Total: *Automobile Propre* (2012), EVs: CGDD (2012c), DEU: KBA (2012), NLD: Total: CBS (2012), EVs: AgentschapNL (2012), NOR: Total: TradingEconomics (2012), EVs: Gronnbil (2012), UK: DfT (2012), USA: Electricdrive (2012)
Notes: EV definition per country as given in Figure 2.5. Vehicle categories: AUT, DEU, FRA, NOR: passenger cars only; CHN, NL, UK: passenger cars, buses, and freight vehicles; USA: unknown. See Annex 2.3 for all values.

Figure 2.6: 2012 EV registrations per country

Figure 2.6 shows that also in 2012, the US has (so far) registered most EVs. Out of over 31,000 newly registered EVs, almost 80 % are either range extended EVs (EREVs) or PHEVs. Especially the PHEV market share among the total number of EVs appears to be significant: In their first year on the market, 7,734 Toyota Prius and 16,348 Chevrolet Volts (both are PHEVs) were sold up until September 2012 (Green Car Reports, 2012; EVsRoll, 2012). The US EV market share among new vehicle registrations is 0.29 % (or 29 EVs per 1,000 registered vehicles). In the Netherlands, the market share is higher (0.45 %); in France, where 4,339 electric passenger vehicles were registered, it is somewhat lower (0.26 %). It is important to note that 1,384 of the French passenger EVs were Bolloré's Bluecars, which act as shared EVs in the Paris' Autolib project (see Section 2.3.2). On the other hand, French numbers do not include light duty vehicles. Between January and June 2012, 1,426 light duty EVs were registered, of which 1,058 were Renault Kangoos (launched in November 2011 on the French market) (*Automobile Propre*, 2012b). The EV percentage share amounts to 0.74 % of 2012 vehicle registrations in the vehicle category and time period (Jan-Jun 2012). By far the largest EV share among all vehicle registrations is observed in Norway. Here, 2.49 % of newly registered vehicles were EVs in 2012. In August 2012, this figure reached 3.7 %; in September 2012 5.2 % (EVUnion, 2012). The Nissan Leaf comprises around 24 % of the total Norwegian EV fleet (Gronnbil, 2012).

Figure 2.7, which shows the 2012 EV registrations as a percentage of the 2011 EV stock, gives an impression of whether, and by how much, EV sales increased due to the changes in the framework conditions mentioned above. It can be seen that a 'surge' in EV registrations compared to previous EV sales mostly failed to appear, especially so in Austria, China and Germany. Here, 2012 sales (from January to June, or, respectively, September) did not attain the 50 % mark of the existing EV fleet. Countries that show a significant increase in the EV stock are France, the Netherlands, and the USA. 2012 sales from January to September reached 154 %, 275 %, and 174 % respectively of the previously existing EV fleet. As mentioned above, in France, this surge is mainly due to the demand of Bollore's Bluecars; in the Netherlands, the increased demand mainly results from the Opel Ampera sales (launched in the Netherlands in September 2011) that attained a total stock of 1,935 vehicles in September 2012 (of which only 8 had been sold in 2011; *Autoweek*, 2012); in the US, also as mentioned above, the increased EV demand is mainly caused by the increased market availability of PHEV models.



Sources: See Figure 2.6.
Notes: See Figure 2.6; 2011 EV fleet according to Figure 2.5 and the underlying vehicle categories (see Annex 2.3 for all values)

Figure 2.7: 2012 EV registrations in relation to 2011 EV fleet

The figures given above show that EV registrations appear to depend heavily on the market availability of certain models. Especially in the US and the Netherlands, the introduction of PHEV models resulted in a significant increase in total EV demand. In Norway, where EV registrations had attained comparatively high levels since 2009, the introduction of the Nissan Leaf gave a further boost to EV sales. China's EV deployment pace appears to be quite modest for the time being. Together with some other European countries (Austria and Germany), 2012 EV registrations do not show a promising picture

for accelerated EV uptake rate. The strong EV policy support in Norway (especially considering the nationwide preferential access rights and parking fees) appears to have been a fruitful method for boosting EV demand.

It is too early to say whether 2020 vehicle deployment goals can be sustained. It is, however, rather questionable. Continuously increasing EV market availability might boost the EV uptake rate in the upcoming years, as this was the case in some selected countries. Nevertheless, this might not be sufficient. Other countries' uptake rates seem, for the time being, to be independent of the existing EV offer. In these cases, ambitious goals can probably not be met without severe adjustments to prevailing EV policy measures. 2015 objectives – as they were defined, e.g. by the Netherlands (200,000 vehicles), France (450,000 vehicles), or the US (1,000,000) – seem to be quite unrealistic. The remaining 3 years will not give enough time for a sufficient EV penetration, even if the counties' recent boost in EV registrations can be maintained over the next 3 years. As in France, this boost might have been the result of selective deployment projects, in which case future uptake rates are likely to drop again. On the other hand, it is hoped that increased EV penetration will result in higher awareness of EVs and denser infrastructure networks over the next couple of years. A resulting network effect could increase EV registrations by a magnitude that is uncoupled from previously observed numbers.

The impact of the increased EV purchase bonus in France remains to be analysed once EV registration numbers of the 2nd semester of 2012 are available. It will give one of the rare opportunities to explore the sole effect of such a measure on EV uptake, since other framework conditions (such as fuel prices or EV market availability) have not been subject to severe changes between the first and second half of 2012. Further, other countries usually introduced a package of policy measures at once, which hampers the analysis of the effect of a single measure.

2.5 Two examples of local initiatives

The main part of this chapter served as review and discussion of policy plans, deployment objectives, and implemented policy measures on a national level. This section now gives two examples of locally defined and implemented EV deployment plans. An impression of how local authorities can take advantage of local settings and framework conditions for defining the most efficient and adapted policy measures is obtained. The first case, London, gives an example of a metropolitan area, while the second case, the deployment project VLOTTE in Austria shows what can be done in a much less dense urban environment.

2.5.1 London

The Mayor of London launched an Electric Vehicle Delivery Plan (Greater London Authority, 2009a) in May 2009. It sets out the roadmap to deploy charging infrastructure for privately-owned EVs up to 2015. Altogether 25,000 charging points are to be installed and 100,000 EVs are targeted for London's roads. The main reasons for London to promote EV development are to reduce carbon emissions, to improve air quality, and to reduce noise.

Infrastructure

London makes three main types of charging points in the public-access charging network available. Slow charging points (6-8 h charging time), fast charging points (30 min-3 h charging time), and rapid charging points (entailing either a 15-20 min charging time, or a 5-min battery exchange procedure) are deployed. The development of the private charging network, in residential homes, at workplaces, and for new sites is supported. Besides residential off-street charging points, installations at private car parks and customer car parks make up the largest share in the network (altogether 22,500 installations). The envisaged public charging network will have 500 on-street charging points and 2,000 installations in publicly accessible car parks. The main goal is to insure that every Londoner has access to a public charging point within a 1-mile radius of their dwelling by 2015 (Greater London Authority, 2009b). For this purpose, *Source London* was launched on 26 May 2011 – the first city-wide EV charging point network and membership scheme. Source London will install 1,300 charging points by 2013 (766 were made available by October 2012). A £ 10 (approx. EUR 12) annual membership fee allows access to the entire recharge network (with no extra charge for the electricity used). Besides *Source London*, London's boroughs also independently install recharge infrastructure spots (Source London, 2012).

Since October 2012, EV drivers can join an EV infrastructure trial in order to receive a free home charging unit. The drivers have access to an online account where they can view energy use and details. The project permits examination of EV drivers' habits, which will help to project peaks on the electricity network, and to evaluate the potential impact on the electricity network if the majority of London's vehicles run on electricity (Energy Efficiency, 2012).

Vehicles

London aims to increase the number of EVs on the capital's streets as soon as possible to 100,000 vehicles (or 5 % of London's fleet). To achieve this target, the city continues with EV trials and increases the share of EVs in the Greater London Area group fleet. It also encourages the use of EVs amongst its suppliers. EV options for the wider public transport, such as, for taxis, private hire vehicles

and buses, are offered, and the private sector is incentivised to acquire EVs (Greater London Authority, 2009a).

Incentives

London provides EV users with incentives that complement the national UK incentives. A number of boroughs offer subsidised parking for EVs, saving the user up to £ 6 000 (approx. EUR 7,000) a year. Also, there is a 100 % congestion charge discount for EVs (worth up to £ 2,278, or approx. EUR 2,700) per year for regular travellers; Greater London Authority, 2009a).

2.5.2 Vorarlberg, Austria – The VLOTTE project

VLOTTE is the project title of an EV demonstration and testing program taking place in the Western part of Austria, Vorarlberg, since August 2009. It belongs to the biggest EV model regions in Europe.

In 2008, the Austrian Climate and Energy Fund selected Vorarlberg to become a model region of electric mobility and appointed EUR 4.7 million to its development. The "backbone" of the region is the Vorarlberg Rhine Valley. The Rhine Valley is characterised by a relatively low population density and a simultaneous homogeneity of the settlement structure: an urban-sprawled landscape.

In 2009, 100 EVs were distributed and assigned to interested parties of an exclusive circle: 40 cars were given to companies, 40 to public institutions and non-profit organisations and 20 to private users. The customer is offered a "mobility card" for approximately EUR 500 a month (depending on the vehicle). The mobility card includes the leasing of the car, maintenance costs of the electric parts, a railway pass for the Vorarlberg Public Transport System and free-of-charge refilling at all public energy recharging stations. After four years the car is purchased by the customer for a residual value of 25 % of the initial purchase price. In addition, VLOTTE-customers get free membership to the Austrian Automobile Association.

Vehicles and Energy Supply

Different types of vehicles have been supplied to the project participants. Most of them were produced by the Norwegian car producer TH!NK. The energy used for vehicle operation is compensated for by regional, renewable energy production – mainly from solar panels specifically installed for the project.

Charging and its Infrastructure

The vehicles can be charged using any ordinary electricity plug. The regional electricity supplier offers reduced tariffs at night. Charging takes on average 7-8 hours, which is drastically reduced if a 3-phase current is available. Furthermore, every project participant has the possibility to charge their vehicle for free on the public charging infrastructure network in Vorarlberg (which

currently comprises 32 charging stations), in Germany, Switzerland and Liechtenstein. Both the cars and the filling stations were equipped with measuring devices in order to analyse the energy demand on a disaggregate basis. The collected data are used to decide upon expanding the charging network.

Results and outlook
Within almost a year the VLOTTE vehicles covered more than 150,000 km. However, a better result could have been achieved if sufficient vehicles had been available. More than 200 interested people had to join a waiting list due to insufficient supply of EVs. The success of the project led to a second step, VLOTTE II. Here, the focus was on establishing so-called 'mobility-hubs' – vehicle sharing points where as well as EVs electric scooters and electric bikes can also be hired. The VLOTTE fleet has been expanded to 250 vehicles and two-wheelers are complemented. The number of charging points has been augmented; the supplied electricity still originates from renewable energy sources deployed in the region.

2.5.3 Synthesis

The two selected local deployment initiatives give quite a comprehensive overview of measures that can be deployed on a local level. Policy measures for the dense area of London can augment the attractiveness of EVs by exempting these vehicles from congestion charging and by offering preferential rights for public parking. Both of these measures can, theoretically, also be defined on a national level. The national policy review showed that this is hardly ever the case (the cases of Norway and Portugal are the only exceptions), since this would anticipate measures that are best defined on the scale where they actually take effect.

The less dense region of Vorarlberg appears to have less scope of action with regards to typical EV-supportive policy measures. Existing traffic conditions do not necessitate congestion charging for which EVs could be exempted; parking policies have less of a financial effect on the vehicle user, since parking fees and, as a consequence, their exemptions are less significant. The region of Vorarlberg therefore follows quite a different strategy: a mobility *package* is offered to attract single mobility users. A monthly payment for a "mobility card" gives access to an EV as well as to all public transport, and makes sure that all EV-related service needs are taken care of. Here, the private customer is attracted by the convenience of the service on offer rather than by a significant financial incentive..

The two local examples show the importance of the local authorities' involvement when aiming to support the development of EVs. The local authorities are the best to define policy measures adapted to prevailing

framework conditions, and also the most likely to be able to foresee the effects of policy measures. While dense urban areas can easily fall back on the classic financial instruments, less dense areas will most often be obliged to implement more innovative measures and incentive systems that attract vehicle users to EVs.

2.6 Conclusion

2.6.1 Concluding summary

This chapter gives first an overview and categorisation of policy measures that support the uptake of alternative fuel vehicles (in general), and of electric vehicles (more specifically). The portfolio of policy measures is shown to be manifold. Defined measures should be in line with national framework conditions, (financial) capabilities, and expectations with regards to vehicle and infrastructure deployment. The introduced typology of instruments helps to identify the scope of the international policy review. It is limited to policy measures defined on a national level and, given the single user focus of this work, mainly demand-side policy measures that enhance the demand for privately owned EVs (electric vehicles). Special focus is put on financial measures that have an effect on the purchase and/or usage costs of a vehicle. The geographic scope of the review is predominantly European countries that are expected to constitute the first major demand for EVs. Besides European countries, also China, India, Korea, Japan, and the US are reviewed..

Comparing the findings by country reveals that basically all reviewed countries have recognised the many potential advantages of EVs over CVs (conventional vehicles). In general, all, environmental, economic, and industrial benefits, give reason for a country's EV policy support.

2020 vehicle deployment objectives appear to range from very ambitious (e.g. in Ireland and Denmark), to comparatively modest (e.g. in the US). The deployment targets of fast developing nations appear realistic if assuming that conventional technologies will successfully be leapfrogged. Growing automobile markets are likely to allow a faster EV penetration rate than in saturated markets, such as in Europe or in the US.

Existing evidence of EV deployment numbers suggests that the EV uptake rate is currently too slow for attaining the ambitious 2015 or 2020 targets. However, especially with regards to 2020 goals, it is still too early to comment on their achievability. Recent boosts to EV uptake rates (as they were observed in several countries) actually suggest that targets might be met thanks to (extremely) supportive policy measures, EV-favorable market conditions, and enlarged EV market availability. Furthermore, a network effect might boost the EV deployment. On the other hand, some countries' EV registration numbers

appear to be decoupled from any currently prevailing framework conditions. In these cases, significantly increased policy support might be the only way to insure that EV deployment numbers reach defined 2020 goals. Such measures do not necessarily need to be of financial nature. Norway's policy support that is, to a significant part, based on preferential access rights, appears to be highly fruitful. Financial demand-side measures will, however, remain of utmost importance in these upcoming years. Many countries have recognised the importance of such measures focusing on the single user, and have implemented a range of different instruments mainly in order to alter vehicle purchase or usage costs. Frequently, these are complemented by measures offered by local authorities. Funds supporting the uptake of infrastructure are mainly dedicated to the installation of public recharge infrastructure. The issue of private recharge infrastructure installation, which, undoubtedly, often entails significant private financial investments, appears to be largely neglected. The facilitation of administrative procedures related to the installation of recharge infrastructure is a further measure that appears to be of utmost importance. Only this way, a denser infrastructure network and increased EV uptake can be assured during the upcoming years.

2.6.2 On the importance of local measures

National policy measures are an essential contribution to the uptake of EVs. Local policies appear to be of even higher importance though. Only local authorities can be aware of local settings, local mobility needs, constraints, and transport problems. This knowledge allows defining most adequate policy measures adapted to the prevailing local conditions that are sustainable for the authority's budget. Presented examples of the metropolitan area of London and the urban-sprawled region of Vorarlberg in Austria show the many possible policy measures deployed on a local scale. Measures deployed in those two regions are as diverse as the regions themselves. They are well adapted to the local conditions and, moreover, they effectively exploit already existing measures..

Local policy measures are best tested within the framework of pilot or demonstration projects. This appears to have been recognised. Such projects have become increasingly popular in most reviewed countries. Frequently, they fall back on major financial support from public sources. Partly, they are (also) financed by a consortium of, for example, utility and car manufacturers that look for test areas for their newly developed technologies. The most successful and impactful demonstration projects appear to be those that involve a large number of different stakeholders, such as the VLOTTE project in Austria. This way a holistic approach is guaranteed that comes to the benefit of the single user (e.g. by integrating public transport services, vehicle insurers, vehicle service providers etc.).

Chapter 3
EVs' financial impact on the private user: a total cost of ownership approach

3.1 Introduction

3.1.1 Context

As sketched in Chapter 1, one of the main barriers to EV (electric vehicle) uptake is the difference between the prevailing purchase cost of the vehicles and their conventional counterparts, CVs (conventional vehicles). Thanks to lower energy costs, an EV is, on the other hand, likely to result in lower vehicle operating costs for the vehicle user. The determining factor of whether an EV or a CV will be in the end most cost-effective to a single vehicle user will be the user's vehicle usage behaviour. In particular, annual driven distances and vehicle ownership periods will have most important effect on the financial equation. Comparing purchase and operating costs of different vehicle types necessitates a total cost of ownership (TCO) approach, which accounts for all vehicle-related expenditures during the ownership period of the vehicle. Only cost calculations that are based on such an approach put the EVs' elevated purchase costs into the right perspective and provide for a fair basis of comparison of different vehicle technologies. Further, the approach takes account of all cost-influencing framework conditions that are subject to change over time. Financial public

policy measures (such as presented in Chapter 2) or economic trends that have an effect on energy prices are incorporated.

3.1.2 Study objectives

The objective of this study is to develop a *TCO model for private vehicle owners in the Paris (Île de France) region* that can also be applied to the whole of France with a satisfying degree of detail. The study incorporates CVs and EVs. For the latter a distinction into battery electric vehicles (with a battery purchase (BEV) and a battery hire option (BEV-Hire)) and plug-in hybrid electric vehicles (PHEVs) is made. Specific vehicle models that are currently available on the French market are taken as reference vehicles to represent the analysed vehicle types. The explored PHEV refers here to a vehicle that shows a high electric range. The study complies with a set of criteria as later defined in Section 3.1.3 (Table 3.2). These criteria assure a comprehensive and meaningful approach to the study.

The application of the TCO model sheds light on the financial aspects of different vehicle types from the customer's point of view. Understanding is developed, which determines the conditions under which a certain vehicle type will be the most financially competitive. The set-up TCO model is conceived in such a way that it can serve as profound basis for subsequent analyses on EV's potential based on a TCO approach. The questions of whether or not a single customer confronted with a vehicle purchase decision considers TCO before making a purchase decision, and if so, at which level of detail, are not discussed here. The study, rather, postulates fictive rational decision makers that base their purchase decision solely on financial considerations. Clearly, such an approach is very simplistic and does not reflect real purchase behaviour. This work is therefore seen only as a first methodological step necessary for constructing more detailed EV demand analyses (as presented in the following Chapters 3 and 4), which take other limiting and encouraging EV-purchase factors into account.

3.1.3 Review of existing studies

In recent years the TCO approach, which is often used for subsequent demand analyses, has become routine for comparing the economics of EVs and CVs. TCO are calculated with differing level of detail, taking more or less recent data concerning vehicle costs and specifications into account. Table 3.1 beneath states reviewed TCO studies, shows their application area and outlines some of the major results. Results are given for the comparison of battery electric vehicles (BEV) with conventional vehicles (CVs).

Study	Area	Results - BEV/CV Comparison
Funk and Rabl (1999)	France	**BEVs 30-40 % more expensive** than CVs
Delucchi, Lipman (2001)	US	Cost **break-even at 0.59 $/l fuel retail price**
Carlsson and Johansson-Stenman (2002)	Sweden	Cost **break-even at $3,840 subsidy** for BEVs
BCG (2009)	Germany	Cost **break-even at 280 $/barrel oil price** in 2020 (or at 120 $/barrel if battery costs are lowered to 500 $/kWh)
Becker (2009)	US	Unsubsidized **BEV saves**: *(high oil price/with subsidy)* **2012: -3c$ to 0c$ per mile** *(up to 3c$/up to 11c$)* **2017: 1c$ to 3c$ per mile** *(up to 7c$)*
Biere et al. (2009)	France	City BEVs **break even in 2020** - dependent on vehicle usage
Deutsche Bank (2009)	US	Cost **break-even at 1.05$/l** (or 4$/gallon) **fuel retail price**
EDF (2009)	France	2012: **BEV 16c/km more costly** than CV, 2020: BEV 6c/km more costly than CV
Figliozzi et al. (2010)	US	BEVs are **not profitable** in vehicle fleets in a 14-year time frame (base case scenario)
Prud'homme (2010)	France	**TCO BEV EUR 10-12,000 higher** than TCO CV
Deutsche Bank (2011)	-	Cost **break-even after 330,000 kms**
CAS (2011)	France	Even under favorable policy settings the **BEV is not competitive to CV**
CE Delft (2011)	EU	TCO of medium BEV compared to CV: **2010: +60% ; 2030: +20%**
CDGG (2011)	France	**2010:** TCO BEV EUR **12,000 higher** than TCO CV **2020:** TCO BEV EUR **1,000 higher** than TCO CV
ITF (2012)	France	**TCO BEV EUR 4-5,000 higher** than TCO CV

Table 3.1: Overview of reviewed TCO studies and their main results

Most studies elaborate further on their results as stated in Table 3.1. Certain studies test various parameter settings and combinations, others model differing time scales. Table 3.1 can therefore only give an impression of the magnitude of TCO differences between the two vehicle technologies, and of how these differences are often analysed and presented (e.g. expressed in cost break-even points, in absolute cost terms, in higher/lower costs per driven distance etc.). It becomes apparent that results are difficult to compare due to different vehicle comparison methods, but also due to different geographic scopes of the study (entailing e.g. different market conditions such as fuel prices or vehicle costs). Also within the same geographic areas results show differences. This is due to varying assumptions of parameter values, often such as battery costs or annual driven distances. Annex 3.1 shows the most important and stated parameter settings of each study. An impression of where TCO differences result from can

be obtained. The most obvious reasons for differences in results stem from differing assumptions concerning vehicle usage.

In view of the reviewed TCO studies, the following list of criteria was established. This allows us to verify the validity and informative value of a study based on the financial aspects of an electric vehicle for a single vehicle user:

1. **Detailed TCO calculation.** The study takes a comprehensive TCO approach. Besides vehicle purchase costs and energy costs, costs for maintenance and insurance are also accounted for. Residual values and potential usage costs for recharge infrastructure are considered; parameter settings (in particular those for fuel prices) are adjusted throughout the ownership period of the vehicle.
2. **Territorial approach**. The study focuses on a sufficiently small geographic area that allows locally specific parameters (such as parking costs), as well as sufficient precision (e.g. concerning fuel prices, taxes) to be incorporated.
3. **Disaggregate approach.** The study acknowledges vehicle owner (and/or household) specifications concerning mobility behaviour and vehicle usage (such as annual driving distances or vehicle usage areas) in order to be able to better reflect possible differences in TCO of different user types.
4. **Scenario modelling**. In order to account for the many uncertainties concerning TCO influencing factors (such as the precise offer on the market, the development of energy prices, etc.) the study explores various potential market development and policy scenarios.
5. **Sensitivity analysis**. In order to analyse the impact of still uncertain cost components, sensitivity analysis for most influential cost parameters is carried out.
6. **Up-to-date**. The study is based on most recent cost information and EV specifications.

A study that complies with the above set of criteria is seen to have potential to appropriately predict the cost advantage or disadvantage of EVs over their conventional counterpart. They can then serve as profound basis for subsequent EV demand projections. The following table shows the reviewed studies in light of the list of criteria developed above.

Reference	Detailed TCO calc.	Territorial approach	Disaggregate approach	Scenario modelling	Sensitivity analysis	Up - to - date
Funk and Rabl (1999)	+	+	-	-	o	-
Delucchi and Lipman (2001)	+	-	-	+	-	-
Carlsson and Johansson-Stenman (2002)	o	+	-	-	-	-
BCG (2009)	o	-	-	-	-	+
Becker (2009)	+	-	-	o	o	+
Biere et al. (2009)	+	o	o	-	-	+
Deutsche Bank (2009)	+	-	-	+	-	+
EDF (2009)	o	-	-	-	-	+
Figliozzi et al. (2010)	+	-	-	+	-	+
Prud'homme (2010)	+	o	-	+	+	+
Deutsche Bank (2011)	o	-	-	o	-	+
CAS (2011)	+	-	-	+	+	+
CE Delft (2011)	+	-	-	+	+	+
CDGG (2011)	+	-	-	-	-	+
ITF (2012)	+	-	o	+	+	+

o *partly complies with criterion* + *fully complies with criterion*

Table 3.2: Reviewed studies evaluated according to list of criteria

Table 3.2 shows quite clearly that none of the reviewed studies complies entirely with the criteria we define to be important for insightful cost analyses of EVs. Many studies incorporate a detailed TCO approach. However, all of them neglect the importance of taking household-specific parameters into account. Often, an average annual distance is used for all TCO calculations without testing any sensitivity of the results to this parameter or discussing the possible effects of household dependent vehicle usage behaviour. Striking is the commonly misleading assumption of the vehicle usage period (as can be seen in Annex 3.1). Most studies assume a period of 10-15 years, which reflects the lifetime of the vehicle rather than the vehicle ownership period of a single vehicle owner. INSEE (2012a) shows that the vehicle ownership period of French households has risen from 3.7 years in 1990 to 5.0 years in 2010. It seems that many studies confound a life-cycle analysis (necessary for *social* cost-benefit analyses) with a TCO analysis (necessary for *financial* cost-benefit analysis for a single user).

3.1.4 Outline of the paper

The paper is organised as follows: Part 2 (Methodology and underlying data) gives an overview of the constructed model, briefly describes the study area and gives a detailed description of all underlying data and assumptions. The applied methodology is critically discussed. Part 3 (Results) then shows the results of scenario analyses, sensitivity analyses and break-even analyses carried out for selected parameters. Part 4 (Conclusions) summarises main findings, concludes on the chosen TCO model approach, outlines/highlights mains observed deficiencies, and gives an outlook on subsequent work.

3.2 Methodology and underlying data

This section describes the set-up TCO calculation model. A graphical and mathematical description of the TCO model is given; the study area is sketched. Input parameters specifying vehicle, vehicle user and vehicle usage characteristics, as well as policy settings and assumptions concerning the development of market trends are shortly described. Finally, we critically discuss the applied methodology.

3.2.1 Model overview

Figure 3.1 gives a comprehensive overview of the set-up TCO model. The main intention of the figure is to reveal the dependence of the model output (the TCO per vehicle type) on input attributes that can be categorised into (i) vehicle/battery attributes, (ii) vehicle user attributes, (iii) vehicle usage attributes, (iv) attributes describing the policy framework, and (v) attributes describing the expected development of market trends.

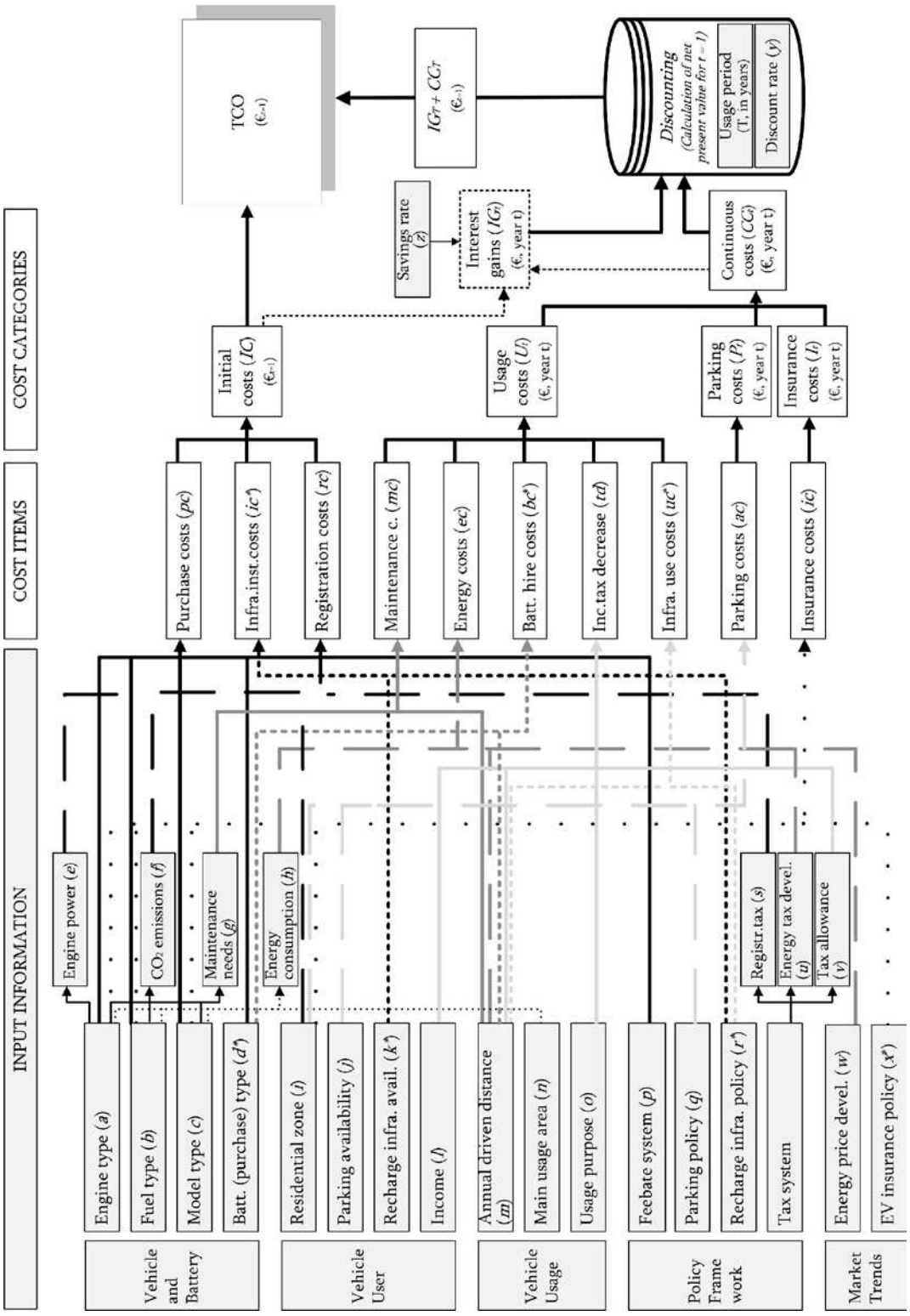


Figure 3.1: TCO model overview

3.2.2 Mathematical description

This section gives a mathematical description of the TCO model. In order to facilitate the reading, cost components are introduced incrementally. Figure 2.1, which depicts most attribute abbreviations, serves as reference. Big (one or two digit) letter abbreviations indicate defined major cost categories of the TCO. These result from cost items that are abbreviated in small-letter, two-digit form. Small single letters are used as i) abbreviations for cost determining attributes (see the list underneath) ii) the time instant $t \in [1, T]$, where T gives the total ownership period in years and iii) the discount rate y and the saving rate z. The exponent (*) points to cost items/attributes that are specific to EVs.

Information on the defined possible (range of) values of cost attributes and the resulting cost components can be found in Section 3.2.4 (by searching by the parameter type – being either a vehicle or battery specification, a vehicle user or usage specification, a specification of the underlying policy framework or a market trend specification).

The following list gives an explanation of all attributes that define cost items of the total cost of ownership (TCO), which are defined thereafter:

a	…	Engine type (EV, CV or PHEV)
b	…	Fuel type (petrol or diesel)
c	…	Model type (compact or sedan)
d^*	…	Battery acquisition option (purchase or hire)
e_a	…	Engine power of the vehicle subject to be purchased (in the French fiscal power unit), depending on *a*
$f_{a,b,c}$	…	CO_2 emissions of the vehicle subject to purchase (g/km), depending on *a*, *b*, and *c*
$g_{a,b,c}$	…	Maintenance needs of the vehicle subject to purchase (in EUR/km), depending on *a*, *b*, and *c*
$h_{a,b,c,n}$	…	Energy consumption of the vehicle subject to purchase (in kWh and/or l per 100 km), depending on *a*, *b*, *c*, and *n*
i	…	Residential zone of the household in question (Paris, Grande Couronne, Petite Couronne or the rest of France)
j	…	Attribute defining the home-parking availability of the household (yes or no)
k^*	…	Availability of EV recharge infrastructure at the household (yes or no)
l	…	Income of the reference person of the household

m … Expected annual driven distance of the vehicle to be purchased (in km), assumed to be constant during the vehicle ownership period

n … Main usage area of the vehicle to be purchased (urban, ext-urban, or mixture)

o … Usage purpose of the vehicle to be purchased (professional usage in percent of the total usage)

p … Applicable purchase fee or rebate (the French bonus/malus) depending on f (in EUR)

q_i … Index referring to the parking policy applied in the residential area i of the household

r_i^* … Index referring to the recharge infrastructure policy in the residential area i of the household

s … Registration taxes to be applied to the vehicle subject to purchase depending on e

u_t … Energy taxes specific to year t

v … Index defining the applicable tax allowance scheme according to the French "barème kilométrique"

$w_{t,a,b}$ … Energy price specific to year t, the engine type a and fuel type b of the vehicle to be purchased (in EUR/kWh or EUR/l)

x^* … Index referring to EV insurance policies put in place

The **Total Cost of Ownership (TCO)** of a vehicle is defined as

$$TCO = IC + CC_T + IG_T \quad (1)$$

where

IC … Initial costs incurred for the purchase of the vehicle (in EUR)

CC_T … Continuous costs incurred due to the usage of the vehicle during the ownership period T of the vehicle (in EUR)

IG_T … Interest gains (or losses) due to interest payments for (missed) savings resulting from IC and CC_T differences of different vehicle purchase options during the whole vehicle ownership period T (in EUR)

Initial Costs (*IC*) are further defined as

$$IC = pc_{a,b,c,d^*,p} + ic_{k^*,r^*}^{*} + rc_{e,f,i,s} \quad (2)$$

where

$pc_{a,b,c,d^*,p}$ … Purchase costs depending on attributes *a*, *b*, *c*, *d**and *p* (in EUR)

$ic^{*}_{k^*,r^*}$ … Home infrastructure installation costs depending on attributes *k**and *r**(in EUR)

$rc_{e,f,i,s}$ … Registration costs depending on attributes *e*, *f*, *i* and *s* (in EUR)

Continuous Costs (*CC*) of the total ownership period (of *T* years) are defined as

$$CC_T = \sum_{t=1}^{T}\left(CC_t \cdot \frac{1}{(1+y)^t}\right) = \sum_{t=1}^{T}\left((I_t + P_t + U_t)\cdot \frac{1}{(1+y)^t}\right) \quad (3)$$

where

CC_t … Continuous costs in year *t*

I_t … Insurance costs in year *t*

P_t … Parking costs in year *t*

U_t … Usage costs in year *t*

y … Discount rate

Insurance costs (*I*) of year t are more explicitly defined as

$$I_t = ic_{t,a,b,c,i,x^*} \quad (4)$$

where

ic_{t,a,b,c,i,x^*} … Insurance costs in year *t* (in EUR) depending on attributes *a*, *b*, *c*, *i* and *x**

Parking costs (*P*) of year t are more explicitly defined as

$$P_t = ac_{t,i,j,q} \quad (5)$$

where

ac_{t,i,j,q_i} … Parking costs in year *t* (in EUR) depending on attributes *i*, *j* and q_i

Usage costs (U) that depend on the annual driven distance m of the vehicle are more explicitly defined as

$$U_t = mc_{t,g,m} + ec_{t,h_{a,b,c,n},m,u,w_{t,a,b}} + bc_{t,d,m}^{*} + uc_{t,m,r^*}^{*} - td_{t,l,m,o,v} \quad (6)$$

where

$mc_{t,g,m}$ … Maintenance costs in year t depending on attributes t, g and m (in EUR)

$ec_{t,h_{a,b,c,n},m,u,w}$ … Energy costs in year t depending on attributes t, h, m, u and w (in EUR)

$bc_{t,d^*,m}^{*}$ … Battery hire costs in year t depending on attributes d and m (in EUR)

uc_{t,m,r^*}^{*} … Infrastructure usage costs in year t depending on attributes m and r^* (in EUR)

$td_{t,l,m,o,v}$ … Income tax decrease in year t depending on attributes l, m, o and v (in EUR)

Interest Gains (IG) of year t

When calculating the TCO, importance is given to the difference in TCO of the vehicle options analysed. In order to reflect this approach, the *IG* cost component adds earnings due to received interest payments (in case savings can be put aside compared to a reference purchase option), or subtracts missed earnings (in case the alternative chosen vehicle purchase signifies a loss of savings compared to the reference purchase option). The components of *IG* are made up by i) the difference in the initial costs of the vehicle purchase to the reference purchase option and ii) the difference in continuous costs of the chosen vehicle compared to the reference purchase option. It is decided to take the BEV with up-front battery purchase as reference option. The difference in initial costs (compared to a conventional vehicle purchase) will therefore (due to the likely higher purchase price of the BEV) be positive for the CV, which entails a cost advantage for the CV. The saved money for choosing the CV option over the BEV option can be put aside and annual interest is gained. However, the savings from the initial vehicle purchase are reduced every year during the vehicle ownership period by the difference of continuous costs of the two vehicle options. Taking the EV as reference vehicle, this difference will most likely be negative for the CV and an annual reduction of the initial savings can be expected. Obviously, interest earnings of previous years also contribute to interest earnings in that specific year. Total annual earnings (or losses) are (as all other cost components) discounted to the reference year 1, the year when the vehicle is purchased.

For the reference vehicle (BEV with up-front battery purchase) the *IG* of a year *t* is set 0. For the other vehicle purchase alternatives, the *IG* in year *t* are therefore defined as:

$$IG_t = z \cdot \left(dIC + \sum_{i=1}^{t} dCC_i + \sum_{i=0}^{t-1} IG_i \right) \quad (7)$$

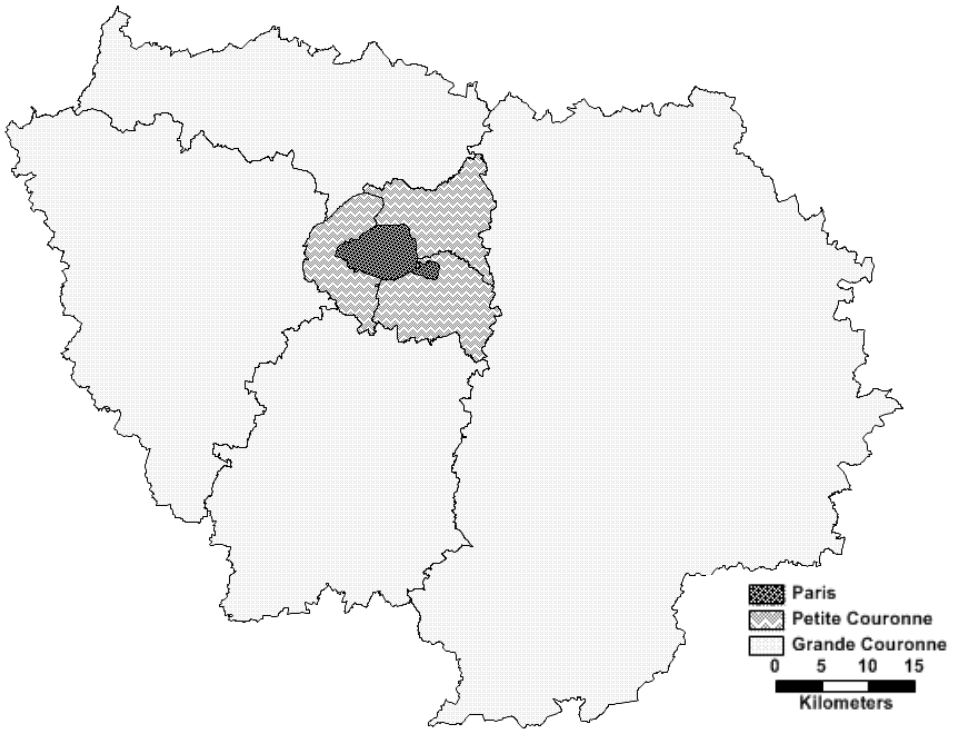
where

dIC	…	Difference in initial costs between regarded vehicle purchase option and reference vehicle purchase option (= EV) (in EUR)
dCC_i	…	Difference in continuous costs between regarded vehicle/purchase type option and reference vehicle/purchase type in year *i* (in EUR)
IG_i	…	Interest gains (or losses) in year *i* (where $IG_0 = 0$)
z	…	Savings rate

The fact that interest earnings of previous years contribute to the total interest earnings in year t entails that they can only be calculated incrementally.

3.2.3 The study area

The focus of this study is the Paris region (the Île-de-France), which shows quite diverse characteristics mainly due to varying population densities and different levels of public transport (PT) access in its distinct sub-regions. Figure 3.2 gives an overview of the main characteristics of the Île-de-France (IDF) region. The region is divided into the 3 residential zones Paris, the 'Petite Couronne' (3 districts) and the "Grande Couronne" (4 districts). Districts in the same sub-region show largely similar characteristics. However, differences between the sub-regions are remarkable. Whereas Paris can be perceived as an extremely dense urban area that is very well served by PT (Bus, Metro, Tram, Train), the "Petite Couronne" shows typical suburban characteristics of a periphery. Accessibility is mainly assured by suburban trains and bus services. The "Grande Couronne" area, on the other hand, shows a mix of pre-urban and almost countryside-like characteristics. The PT network is much less dense and relies mainly on buses and a few connecting train lines. These different land use structures cause quite diverse mobility needs of the inhabitants of the different sub-regions.



	Population *(million)*	Surface *(km2)*	Density *(inhabitants/km2)*
Paris	2.2	104	21,000
Petite Couronne	4.4	657	6,647
Grande Couronne	5.1	11,249	450

Figure 3.2: The Ile-de-France study area[54]

For this reason, the IDF region serves as an interesting study area. The economics of EVs for diverse user groups showing different mobility patterns can be explored. Furthermore, the IDF region (as with the whole of France) benefits from comparatively strong governmental support for EVs. The usefulness of many already implemented and likely future measures can be explored.

The defined residential zone "rest of France" is assumed to take on average similar characteristics to the Grande Couronne area. TCO model settings for this area are set to be identical to those of the Grande Couronne area. Exploring the whole of France only serves as demonstration. Regional distinctions cannot be taken into account; the disaggregate approach, where for example region-specific parking policies can be taken into account, is neglected.

[54] Insee, Recensement de la population, 2008

3.2.4 Input data and assumptions

This section describes input data and underlying assumptions. Resulting parameter settings can be found in the overview Tables 3.3-3.6, which also give details about the references used.

Parameters describing the vehicle and battery

Engine/Model type. The engine and model type define whether the TCO are calculated for a compact or a sedan model and whether an electric or a conventional vehicle is being studied. Specifications for each engine/model type are based on specific vehicle models that are available on the French market. To represent the CV and BEV types, Renault's currently (or soon to be) available models are taken as reference vehicles (for the compact vehicle, the Renault Clio is compared to the Renault Zoe Z.E.; for the sedan vehicle, the Renault Fluence is compared to the Renault Fluence Z.E.). The Opel Ampera represents the PHEV – the only PHEV that has a significant all-electric range and that is currently available on the European market. The same Opel Ampera model is used as a reference for the compact and the sedan PHEV in the study, since there are no other models available. The fact that the different vehicle technologies are represented by single reference vehicles is an important limitation of the study that has to be kept in mind for all conclusions drawn. In particular, the fact that a very expensive PHEV model is compared to both compact and sedan CVs is not the most appropriate way to represent the pertinence of this vehicle technology. The reason for this approach is the lack of other PHEV models available on the European market that would be more comparable to compact CVs. *See Table 3.3 for specifications of the different vehicle types.*

Fuel type. The fuel type attribute determines if the EV is compared to a petrol or a diesel CV. For the sedan CV, only a diesel version is available in the set-up TCO model (since the Renault Fluence is only available with a diesel motor). *See Table 3.3.*

Battery ownership. Battery ownership determines if the battery is purchased or hired (according to Renault's battery hiring model). In the latter case the battery costs fall as reoccurring hiring costs of the usage costs of the vehicle. Otherwise they are comprised in the initial costs of the vehicle purchase. Battery specifications used are from data published by Renault and depend on the annual driven distance and the hiring period of the battery. Since Renault does not offer a battery purchase business model, the purchase price of the battery is assumed. It is set to 450 EUR/kWh – a moderate value compared to reviewed studies. For example, Zero Emission Vehicles (2010) predicts the value of 450 EUR/kWh to be the production cost level for the year 2015. However,

production costs do not necessarily reflect sales prices – especially if a first EV market still has to be created. Also Lidicker et al. (2011) takes the moderate price estimate of 500 USD/kWh for the year 2012. Assuming a battery price of 450 EUR/kWh puts the hypothetical EV with battery purchase option underlying this study (assumed to be the Renault ZOE that is actually not offered with battery purchase) at a similar price level as the Citroen C-Zero that is offered with the battery purchase option on the French market. *See Table 3.3.*

Parameters describing the vehicle user

Parameters in this category are to be set in accordance with the vehicle user (and his/her household) to be simulated.

Residential zone. This parameter states whether the household is located in Paris, in the Petite Couronne, the Grande Couronne or the "rest of France". *See Table 3.4.*

Parking availability. This parameter states whether the household to be simulated is equipped with private parking facilities. Households that are not equipped with private facilities are assumed to rent them in case an EV is purchased. The assumption is made that the current provision of infrastructure on public grounds does not allow for overnight battery charging. Access to overnight charging facilities is seen as a necessary condition for an EV purchase. The additional fees to rent a parking space when purchasing an EV depend on the household's residential zone. *See Table 3.4.*

Recharge infrastructure availability. This parameter states whether initial investments into a "wall-box", which allows home charging of the EV, are considered as vehicle expenditure or as general investment into a household's premises. The latter case means wall-box costs (and costs for its installation) can be excluded from the initial vehicle purchase costs. In case the household is not equipped with a private parking space, it is assumed that the household bears costs for renting such a parking space (variable "parking availability"). The infrastructure installation costs then represent supplementary costs for renting a parking space equipped with recharge infrastructure. An "all-in" price in line with current offers (Sadeghian et al., 2012) of EUR 590 (including the wall-box and its installation) is assumed[55]. *See Table 3.4.*

Income. The annual income is a necessary parameter for calculating the possible income tax reduction due to professional usage of the vehicle. The tax reduction is calculated in accordance with the French "barème kilométrique" (DGFP,

[55] This is certainly a severe simplification: actual recharge infrastructure installation costs will be case-dependent and moreover depend on the exact parking infrastructure available to the potential EV purchaser.

2012) by applying the amount of kilometres driven for professional reasons. *See Table 3.4.*

Parameters describing the vehicle usage

Parameters of this category are to be set in accordance with the vehicle usage of the vehicle user to be simulated.

Annual driven distance. The annual driven distance is the main factor determining usage costs. It is assumed to remain constant over the vehicle's usage period and unchanged for each considered vehicle type. *See Table 3.4.*

Main usage area. The main usage area variable states the type of environment in which the vehicle is principally used. The different settings are "urban" – referring to a very dense area (Paris), "ext-urban" – referring to a remotely dense area (the Grande Couronne area) and "mixed used" – referring to a mixture of the two above. *See Table 3.3.*

Usage purpose. This variable states the share of the annual kilometres driven for professional reasons. It determines a possible income tax reduction. *See Table 3.4.*

Usage period. A time frame of 1-10 years can be covered by the set-up TCO model. Keeping in mind that the average ownership period of a vehicle in France is 5 years (INSEE, 2012a), this foreseen possible timeframe covered is considered to be sufficient. *See Table 3.4.*

Parameters describing the policy framework

The French fee and rebate system (The bonus/malus). This parameter reflects the fees or rebates that are charged/accorded to private vehicle purchasers and that are based on a vehicle's CO_2 emissions put in place in France. The results presented here refer to the system as put in place up until July 2012: EVs were subject to a purchase subsidy (a bonus) of EUR 5,000. In August 2012, a new regulation was put in place that foresees a maximal EV purchase of EUR 7,000. All CV reference vehicles used for this study are subject to a EUR 0 bonus/malus. *See Table 3.3.*

Parking policy. The parking policy parameter allows the simulation of three different parking policy settings. A "no policy" scenario assumes that there is no parking policy put in place that assigns preferential rights to EVs. A "free public parking" scenario assumes that EVs park for free in public areas. A "free parking" scenario assumes that the purchase of an EV comes along with the exclusive access to a parking facility equipped with recharge infrastructure close to the vehicle user's dwelling. This scenario therefore assumes that vehicle users without private parking facilities also do not face any parking costs in order to

access overnight parking infrastructure. This seemingly hypothetical scenario was applied in the city of Amsterdam in 2011 (SmartPlanet, 2011).
See Table 3.4.

Recharge infrastructure policy. For the successful deployment of EVs, the construction of accompanying infrastructure is essential. The build-up of this infrastructure, which might entail "slow" charging and "fast" charging options, but also battery swap stations, will be connected with investment costs. From today's point of view it is still unclear how, by whom, and in which way this infrastructure will be financed. A combination of public and private investments appears to be likely. Also the costs of such infrastructure are still uncertain. They will depend on the exact infrastructure to be deployed (which stations at what price and in what location), but also on the density of the infrastructure net that is envisaged. It is likely that the infrastructure costs will be, in one or the other way (fully/partly), passed on to the customers. For example, they could be levered by increased parking costs for EVs next to infrastructure, by increased costs for the electricity used for charging EVs in public areas (e.g., in case infrastructure is mainly provided by electricity providers), by charging directly the actual use of the infrastructure (e.g., by a monthly subscription fee) or by including its costs in a mileage based subscription model (such as the business model of the company Better Place[56]). In either case, the exact costs that will be passed on to the customer are uncertain. Discussions have been launched about possible future costs for the public or private hand; but estimates about future costs for the private customer are rare.

A study released in December 2010 (EcoTechnologies, 2010) tries to shed light on a possibly profitable pricing scheme for a business model like Better Place (users are charged costs per km, which cover costs of battery usage, electricity needs, infrastructure supply, technical support, and communication systems). The resulting price estimates, which make such a business model profitable according to the study, are seen in graph 6 underneath (values are transferred to EUR cent prices using the USD to EUR Interbank rate on the 10/12/2010 : 0.75450).

[56] See http://www.betterplace.com/, accessed 15 December 2012

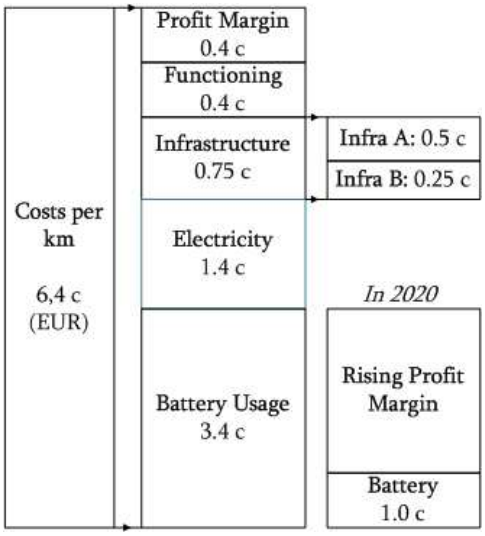


Figure 3.3: Estimation of a profitable mileage-based infrastructure pricing structure (based on EcoTechnologies, 2010)

It can be seen that a large part of the costs per kilometer are made up by the costs for the battery, as well as by the costs for electricity. The costs for infrastructure is divided into installation and usage costs of Infrastructure A, being the 'basic' infrastructure (comprising recharge infrastructure at home and 1 public recharge spot/vehicle in a regarded area), and of Infrastructure B, being (optional) 'range-extender' infrastructure, meaning battery swap stations. For the time being our study does not consider battery swap stations as part of a recharge infrastructure network available until the year 2020. The comparable infrastructure costs are therefore the costs only for infrastructure A, being 0.5 cEUR/km. Since home infrastructure installation is already covered in the underlying TCO model by a separate cost item, we assume that 0.4 cEUR/km could cover the costs of public infrastructure installations. We estimate the price for the functioning of such a reduced system to be 0.2 cEUR/km and add the adequate share of the profit margin. A total price per kilometer of a bit more than 0.6 cEUR/km is obtained. However, it can be assumed that a significant share of the costs of publicly accessible recharge infrastructure is carried by private institutions that, e.g. due to marketing reasons, support the installation of such infrastructure in front of/at/in the proximity of their premises. Our final kilometer-based infrastructure costs that fall onto the private customer are assumed to be 0.26 cEUR/km. Compared to the assumptions of the few existing studies that take infrastructure usage costs into account (see Annex 3.1), this value is a moderate estimate, however applied to every driven kilometre (whether the vehicle is charged at home or at public premises). The recharge infrastructure costs are assumed to stay constant over the usage period of the vehicle. *See Table 3.6.*

Tax system. This parameter comprises all information necessary for (i) assigning registration taxes to a household that are specific to the residential zone and the vehicle engine/model type (year 2012 values are used), (ii) calculating applicable tax allowances on the taxable income of the household in case the private vehicle is also used for professional reasons (hereby using the French "barème kilométrique" 2012 (DGFP, 2012) and household-specific input data on the professional usage of the vehicle), (iii) forecasting energy price developments due to tax increases or decreases on fuel and electricity.

Fuel taxes reference the TICPE, the French "Taxe intérieure de consommation sur les produits énergétiques" that exists in its form since 2011 and was derived from the TIP, the "Taxe intérieure pétrolière" that was implemented in 1928. Projections for the future development of the TICPE have been made on the basis of observed taxation levels on fuel (not including the VAT) in the period from 2000 to 2011 (DGEC, 2012). These show progressively increasing tax levels. For the time period 2012 to 2023 increases from 0.61 EUR/litre to 0.65 EUR/litre for petrol and from 0.45 to 0.51 EUR/litre for diesel are assumed. This reference scenario does not assume any additional TICPE increases. The VAT is assumed to stay constant at 19.6 % within this time frame. See Table 3.5 for resulting total fuel prices.

Taxes on electricity comprise the VAT, which is specific to the exact consumption of a household, and electricity-specific taxes. Recent electricity prices (before and after taxation) have been obtained from Eurostat (2012), from which the average VAT is derived. Projections on the basis of these allow for an assumption on their further development until 2023 (i.e. they increase on average 0.25 % per year). Electricity-specific taxes lie in the range of about 20 % of the electricity prices before tax. For the reference scenario an annual increase of 0.3 % is assumed, which is a moderate increase compared to previous values (which lie at around 1.5 %). However, increasing electricity prices (before tax; see the next section) let one assume that the increase of tax levels might be moderate in the upcoming years in order to avoid supplementary burden to households. See Table 3.5 for resulting total electricity prices.

Parameters describing market trends

Energy price development

Fuel prices: For the fuel price 3 different scenarios are developed. These are based on the projections of crude oil prices found in the Annual Energy Outlook 2011 of the US Energy Information Administration (EIA, 2011). In order to convert found values, a constant EUR-$ exchange rate of 0.75 is assumed. Deriving French price levels before tax from the crude oil price levels is done by projecting the differences of these two prices of previous years into the future (the database of DGEC (2012) is used). Table 3.5 gives the resulting assumed future petrol and diesel prices after tax for the three scenarios.

Electricity prices: Electricity prices (before tax) are assumed to increase by either 5 or 7 % per year according to the selected scenario. This seemingly high annual increase appears to be justified due to recently reinstated French policy measures that serve for financing renewable energy sources (see, for example, Figaro, 2012). Table 3.5 gives the resulting assumed future electricity prices after tax for the two scenarios. Given this comparatively high increase in electricity prices, additional electricity price increases that are due to the introduction of EVs, or that solely apply to the electricity used for recharging EVs, are not assumed.

EV insurance policy. This parameter states whether or not an insurance price reduction for EVs compared to CVs is considered and, if so, at which level. French insurers have launched offers that give advantage to BEVs. A reduction of 20 % for BEVs is therefore assumed as base level that is applied to the CV insurance costs (that depend on the residential zone of the regarded household). For PHEVs an increase of 20 % is assumed. For the latter one, increases between 0 and 50 % have been found at various French insurers. *See Table 3.3 (also for the related sources).*

Discount rate. The discount rate is essential for modelling costs that occur in the future since the TCO are defined to be the net present value of all considered costs discounted to year 1 of the vehicle ownership period. It was decided to use the market interest rate as nominal discount rate (NDR) reflecting expected inflation (and therefore being applied to inflated forecasted values). The real discount rate (RDR), applied to "real" (non-inflated) values, is the NDR minus the inflation rate (e.g. applied to parking public infrastructure usage costs). A higher discount rate (a higher market interest rate) abates an alleged advantage of EVs, since future costs (usually especially occurring for conventional vehicles during the time of usage) then have less impact on the total TCO. For the definition of the market interest rate (=NDR) an efficient (perfect) market was assumed, where interest rates for loans are equal to those for savings. The NDR was therefore based on the costs of 5-year loans (the average duration a vehicle owner can use (and invest) his saved money throughout time assuming a 10-year vehicle ownership period). The interest rate comprises a risk free rate and a profit margin. The risk free rate was set to be the average 5 year Euro Swap value of the last 4 years in order to even out observed heavy fluctuations during this period. It amounts to 2.3 %. The profit margin is set to 4.2 %. The NDR therefore amounts to 6.5 % – a value in line with interest rates provided by Société Générale for 5-year loans[57]. The RDR amounts to 4.8 % (6.5 % - 1.7 %, which is the assumingly constant inflation rate). *See Table 3.6.*

[57] See https://particuliers.societegenerale.fr/emprunter/prets_vehicule/pret_expresso_auto.html (rates simulated on July 16, 2012 on the basis of a EUR 17,000 loan)

Vehicle/Battery Type Options						
Engine Type - Model Type	CV - Compact		CV - Sedan	EV - Compact	EV - Sedan	PHEV - Sedan
Fuel Type	Petrol	Diesel	Diesel	Electricity	Electricity	Electricity/Petrol
Battery Purchase Type	-	-	-	purchase/hire	purchase/hire	purchase
Reference Vehicle	**Renault Clio** Clio iii Live 3P 1.2 16V (75ch)	**Renault Clio** CLio iii 3P dCi (90ch) eco2	**Renault Fluence** FLUENCE dCi (110ch) eco2	**Renault ZOE Z.E.**	**Renault Fluence Z.E.**	**Opel Ampera**
Vehicle/Battery Specifications						
Engine Power (max. kW) (1)	55	65	81	65	70	111
CO2 Emissions (g/km) (1)	135	106	120	0	0	27*
Range (NEDC) (km) (2)		1375	1364	200	185	610 (petrol) 56 (electr.)
Energy Consumption per vehicle usage area (in kWh/100km or l/100km) (3)						
urban	7.6	4.9	5.6	13.9	14.3	16.9 / 5 / 90**
ex-urban	4.9	3.5	4.0	17.0	17.5	16.9 / 5 / 70**
mix	5.8	4.0	4.6	15.5	15.9	16.9 / 5 / 80**
Battery Capacity (in kWh) (4)	-	-	-	22	22	16
**according to EU-approved UN ECE R101 carbon dioxide emission rating*				** electr. / petrol / % of electricity mode usage (assumption)		
Vehicle/Battery (+Registration) Costs						
Vehicle Purchase (in Euro) (4)	16,650	17,450	22,850	20,700	26,300	37,300*
Battery Purchase* (in Euro)	-	-	-	9,900	9,900	7,200
Bonus/Malus (in Euro) (5)	0	0	0	5,000	5,000	5,000
Registration Fees (in Euro) (6)	330	237	376	0	0	141
Battery Hire Costs (in cEuro/km) (7)	-	-	-	6-10	6-10	-
**based on 450 Euro/kWh assumption (EVs only offered with battery lease / PHEV only offered with battery purchase)*						
Maintenance Costs (in cEuro/km) (8)						
Total	4.3	4.3	5.6	4.0	5.4	6.6
Tire Costs	2.0	2.0	3.0	2.2	3.3	4.0
Service Costs	2.3	2.3	2.6	1.8	2.1	2.6
Insurance Costs per residential zone* (in Euro/year) (9)						
Paris / Petite Couronne	536	548	548	429	438	658
Grande Couronne / Rest of France	430	460	460	344	368	552

** 13% decrease in case private parking avail-[11]*

Table 3.3: Vehicle-type-specific data

(see footnotes on next page)

(1) Values for EV obtained from http://www.renault.fr/gamme-renault/vehicules-particuliers/index.jsp; values for CV and PHEV obtained from ADEME (2012c); CO2 emissions refer to tank-to-wheel emissions (sources accessed in June 2012)
(2) Values for CV and EV according to the New European Driving Cycle from http://www.renault.fr/gamme-renault/vehicules-particuliers/index.jsp, values PHEV: http://www.opel.fr/flash.html (all accessed June 2012)
(3) Values for CV and PHEV according to ADEME (2012c), values for EVs based on http://www.avem.fr/actualite-les-resultats-des-rallyes-du-challenge-bibendum-2011-a-berlin-2304.html (accessed June 2012)
(4) As advertised on http://www.renault.fr/gamme-renault/vehicules-particuliers/index.jsp (EVs + CVs) and http://www.opel.fr/flash.html (PHEV).
(5) see http://www.service-public.fr/actualites/00694.html, 'Bonus pour les véhicules propres' and 'Malus pour les véhicules polluants' (accessed June 2012)
(6) Including (i) regional fees as in the IDF region (46 Euros * 'Puissance fiscale' of the vehicle in case the vehicle emits tank-to-wheel emissions), (ii) 'frais de gestion' and (iii) 'frais de port'.
(7) Here shown prices are average value ranges of Renault's tariffs that are dependent on the annual distance driven and the duration of the hire contract. The underlying TCO model is based on Renault's business model: Battery hire costs increase incrementally with an increasing annual driven distance and an increasing vehicle ownership period. Values were obtained from http://www.renault.fr/gamme-renault/vehicules-electriques/fluence-ze/fluence-ze/ze-battery/ (accessed June 2012). Not yet advertised battery hire costs for the ZOE Z.E. model are assumed to be the same as for the Fluence Z.E. model.
(8) Costs comprise service and car tyre costs. Service costs for CVs are based on a study recording the costs of over 5,000 vehicles in France (Carnet d'entretien en ligne, http://www.entretien-auto.com, accessed June 2012). Service costs for EVs are assumed to be 20 % less than for CVs (according to discussions with Renault). Costs for PHEV assumed to be the same as for CV sedan model. Car tyre costs for CVs are based on http://www.linternaute.com/auto/entretien-voiture/les-couts-moyens-d-entretien-automobile/changement-de-pneus.shtml (accessed June 2012). Tyre costs for EVs (PHEV) assumed to be 110 % (112 %) of those of the comparable CV (the sedan model), due to increased vehicle weight.
(9) Reference values for CV obtained by an online calculation template, see http://www.caradisiac.com/service/assurance-auto/ (accessed June 2012), prices for an all-risk insurance.

Vehicle user categorisation						
Residential area	Paris		Petite Couronne		Grande Couronne	
Parking availability	yes	no	yes	no	yes	no
Parking costs per parking policy scenario *(in Euro/year)* **(1)**						
CV	902				221	
EV						
1 - No EV parking policy	902	2,342	902	2,342	221	1,001
2 - Free public parking for EVs	0	1,440	0	1,440	0	780
3 - Free public parking incl. overnight infra. availability for EVs	0	0	0	0	0	0
Income (2) (3)						
in Euro/year	25,643				23,854	
Annual driven distance (3) (4)						
in 1,000 km	12.0 - 19.0		11.5 - 19.0		15.0 - 20.0	
Usage purpose (all user cat.) **(3)**				**Usage period (T)** (all user cat.) **(3)**		
0 - 100% professional usage				1-10 years		

(1) Based on own estimates and parking tariffs in the ÎDF region
(2) Average salaries in the ÎDF region for the year 2008, INSEE (2009a).
(3) Exact values to be defined by the model user, in accordance with characteristics of the household to be simulated
(4) Value ranges give indications on typical annual distances as found in the EGT (Enquête Globale de transport) 2001 in the ÎDF region

Table 3.4: Vehicle-user-specific data

Energy Prices (1)								
	Fuel Price (€/l)						Electricity Price (c€/kWh)	
Scenario	Low Oil Price		Medium Oil Price		High Oil Price		Medium	High
	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	*(+4%/year)*	*(+7%/year)*
2012	1.22	1.00	1.38	1.26	1.60	1.63	14.45	14.87
2013	1.22	1.00	1.40	1.30	1.66	1.73	15.14	16.02
2014	1.22	1.01	1.42	1.35	1.71	1.81	15.83	17.24
2015	1.22	1.01	1.45	1.39	1.74	1.88	16.55	18.55
2016	1.22	1.00	1.47	1.43	1.80	1.98	17.31	19.95
2017	1.22	1.01	1.51	1.48	1.85	2.06	18.10	21.47
2018	1.23	1.02	1.54	1.53	1.90	2.14	18.92	23.09
2019	1.24	1.03	1.57	1.58	1.95	2.22	19.79	24.84
2020	1.24	1.04	1.60	1.64	2.00	2.30	20.69	26.72
2021	1.25	1.05	1.63	1.69	2.05	2.38	21.63	28.75
2022	1.25	1.07	1.66	1.73	2.09	2.46	22.62	30.92
2023	1.26	1.08	1.68	1.78	2.14	2.53	23.64	33.26

(1) All shown values comprise energy tax forecasts of the reference scenario (as described in Section 3.2.4)

Table 3.5: Energy price forecasts per scenario

Other	
Infrastr. usage costs / scenario (EV)	0,26 cEuro / 0,0 cEuro (1 - No policy / 2 - Free infra. use scenario) (1)
Infrastr. installation costs (EV)	590 Euro (for 1 wall-box at the household)
Tax allowance	according to French barème kilométrique (DGFP, 2012)
Discount rate	Nominal: 6,5 % Real: 4,8 %
Inflation rate	1,7% (2)
Depriciation costs / residual value	Not considered (3)

(1) Assumed to be constant over the vehicle ownership period
(2) Average inflation rate in France throughout the last 20 years
(3) In line with the assumption that the depreciation costs are the same for all vehicle types

Table 3.6: Other assumptions necessary for TCO calculations

3.2.5 Comments on the methodology

With regards to the methodology, six important issues are to be highlighted.

Firstly, the set-up TCO model takes monetary costs into account exclusively. There is no attempt to quantify, for example, possible range anxiety (caused by the limited range of BEVs), time gains (thanks to the home recharging possibility for all EVs), or potential environmental benefits of new vehicle technologies. Accounting for such factors in the TCO approach could potentially reflect cost (or disadvantages) and benefits of these technologies in a more adequate way. However, such an approach is not the objective of this study. Limitations and needs that come with the purchase of an EV and are crucial factors for a vehicle purchase decision will be treated in subsequent steps when building up on the TCO model introduced here.

Secondly, attention is drawn to the fact that different vehicle technologies are represented by a very small number of reference vehicles. When making a vehicle purchase decision, the decision maker is not only confronted with even more different technologies, but with a large portfolio of choice options within each vehicle technology choice. Basing the available CVs and BEVs in the model on only two different reference vehicles each, and basing the PHEV on only one reference vehicle, is a severe limitation to the set-up model. Conclusions about the general financial advantage or disadvantage of certain vehicle technologies can therefore not be made. All results stemming from the underlying model are only valid for the specific vehicle comparisons that are carried out. They give, however, valuable insight on the likely magnitude and repartition of TCO, and, moreover, the differences of these for various vehicle technologies.

Thirdly, the underlying TCO model makes the rather brusque assumption that compared vehicles of different vehicle technologies attain the same residual value after the vehicle ownership period. In none of the reviewed studies could a thorough approach for evaluating resale values of EVs be found. Frequently, they are either ignored, or assumed to be the same for the vehicle technologies in question. Future EV demand and uncertain resale values of EVs' batteries

make any sound evaluation extremely difficult. While assuming similar values might actually be a valid approach, for example, when comparing an EV with its conventional counterpart, the assumption that an EV with a battery hire model attains a similar resale value does not appear entirely coherent from today's point of view. After a certain ownership period the EV user that disposes of the battery in his vehicle should be able to achieve a higher resale value than the EV user that disposes of the vehicle only. Following this reasoning, findings obtained by the underlying model underestimate the TCO of the EV with the battery hire model compared to the EV with the battery purchase model. This argumentation is only invalid if the battery value after the ownership period has dropped to zero, or even to a negative value reflecting a situation where the disposal of the battery comes along with costs to the private vehicle user.

Fourthly, infrastructure installation costs for private households are assumed to equal for all households. In reality, these costs will strongly depend on the exact configuration of the parking space. Especially in Paris, where the private parking space will frequently be situated in co-owned properties, the installation of recharge infrastructure is likely to entail much more costly works than simply the installation of a "wall-box", as it might be the case in a private garage. Data and methods that allow estimating infrastructure installation costs per parking type (and/or per type of residence) remain to be developed.

Fifthly, the underlying model is based on the assumption that a vehicle purchase occurs in year 0 (the year 2012) of the ownership period and all purchase related costs are covered instantly at this time. Different vehicle financing models are not considered. The impact of such financing models offered by the vehicle provider on the TCO difference of two compared vehicle technologies is, however, assumed to be negligible.

Lastly, only selected framework conditions are assumed to change over time in the underlying model. Mainly, these refer to energy prices and related taxation policies. Numerous parameters, such as the annual driven distance of the vehicle in question, or the share of the professional vehicle usage are supposed to stay constant over the ownership period of the vehicle. Especially the first is, however, likely to change over time. Reduced usage of the private vehicle might be a result of changing framework conditions, such as an increased offer of and/or access to (individual) public transport means, changing lifestyles, or increased environmental awareness of vehicle owners. On the other hand, the event of a vehicle replacement could result in either increased or decreased vehicle usage – depending on the technology of the newly bought vehicle, its related energy costs, and range restrictions[58]. Further, also household characteristics are supposed to stay the same over the vehicle ownership period:

[58] This issue will be further discussed in chapter 4, section 3.3, and in chapter 5, section 2.2, when forecasts on potential EV demand are developed.

annual incomes only change with the inflation rate; the residential zone of the households remains the same. Next, also vehicle characteristics and related costs, such as the energy consumption of the vehicle, remain unchanged during the vehicle ownership period. Costs related to the vehicle that occur over time and do not refer to energy costs, i.e., maintenance and parking costs, are supposed to change with the applied inflation rate. The related policy measures (e.g. with regards to infrastructure usage costs or parking costs) remain the same over the ownership period of the vehicle.

3.3 Results

This section shows major results of TCO model applications. The first section (3.3.1) gives results of a reference scenario, which serves for first insights into the composition of TCO and for comparisons for subsequent scenario modelling. The second section (3.3.2) gives the results of scenario analyses. Scenarios have varying vehicle user/usage characteristics, policy settings and market trends are explored. The third section (3.3.3) is dedicated to a sensitivity analysis of selected parameters. The last section (3.3.4) then gives the results of 'break-even' analyses that explore necessary parameter settings of main TCO influencing parameters in order to balance the TCO of different vehicle types. At the end of each section a short conclusion on the findings is given.

3.3.1 The reference scenario

The reference scenario portrays a random household in the IDF region. The reference scenario is not to be seen as an "average" household in the IDF, which would be against the idea of a disaggregate approach reflecting the specifications of each single household. The reference scenario serves to obtain an impression of a typical repartition of TCO for the different cost categories for the various vehicle types. Further, it gives an idea of the total amount of TCO. Settings are chosen in such a way that they reflect a realistic scenario, while evening out TCO between the CV and the BEV. This way, further scenarios that are built on the reference scenario and that serve to analyse the influence of different parameter categories, do not show a biased picture towards either the EV or CV technology. The settings for the reference scenario are given in Table 3.7 and are explained thereafter.

Vehicle type to compare		*Policy measures*	
Model type	compact	Bonus/Malus (PH(EV), in Euro)	5,000
Fuel type	petrol	Parking policy	Scen. 2
Vehicle user characteristics		Recharge infra. policy (in cEuro/km)	0,26
Residential zone	GC	Registration tax exemption	yes
Parking availability	yes	Additional increase of TICPE (in % per year)	0
Recharge infra. availability	no	Increase of electricity tax (in % per year)	0,3
Vehicle usage characteristics		*Market trends*	
Yearly driven distance (km)	18,000	Oil price development	med
Vehicle usage period (years)	7	Electricity price development	med
Main usage area	mix	BEV *i*nsurance cost reduction (%)	20
Share professional usage (%)	30	Discount rate (%)	6,5

(for details on specific settings refer to Chapter 2)

Table 3.7: Settings for the reference scenario

In order to come up with a valid comparison of the different vehicle technologies, it was decided to compare only one CV type (defined by the model type and the fuel type) at a time with the appropriate EV type (keeping in mind that for the PHEV, only one single model is available for comparisons). In the reference scenario a compact vehicle running on petrol is compared to the appropriate EV models (i.e. the Renault CLIO running on petrol is compared to the Renault ZOE Z.E. and the Opel Ampera). The Renault ZOE Z.E. is assumed to be available with a battery purchase and a battery hire business model. Since Renault currently only offers its EVs with battery hire, the purchase price of the battery is assumed (*according to Table 3.3*) in order to construct this hypothetical choice option.

Vehicle user and vehicle usage characteristics refer to a household in the Grande Couronne area. The household is equipped with private parking infrastructure but has not yet been equipped with EV recharge infrastructure. The annual driven distance is according to typical values in that residential zone (see Table 3.4). An annual driven distance of 18,000 kms could, for example, translate into a daily usage of around 70 kms on workdays (excluding holidays), and a weekend vehicle usage of around 60 kms (for both days). According to values found in the EGT 2001 database (the Enquete Globale de Transport for the Île-de-France region), these values are realistic for the "first" vehicle of a multi-motorised household in the Grande Couronne area. CGDD (2010) shows that the average annual driven distance of newly bought household vehicles lies above 16,000 km in the first three years. Also from this perspective the assumption of a vehicle usage of 18,000 km per year does not seem to be too farfetched or unrealistic. The vehicle usage period lies 2 years above the French average usage (ownership) period (INSEE, 2012a), which appears to be a realistic assumption for a newly purchased vehicle. The vehicle is used in both, urban and exterior-urban settings, and is partly used for professional reasons.

Policy measure settings in the reference scenario refer to the actual French policy settings as in the first half of the year 2012. The parking policy scenario assumes that EVs are treated preferentially compared to CVs, reflecting the case of Paris and various French communities in 2012. It is assumed that these policy settings remain the same over the vehicle ownership period. The increase in energy taxes is assumed to be moderate. For the TICPE only increases that are in line with past observations are assumed (there is no additional increase); the electricity taxes are assumed to increase by 0.3 % per year, which is less than what has been observed in the past (it is assumed that projected high increases of electricity prices will have this effect on the development of electricity taxes).

Settings defining market trends refer to the most likely developments from today's point of view. Energy prices follow a "medium" forecast scenario; insurances are assumed to hold their offers of a reduction for EVs over the ownership period of the vehicle; the discount rate takes the value as defined in the previous chapter.

The results for the reference scenario are shown in Figure 3.4. The upper part shows the repartition of the TCO after 7 years for the regarded CV and the different EV options. The term "BEV-Hire" refers to the BEV, where the battery is hired instead of purchased. The repartition of the TCO over the defined cost categories is consistent with Figure 3.1. The lower part of the figure shows the development of the TCO over time up until an ownership period of 10 years. Interest gains are here (for presentation reasons) comprised in the usage costs of the vehicle.

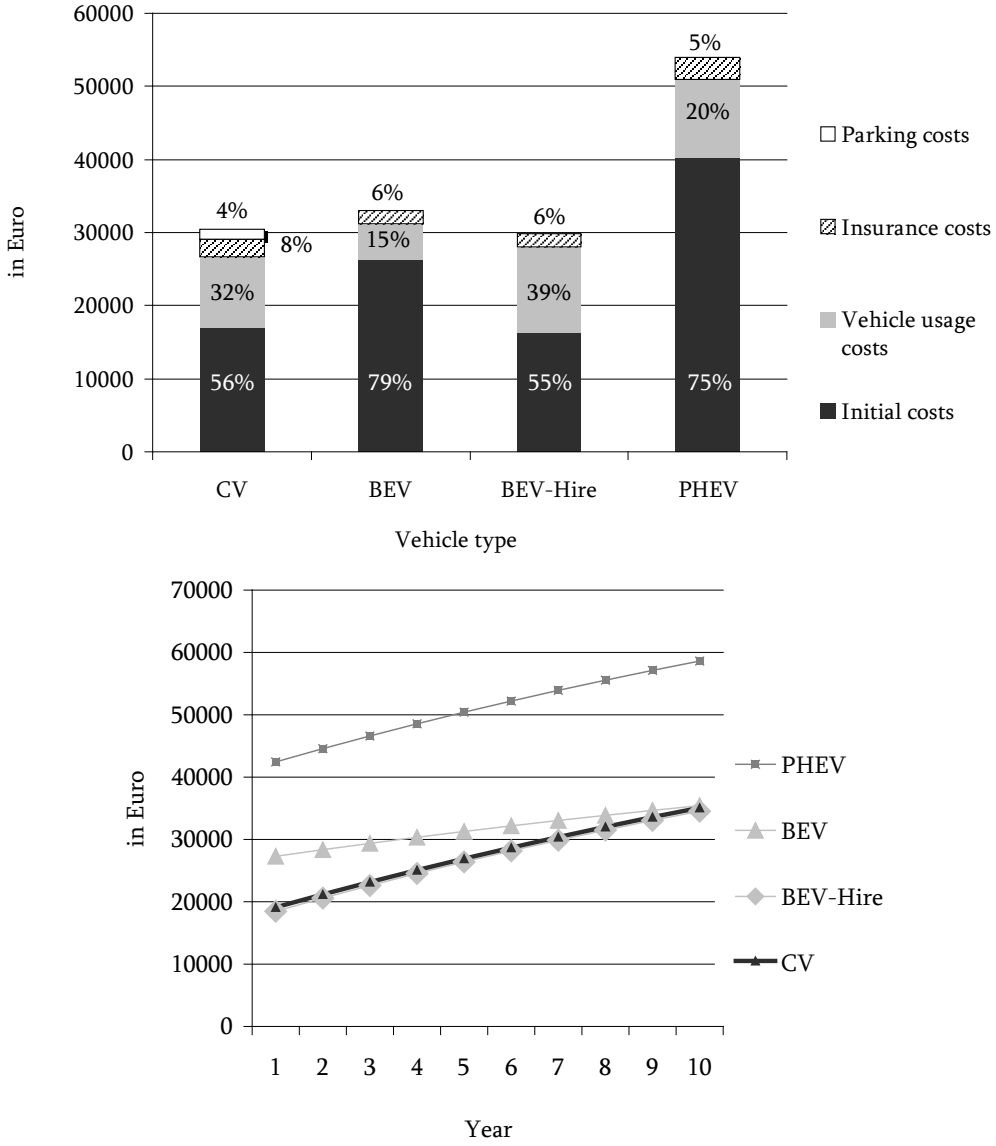


Figure 3.4: Results for the reference scenario

It becomes evident that initial costs constitute the largest cost component for the BEV and the PHEV: they amount to 79 % and 75 % of the TCO respectively. For the CV and the BEV-Hire they amount to around 55 %. Usage costs show a contrary tendency: they amount to 32 % for the CV and to 39 % for the BEV-Hire, but only 15 % for the BEV and 20 % for the PHEV. With increasingly high usage of the vehicle (either due to a high annual driven distance or a long ownership/usage period of the vehicle) the acquisition of a BEV or a PHEV becomes progressively more advantageous compared to a CV or a BEV with a battery hire option. Looking at the whole TCO though, it becomes apparent that a cost advantage of the underlying PHEV over any other vehicle

type is difficult to obtain. The TCO of a PHEV are around EUR 54,000 for the reference scenario. For the other three vehicle options they take a value of around EUR 30,000. The high purchase price of the Opel Ampera (see Table 3.3) compared to the other underlying reference models shows its effect on the TCO. The CV, the BEV, and BEV-Hire are very competitive vehicle choice options from a financial point of view.

The cost development over time (as shown in the lower part of Figure 3.4) shows at which point in time the TCO of the different vehicle types attain a similar level. For the BEV and the CV this is the case in year 10 of vehicle ownership (assuming a constant vehicle usage over time). In the first 5 years of vehicle ownership the TCO difference remains significant. The BEV-Hire option is competitive right from the beginning: TCO for this vehicle option develop in almost the same way as for the CV. Battery hiring makes the BEV-Hire to a very interesting purchase option for any forecast vehicle usage period. However, an alleged advantage of the BEV-Hire thanks to an increased annual distance driven is abated due to annual distance-dependent battery hire costs.

The following table gives detailed cost values per cost category and vehicle type for the reference scenario. TCO are also shown per year and per driven kilometre.

Reference scenario	Years	7	Km/year	18 000	Average km/day	49

	TCO (Euro)				**TCO/year (Euro/year)**			
Vehicle type	*CV*	*BEV*	*BEV - Hire*	*PHEV*	*CV*	*BEV*	*BEV - Hire*	*PHEV*
Initial costs	16980	26193	16293	40231	2426	3742	2328	5747
Purchase costs vehicle	16650	20700	20700	37300	2379	2957	2957	5329
Purchase costs battery	0	9900	0	7200	0	1414	0	1029
Registration costs	330	-4998	-4998	-4859	47	-714	-714	-694
Infra installation costs	0	590	590	590	0	84	84	84
Vehicle usage costs	10324	4962	12334	8294	1475	709	1762	1185
Fuel/El. costs	8276	2494	2494	3606	1182	356	356	515
Infrastructure usage	0	271	271	189	0	39	39	27
Battery hire costs	0	0	7371	0	0	0	1053	0
New battery costs	0	0	0	0	0	0	0	0
Maintenance costs	4553	4272	4272	6232	650	610	610	890
Tax reduction	-2506	-2075	-2075	-1734	-358	-296	-296	-248
Insurance costs	2358	1887	1887	3027	337	270	270	432
Parking costs	1289	0	0	0	184	0	0	0
Interest gains	575	-	641	-2356	82	-	92	-337
Total	**30376**	**33042**	**29872**	**53909**	**4339**	**4720**	**4267**	**7701**

Table 3.8: Detailed results for the reference scenario

Table 3.8 reveals the quite insightful repartition of the vehicle usage costs over the different cost items. It can be seen that maintenance costs play an important role for all vehicle types. The comparatively high maintenance costs for the PHEV are due to the fact that a sedan PHEV is compared to the compact

BEVs and the compact CV. Energy costs obviously play a much more important role for the CV than for the EVs. The battery hire costs that occur for the BEV-Hire option show a similar magnitude to the fuel costs for the CV.

As mentioned above, the reference scenario only serves for demonstration purposes and for showing main tendencies when comparing the vehicle purchase options selected here with each other. In the following section, different scenarios are developed that underline the importance of disaggregate analyses when using TCO as an exogenous variable for studies on future EV demand. TCO can vary enormously with vehicle user and usage characteristics. Also, policy settings and assumptions on accompanying market trends have significant impact on the TCO of the different vehicle types. The magnitude of possible TCO differences due to changes in the parameter settings is studied.

3.3.2 Scenario analysis

This section develops scenarios that show the impact of (simultaneous) parameter changes on the TCO of the various vehicle types. Parameter changes are carried out per parameter category (as shown in Figure 3.1). It is avoided to change more than those parameters belonging to the same category. This helps keeping TCO changes retraceable. Importance is given to carrying out such parameter changes that only result in still realistic scenarios. For each parameter category, one "EV+" and one "CV+" scenario is developed. The first one gives financial advantage to the EV options compared to the CV, whereas the second one does the same for the CV option compared to the EV options. Altogether, 7 scenarios are developed. Table 3.9 gives the scenario settings for each of them. Only values in bold are subject to change per scenario (however, not all of them necessarily change!). Other parameter settings were kept constant as in the reference scenario.

	Ref	*1*	*2*	*3*	*4*	*5*	*6*	*7*
	Reference Scenario	**Vehicle Type Scenario**	**Vehicle User/Usage Scenarios**		**Policy Scenarios**		**Market Trend Scenarios**	
			EV+	**CV+**	**EV+**	**CV+**	**EV+**	**CV+**
Vehicle type to compare								
Model type	compact	**sedane**	compact	compact	compact	compact	compact	compact
Fuel type	benzine	**diesel**	benzine	benzine	benzine	benzine	benzine	benzine
Vehicle user (household) characteristics								
Residential zone	GC	GC	**GC**	**Paris**	GC	GC	GC	GC
Parking availability	yes	yes	**yes**	**no**	yes	yes	yes	yes
Recharge infra. availability	no	no	**no**	**no**	no	no	no	no
Vehicle usage characteristics								
Annual driven distance (km)	18 000	18 000	**20 000**	**12 000**	18 000	18 000	18 000	18 000
Vehicle usage period (years)	7	7	**10**	**5**	7	7	7	7
Main usage area	mix	mix	**mix**	**urban**	mix	mix	mix	mix
Share professional usage (%)	30	30	**30**	**30**	30	30	30	30
Policy measures								
Purchase bonus (PH(EV), in Euro)	5 000	5 000	5 000	5 000	**5 000**	**0**	5 000	5 000
Parking policy*	Scenario 2	Scenario 2	Scenario 2	Scenario 2	**Scenario 3**	**Scenario 1**	Scenario 2	Scenario 2
Recharge infra. policy (in cEuro/km)	0,26	0,26	0,26	0,26	**0**	**0,26**	0,26	0,26
Registration tax exemption	yes	yes	yes	yes	**yes**	**no**	yes	yes
Additional increase of TICPE (in % per year)	0	0	0	0	**2**	**0**	0	0
Increase of electricity tax (in % per year)	0,3	0,3	0,3	0,3	**0,3**	**1**	0,3	0,3
Market trends								
Oil price development	medium	medium	medium	medium	medium	medium	**high**	**low**
Electricity price development	medium	medium	medium	medium	medium	medium	**medium**	**high**
EV insurance cost reduction (%)	20	20	20	20	20	20	**20**	**0**
Discount rate (%)	6,5	6,5	6,5	6,5	6,5	6,5	**4,5**	**6,5**

*see table 4 for definition

Table 3.9: Definition of scenarios

Figure 3.5 below gives the TCO results for the 4 vehicle types (CV, BEV, BEV-Hire and PHEV) per scenario.

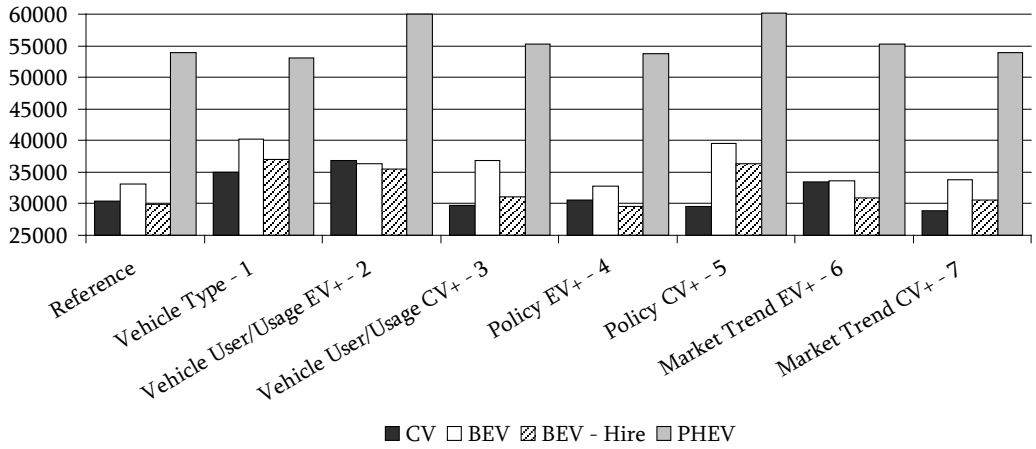


Figure 3.5: TCO results for the defined scenarios

The results for the first scenario show that the change to a sedan vehicle increases the TCO for both, the CV and the EV models. The impact on the PHEV is negligible since the same reference vehicle is used for the comparison. A slight decrease is, however, noticeable. This stems from the assumed fuel change also for the PHEV. The change to a sedan vehicle is not advantageous for the BEV options. Now, both BEV options are more costly than the CV. This is mainly due to the comparatively higher initial costs increase for the EV options than of the CV option.

Scenario 2 shows that a slight increase in the annual driven distance and in the usage period renders both BEV options financially advantageous over the CV. Scenario 3 shows that when assuming a household in the Paris region, for which the vehicle usage parameters decrease, the CV becomes more advantageous. The increased costs for the BEV options compared to the reference scenario (which occur despite the reduced vehicle usage) are present due to the assumption that a household in Paris does not have access to private parking facilities. This causes significant additional costs for the EV models since parking facilities need to be rented to assure access to overnight parking facilities.

Scenario 4 only shows minor changes to the reference scenario. This speaks for the fact that the current French policy setting is already EV favourable. Scenario 5 shows resulting TCO levels in case the policy framework was less EV-supportive. Neither EV option would, under current conditions, be competitive with the CV.

Scenarios 6 and 7 show the impact of market trends, which are largely determined by the development of oil and electricity prices. They can render both, CVs and EVs advantageous.

All scenarios show that the PHEV is, by far, the least financially beneficial choice option among the proposed vehicle types. The elevated purchase price of the underlying Opel Ampera cannot be evened out by lower vehicle running costs in any of the modelled scenarios. Its TCO surpass those of the other vehicle alternatives by EUR 15,000 – 20,000. The BEV-Hire option proves to be always financially better than the BEV (battery purchase) option. In 4 out of the altogether 8 scenarios, it also appears to be financially better the CV.

Results of the underlying scenario analysis emphasise the importance of accounting for the parameters selected here in TCO analyses. Leaving aside market trends and/or policy settings runs the strong risk of distorting the results of TCO comparisons of different vehicle types. Many TCO studies that were reviewed take a large portfolio of parameters into account, but they hardly ever treat them in a sufficiently detailed way. Parameters describing market trends are frequently only set for a certain time span, which neglects their development over the ownership period of the vehicle (e.g. Funk and Rabl, 2009; EDF, 2009; CAS, 2011; CGDD, 2011; etc.). The inclusion of parking policies and resulting parking costs, which necessitates a sufficiently disaggregate model that takes territorial characteristics into account, has been neglected by *all* reviewed studies. Further, all reviewed studies might be aware of the importance of vehicle user/usage characteristics, but they do not emphasise the fact that subsequent analyses on potential EV demand can only be reliable if those disaggregate parameters are *continuously* treated as such. The definition of an "average" household, on which general conclusions are based, is to be avoided by all means. Most studies do not refrain from defining households for the reason of convenience.

3.3.3 Sensitivity analysis

While the previous section explored the impact of simultaneous parameter changes, this section analyses the impact of single parameters. The selection of parameters for which sensitivity analysis is carried out was made according to the following criteria:

- Parameters are subject to significant uncertainty from today's point of view
- Parameters impact the TCO of the EV and the CV *differently* (they are therefore interesting for the EV – CV comparison)
- Parameters do not show direct and therefore obvious impact on the TCO (as e.g. purchase costs or subsidies would do)
- Parameters have not negligible impact on the TCO

Figure 3.6 gives results of all sensitivity analyses carried out. They are discussed thereafter.

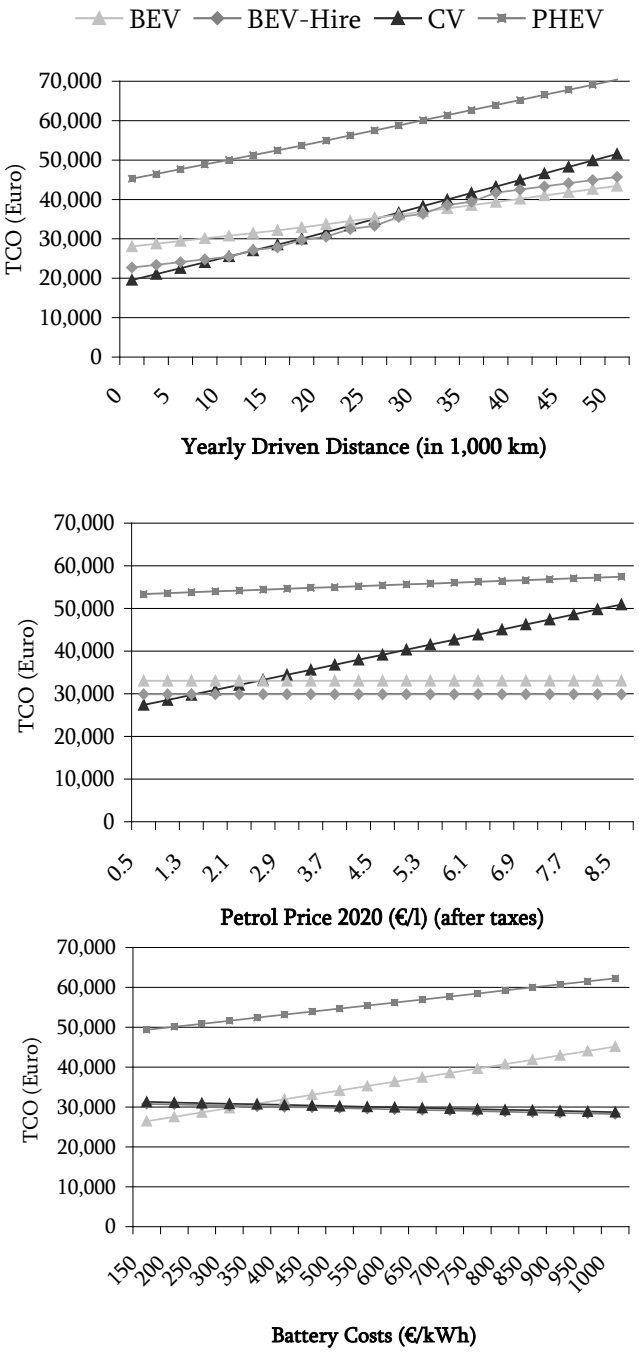


Figure 3.6 (I): Results of sensitivity analyses for selected parameters

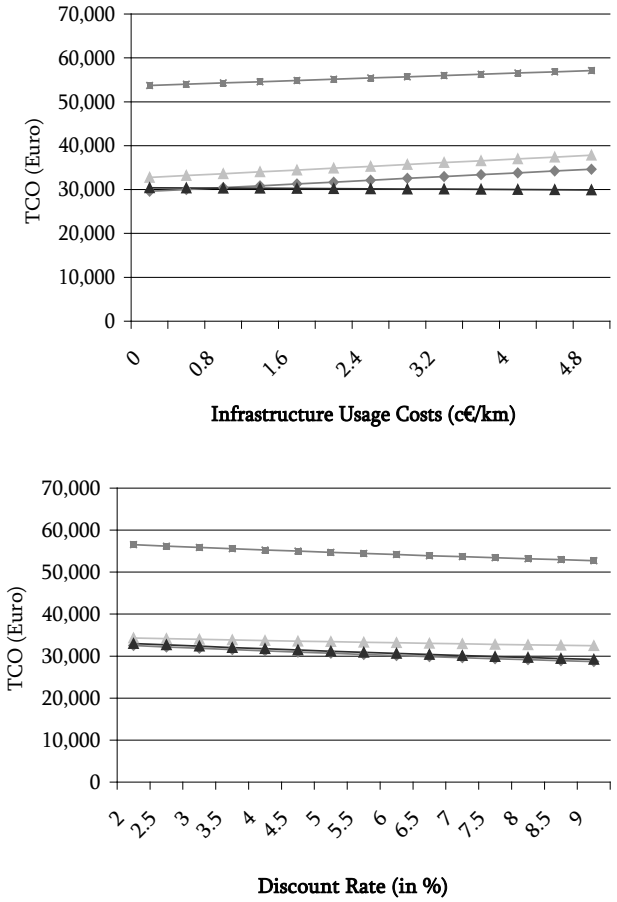


Figure 3.6 (II): Results of sensitivity analyses for selected parameters

Sensitivity analyses are based on the settings of the reference scenario. Only the analysed parameter changes its setting.

The first graph on the left explores the impact of the annual driven distance. Obviously, a higher annual driven distance comes along with higher TCO. This is valid for all vehicle types. However, the different slopes of the curbs show that the impact is vehicle type specific. This is mainly due to the different energy and maintenance costs per kilometre of the vehicle types. Further, it can be seen that the TCO of the BEV fall below those of the BEV-Hire with an increasing annual driven distance. This is due to battery costs that are distance-dependent in the case of the BEV-Hire option. The steepness of the curves indicates that the annual driven distance has significant impact on the TCO.

An increasing petrol price only impacts the CV and the PHEV options. Fuel prices are shown for the year 2020. A linear price increase from today's price until 2020 is assumed. Given the remarkable TCO increases that are caused by fuel price increases, the fuel price parameter proves to have significant impact on the TCO development of CVs.

Increasing battery costs impact mainly the PHEV and the BEV options. For the BEV-Hire, it is assumed that hire prices remain the same. The curves of the BEV-Hire and CV are slightly decreasing due to the fact that interest gains are calculated on the basis of the costs of the BEV (for which the interest gains are set to 0). Higher costs of the BEV, therefore, signify increasing interest gains for the other vehicle types. This lowers their TCO.

Infrastructure usage costs affect only the EV options. The PHEV is (very) slightly less affected since a lower public infrastructure usage is assumed.

An increase in the discount rate lowers the TCO (being the net present value of all considered costs discounted to year 0 of the vehicle ownership period, the year when the vehicle is purchased) of all vehicle options. The impact of the discount rate is higher for the vehicle types that show higher continuous costs. The TCO of the EV options therefore decrease slightly less than those of the CV.

Sensitivity analyses of the shown parameters demonstrate the effect of single parameters on the TCO of the different vehicle type options. Different slopes for different vehicle types reveal variations in the magnitude of impact. Further, the graphs shown reveal at which (approximate) parameter setting a certain vehicle option becomes advantageous over another one – all other settings being equal. These "break-even" points are further explored in the following section.

3.3.4 Break-even analysis

The following analyses give so-called 'break-even points' – the exact settings of parameters at which the EV options have the same TCO as the CV to which they are compared.

The analysis is carried out for major TCO influencing parameters. As identified in the sensitivity analysis, these are the *annual driven distance* (a vehicle user/usage specific parameter) and the *fuel price development* (a market trend parameter). Further, a break-even analysis for the *purchase price* parameter is also carried out, which can be of high value when it comes down to pricing EVs.

The TCO threshold value rendering an EV profitable over a CV is given by

$$TCO^{E} = TCO^{C} \tag{8}$$

where the exponents E and C determine the TCO of an EV option and the CV respectively. In the following, equations (1)-(6) help reformulate equation (8) in order to define break-even settings of the selected parameters. Interest gains (IG) are (for simplicity reasons) left aside. They are, however, considered in the actual calculations using the set-up TCO model.

Break-even distance

Taking the costs per km of the usage cost items (instead of their annual aggregation), the substitution of (2)-(6) into (8) yields the following break-even setting of the annual driven distance d^{BE} (all attribute-indices are omitted)

$$d^{BE} = \frac{\left(IC^E - IC^C\right) + \sum_{t=1}^{T} \frac{1}{(1+y)^t} \cdot \left(\left(ic_t^E - ic_t^C\right) + \left(ac_t^E - ac_t^C\right)\right)}{\sum_{t=1}^{T} \frac{1}{(1+y)^t} \cdot \left(\left(mc_t^C - mc_t^E\right) + \left(w_t^C \cdot h^C - w_t^E \cdot h^E\right) - \left(td_t^C - td_t^E\right) - bc_t^{*E} - uc_t^{*E}\right)} \quad (9)$$

where h is the vehicles' consumption (in l/km or kWh/km) and w_t the energy price per unit of consumption (the fuel price, w_t^C, in EUR/l, or the electricity price, w_t^E, in US/kWh; both specific to year t).

Break-even purchase price (of the EV)

Substituting (2) into (8) yields the following break-even purchase price of an EV, $pc^{E,BE}$, (all attribute-indices are omitted)

$$pc^{E,BE} = pc^C + \left(rc^C - rc^E\right) - ic^{*E} + \left(CC_T^C - CC_T^E\right) \quad (10)$$

Break-even fuel price

Taking the unit costs per km of the usage cost items by labelling the annual driven distance with d, the break-even fuel price $w_t^{C,BE}$ (in US/l) can be expressed as

$$\sum_{t=1}^{T} \frac{1}{(1+y)^t} \cdot w_t^{C,BE} = \frac{\left(IC^E - IC^C\right) + CC_T^E - \sum_{t=1}^{T} \frac{1}{(1+y)^t} \cdot \left(ic_t^C + ac_t^C + d \cdot \left(mc_t^C - td_t^C\right)\right)}{d \cdot h^C} \quad (11)$$

where h is the vehicles' consumption (in l/km). (11) requires an assumption concerning the fuel price's development over time. A linear increase according to

$$w_t^C = w_1^C \cdot p^t \quad (12)$$

is assumed. A single deterministic solution for $w_t^{C,BE}$ (or rather $p^{t,BE}$ since w_1^C is fixed to today's value) – requiring the substitution of $w_t^{C,BE}$ found in (11) by (12) – cannot be found. The break-even fuel price $w_t^{C,BE}$ is therefore calculated heuristically.

Table 3.10 gives the results of the break-even analyses. The first part shows the results when comparing a compact *petrol* CV with the EV options. The second part compares the EV options to a compact *diesel* CV. Analyses are

carried out for the reference scenario and the policy and market scenarios as defined in Table 3.9 (see Section 3.3.2). For the reference scenario, however, the model and fuel type corresponds to the CV vehicle type that is compared in the break-even analysis. Vehicle user/usage scenarios are left aside since these do not analyse general framework conditions that could be applicable for all households. All analysed scenarios therefore refer to a situation where the vehicle ownership period increases to 7 years and the vehicle is used for 18,000 km/year.

Table 3.10 shows the break-even setting (the settings at which formula (8) is satisfied) of each analysed parameter *when keeping all other parameters to their settings as defined by the scenario*. Next to the fuel price break-even point, which is given for the year 2020 (assuming a development over time according to (12)), the necessary price increase (as %) compared to today's levels is given. A negative increase refers to a scenario where 2020 fuel price levels, which render the analysed EV option financially advantageous, lie below today's price levels. The purchase price break-even setting is used to calculate the maximal EV price *premium* compared to the CV in question in order to reach equal TCO for the two vehicle options that are compared. Further, the break-even *ownership period* is also given in case it lies in the range of 1 to maximum 10 years. A "+" indicates that any ownership period from this time period onwards results in lower TCO for the EV than for the CV. In some cases, the EV-advantageous ownership period lies between a minimum and a maximum number of years.

Annual driven distance

Table 3.10 reveals that the PHEV cannot break even by the means of an elevated annual driven distance in any scenario. In those cases where a BE distance could be found, it lies outside the maximum battery lifetime (assumed here to be at 180,000 km at the most – an optimistic value compared to what was found in literature (e.g. CAS (2011): 150,000 km, Lidicker et al. (2011): 130,000 km)). Such scenarios would entail the costly acquisition of a new battery, which would further worsen their financial competitiveness against the other vehicle types. According values are therefore shown in grey/italic. In case the framework conditions are favourable (such as in the reference scenario or the EV+ scenarios) the BEV-Hire option breaks even with the petrol CV at a quite moderate annual distance: For the reference scenario this distance lies at around 14,000 km/year, for the Policy EV+ scenario at 9,000 km/year and for the Market EV+ scenario at only 7,300 km/year. The BEV requires significantly higher distances for these scenarios (25,600; 24,000; and 18,000 km/year). In case the framework conditions are CV friendly, the BE annual driven distances lie far above the distances that can usually be observed among private vehicle owners – both, for the BEV and the BEV-Hire.

Compact Petrol CV		Reference Scenario			Policy Scenarios						Market Scenarios					
					EV+			CV+			EV+			CV+		
(BE - Break-Even)	vs	*BEV*	*BEV Hire*	*PHEV*	*BEV*	*BEV Hire*	*PHEV*	*BEV*	*BEV Hire*	*PHEV*	*BEV*	*BEV Hire*	*PHEV*	*BEV*	*BEV Hire*	*PHEV*
BE Yearly driven distance	*(km)*	25600	14000	*182600*	24000	9000	*2E+05*	*47600*	*54600*	-	18000	7300	*1E+05*	*37500*	*47000*	-
BE petrol price 2020*	*(Euro/l)*	2.19	1.32	9.18	2.11	1.24	9.11	4.18	3.32	11.52	1.99	1.34	10.27	2.4	1.54	9.26
*(% increase to 2012 prices** by)*		*36*	*-18*	*470*	*31*	*-23*	*466*	*160*	*106*	*616*	*24*	*-17*	*538*	*49*	*-4*	*475*
BE purchase price premium EV***	*(%)*	71	28	44	72	30	45	32	-11	6	84	38	54	59	16	36
BE ownership period	*(years)*	-	1+	-	-	1+	-	-	-	-	7+	1+	-	-	1-3	-

Compact Diesel CV		Reference Scenario			Policy Scenarios						Market Scenarios					
					EV+			CV+			EV+			CV+		
	vs	*BEV*	*BEV Hire*	*PHEV*	*BEV*	*BEV Hire*	*PHEV*	*BEV*	*BEV Hire*	*PHEV*	*BEV*	*BEV Hire*	*PHEV*	*BEV*	*BEV Hire*	*PHEV*
BE Yearly driven distance	*(km)*	*43500*	*56800*	-	*39200*	*51200*	-	*87300*	*1E+05*	-	23700	15400	-	*1E+05*	*2E+05*	-
BE diesel price 2020*	*(Euro/l)*	3.42	2.03	17.74	3.29	1.91	17.61	6.64	5.26	22.33	3.1	2.07	16.32	3.77	2.38	25.04
*(% increase to 2012 prices** by)*		*144*	*45*	*1167*	*135*	*36*	*1158*	*374*	*276*	*1495*	*121*	*48*	*1066*	*169*	*70*	*1689*
BE purchase price premium EV***	*(%)*	53	12	28	55	14	29	16	-24	-8	67	23	38	-43	-100	-59
BE ownership period	*(years)*	-	1-4	-	-	1-4	-	-	-	-	9+	1+	-	-	1-2	-

** after taxes, in nominal Euros **taking 1,61 Euro/l Petrol and 1,43 Euro/l Diesel as reference for 2012 after tax prices (ZAGAZ, 2012)*

**** compared to the CV price; BEV and PHEV: including battery; BEV-Hire: vehicle only*

Table 3.10: Break-even analyses for the compact vehicle types

For breaking even with the compact *diesel* CV generally much higher annual driven distances are needed. This is due to lower running costs of the diesel compared to the petrol CV.

2020 fuel price

Looking at the 2020 petrol price break-even setting, it can be noted that the BEV-Hire option only requires very moderate fuel price increases in order to break even – if at all. For some scenarios, even a decrease of today's prices would keep the BEV-Hire option profitable. The BEV breaks even with the petrol CV at fuel prices that approximately conform to the high oil price scenario. The only exception is the Policy CV+ scenario: here, the necessary 2020 fuel price lies well above all forecasted fuel price scenarios. The PHEV would only break even with a fuel price increase that is hardly imaginable from today's point of view. The same is the case for almost all scenarios and EV options when comparing them to a *diesel* CV. Again, the lower running costs due to lower consumption of this vehicle type keep the TCO, in comparison to the *petrol* CV, low and a break-even point is difficult to reach.

Purchase price

The purchase price premium shows the maximal purchase price supplement of the EV compared to the CV at which the TCO of the compared vehicle types are balanced. For the BEV and the PHEV the battery price is included in this premium. In case of the BEV-Hire option only the price of the vehicle is considered. In the EV-favourable scenarios this price premium can augment to 70-85 % of the *petrol* CV price. Current offers show a price supplement of 85 %. However, for the CV-favourable scenarios this price premium should only lie at 32 % for the Policy CV+ scenario and at 59 % for the Market CV+ scenario. For the BEV-Hire option the price premium is lower due to the fact that the battery costs are covered by continuous payments rather than by an up-front purchase. The maximal price premium lies at 30-40 % for the EV-favourable scenarios (which all already take the EUR 5,000 purchase subsidy into account!). For the CV favourable scenarios the price premium lies at -11 % (meaning that the vehicle price of the BEV-Hire option is 11 % lower than the one of the petrol CV), or 16 % respectively. The maximal possible PHEV purchase premiums for achieving a TCO balance lie between only 6 % and 56 % (including the battery!). Considering the current price premiums for PHEVs that are approximately 170 %, such price levels seem to be very difficult to reach in any near future. Looking at the *diesel* CV – EV comparisons, all maximal price premiums are lower than the one found for the petrol CV. In particular, the CV+ scenarios (for which these premiums are mostly negative), show that appropriate price levels for balancing the TCO of the *diesel* CV with the EV options will be difficult.

Ownership period

Most scenarios show that a break-even point cannot be reached for EV options with the CV within 10 years of vehicle ownership. The frequent exception is the BEV-Hire: here, the TCO are right from the time of vehicle purchase lower than the ones of the CV. However, only for some EV-favourable scenarios they remain at a lower level during the whole ownership period of the vehicle. For the other scenarios the BEV-Hire TCO rise above the ones of the CV from year 3 or 4 onwards. This is due to the fact that the sum of battery hire costs and other continuous costs surpass the continuous costs of the CV from a certain ownership period onwards. (Remember that the battery hire costs rise with the annual driven distance, but also with the ownership period of the vehicle – see Table 3.3).

Break-even analyses show that EV options are much more easily (financially) outperformed by a *diesel* CV than by a *petrol* CV. This is due to lower running costs (which are, in turn, due to lower consumption and fuel prices of the diesel vehicle), while the higher up-front costs of the diesel CV are only marginal. However, also when comparing the *petrol* CV to the EV options, break-even points often entail very unlikely parameter settings. This is especially the case for the PHEV, but also for the BEV. Reaching a TCO balance between BEVs and PHEVs under realistic parameter settings most often necessitates the *simultaneous* change of more than one of the regarded parameters. The BEV-Hire, on the other hand, can in most cases compete with the petrol CV under realistic settings.

Break-even analyses for *sedan* vehicles show the same tendencies as the ones for the compact vehicles. However, EV options turn out to be even less competitive when comparing them to compact diesel CV. This supports the assumption that compact vehicles are more likely to be replaced by EVs than sedan vehicles. Detailed results for sedan break-even analyses can be found in the Annex 3.2.

3.4 Conclusion

3.4.1 Summary of the applied methodology

This study analyses the impact of vehicle user and usage characteristics, policy settings and market trends on the Total Cost of Ownership (TCO) of different vehicle types and purchase options. For this purpose, a calculation model is set up that explores the evolution of TCO within a timeframe of up to 10 years. The model covers (1) a battery electric vehicle (BEV), (2) a BEV with a battery hire option (BEV-Hire), (3) a plug-in hybrid electric vehicle (PHEV) with a long all-electric range, and (4) a conventional vehicle (CV). These vehicle technologies

are represented by reference vehicles as they are offered on the French market: Renault's CLIO (for the CV), Renault's ZOE (for the BEV), Renault's FLUENCE (for the CV and BEV), and Opel's Ampera (for the PHEV representing a long electric-range PHEV). All results and conclusions of this study are in reference to these specific models. The fact that other vehicle models with different cost structures also exist is not accounted for. All territorial characteristics that are taken into account refer to the Ile-de-France (IDF) region (the region of Paris). The assumed vehicle purchase takes place in the year 2012. The "rest of France" area is integrated in the model by applying the parameter values of the "Grande Couronne" area.

3.4.2 Summary of results

The analysis of the reference scenario shows the split of the total ownership costs between initial vehicle purchase costs and continuous vehicle operating costs. While the TCO of a CV is more equally divided between initial costs (56%) and continuous costs (44 %), the TCO of a BEV and a PHEV are dominated by the initial costs (79 % for the BEV, and 75 % for the PHEV respectively). The cost split of the BEV-Hire largely resembles the one of the CV. A BEV-Hire and (under more specific settings) also a BEV with a battery purchase option appears to be competitive with a *compact petrol* CV using realistic assumptions. The TCO of the BEV-Hire is 98 % of the TCO of the compact petrol CV. For the BEV this percentage increases to 107 %. The TCO comparison of a PHEV with a compact petrol CV shows, on the other hand, a clear financial advantage for the CV: the TCO of a PHEV is 175 % of the CV's TCO.

The scenario analysis shows the significant impact of the various parameters taken into account. The often-neglected vehicle user and usage characteristics, such as the access to, and cost of, parking infrastructure, seem to be important. Also, policy settings and the *development* of market trends have to be accurately taken into account. Different assumptions with regards to their settings and their development have a significant impact on TCO comparisons.

The break-even analysis identifies the settings of the major TCO influencing parameters that lead to equal TCO between EVs and CVs. It shows that break-even is difficult to reach for EVs under realistic settings for i) PHEVs in all scenarios and ii) for BEVs with a battery purchase option in most scenarios. The BEV-Hire is financially advantageous to a CV under realistic parameter settings. Hence, this purchase option appears to be the most financially interesting one.

3.4.3 Discussion and conclusions

In today's discussions the potential for electric vehicles is often viewed with non-negligible scepticism. This scepticism largely stems from the expected lack

of customer acceptance due to the EV's higher acquisition costs. The underlying study explores the financial viability of EVs in the Paris region given the framework conditions as of the year 2012. The results show that certain types of EVs can be financially advantageous to CVs under 2012 settings. Private demand of these vehicles is therefore not expected to solely rely on utopians or EV-enthusiasts or, alternatively, on non-financial features of this vehicle technology. However, from today's point of view, such "financially rational" demand remains subject to several conditions and limitations. France appears to be an EV marketplace that profits from EV-supportive policy measures, moderate electricity prices, and adequate EV business models. Indeed, analysis shows that especially the EV with battery hire business model can be advantageous for the private user. Whether car producers keep vehicle (and battery) prices intentionally at moderate levels in order to increase sales volumes remains unknown. It cannot be ruled out that significant losses are accepted in the expectance of creating first vehicle demand that gets the "EV-ball" rolling. Whatever the case may be, analyses show that current policy settings allow today's owners of battery hire-EVs to reach similar total cost of ownership levels as they would with a comparable compact petrol vehicle. This observation is largely independent from assumptions on future market trends. In contrast, the comparison of EVs with diesel vehicles, in particular with sedan diesel vehicles, turns out to be significantly less promising for the EV. Here, similar TCO levels are not achieved. EV-favourable market trends (especially concerning fuel price developments) and EV-favourable vehicle usage behaviour (such as exceptionally long ownership periods and/or high vehicle usage) appear to be necessary conditions to result in a financial advantage of BEVs with a battery purchase option over CVs.

While results suggest that a certain BEV demand can potentially evolve thanks to financial reasoning (under all mentioned framework conditions and underlying assumptions), model applications suggest that demand for PHEVs with long electric ranges will mainly rely on the goodwill of vehicle users who are not ready to accept the range limitations of BEVs. The high TCO that are mainly due to the high purchase costs of such PHEV models gives reason to that. Smaller (and less expensive) PHEV models with shorter electric ranges have the potential to decrease the vehicle type's financial disadvantage. The availability of PHEV models on the French market is, for the time being, limited though. Assuming a performance increase of BEV models with regards to range – be it due to developments in the battery technology or due to increasingly dense recharge infrastructure networks – is likely to undermine the PHEV's business model in the long run.

The question of whether those customers, for whom a BEV with a battery purchase or hire option makes financial sense, are also those who are willing to accept range limitations and recharge infrastructure requirements remains to be

examined. This analysis does therefore not provide any conclusions on potential future EV demand.

3.4.4 Shortcomings and outlook

Methodological shortcomings and limitations of the underlying study were discussed in more detail in Section 3.2.5. They mainly refer to (i) the definition of the resale value of different vehicle technologies (notably they are assumed to be the same, i.e., also for the different business models of the BEV – this is likely to distort the results in favour of the BEV-Hire option), and (ii) the fact that different vehicle technologies are represented by specific single reference vehicles. This means that other possible vehicle cost structures and magnitudes that could result from the purchase of other EV models than those underlying the analysis, are not taken into account. Out of the two PHEV models that are currently available on the French market (the Toyota Prius and the Opel Ampera), the approximately EUR 7,000 more expensive Opel Ampera that comes with a longer electric range has been chosen for all underlying comparisons. This distorts the picture to the disadvantage of the PHEV technology. When regarding the results for the PHEV technology, the fact that a long-electric-range PHEV serves as basis for comparisons is to be kept in mind.

In subsequent chapters, the set-up TCO model is used for attempting forecasts on the EVs potential. Household-specific vehicle user and usage data is taken from survey results in order to work on a disaggregate level. Non-financial specifications of EVs, such as range limitations and recharge infrastructure requirements are taken into account.

Chapter 4
Households' compatibility with EVs: a constraints analysis

4.1 Introduction

4.1.1 Background

Chapter 3 showed the significant impact of household and vehicle usage characteristics on the economics of a certain vehicle type. When attempting to evaluate the potential demand for electric vehicles, such characteristics will be important for analysing the financial impact of electric vehicles (EVs) on the vehicle user. EVs come with specific needs and limitations. These refer to recharge infrastructure requirements and the limited range of these vehicles. Irrespective of the potential financial advantage of an EV over its comparable conventional counterpart, household and vehicle usage characteristics need to be in line with these EV-specific needs and limitations. For this reason, estimating EVs' potential necessitates an even closer look at such characteristics than the one that was undertaken in the financial analysis. Only those households that show to be compatible with the EVs' needs and restrictions are considered to be potential EV households.

4.1.2 Objectives and approach

Based on a literature review, practical observations, and given the data availability for the underlying study, this chapter defines specific household and vehicle usage characteristics that render households as, what we define as, *EV-qualifying* households.

These identified characteristics are the basis of a set of household selection criteria that is applied to data about French households and their mobility behaviour. The established constraints analysis applies the selection criteria in a progressive way. Different scenarios are established that allow verification of the effect of different subsets of household selection criteria on the resulting remaining number of potential EV households. The methodology is applied to the different sub-regions of the Ile-de-France area and to the whole of France. This allows for the analysis of geographical differences as well as the identification of most EV-adapted regions, where EV demand can be expected to evolve first. Sensitivity analyses are carried out in order to better understand the effect of certain household selection criteria on the number of potential EV households.

The estimation of potential EV households gives an indication of the EV market potential – the pool from which initial, financially-reasoned EV sales are likely to emerge. Potential increases – or decreases – in EV demand due to irrational behaviour, (missing) network effects, individual tastes, or individual preferences, which might (have already) become the subject of EV marketing measures, is not explored. Further, the study only gives a 2012 snapshot of EV-qualifying households. How the number of these develops over time, due to changing framework conditions, is not analysed in this chapter.

The analysis contributes to understanding the effect and significance of existing or potential policy measures promoting the introduction of EVs. The range of EV-supportive policy measures that are explored is broadened compared to the previous chapter. The analysis is no longer restrained to financial policy measures altering vehicle purchase or usage costs as in Chapter 3. Also, the potential effect of behavioural, institutional or technological changes is analysed. These changes are expected to (partly) result from policy measures. Finally, household characteristics of the identified target market are revealed.

Results can serve the design of vehicle manufacturers' marketing strategies. Insight into the value of certain vehicle features and the importance of household configurations for the adoption of EVs are obtained. Drawbacks of the approach are identified and discussed.

4.1.3 Outline of the chapter

In this chapter, Section 4.2 gives a detailed literature review of studies that work with constraints analyses for identifying the potential of alternative-fuel

vehicles. Section 4.3 gives an overview of the data source underlying this study, and a detailed description of the constraints analysis applied. Findings of the literature review help define specific constraints on the basis of which EV-qualifying households are identified. Section 4.4 shows the stepwise application of the constraints analysis for France and, more specifically, for the Île-de-France region. Sensitivity analyses of single constraints are carried out, characteristics of EV-qualifying households are explored, and differences within the Île-de-France region are analysed. Section 4.5 then provides a summary and discussion of results by comparing them with those of the reviewed literature. The relevance and validity of obtained results are put into perspective. Section 4.6 then concludes the chapter by offering a concise summary of the applied methodology and the main findings. Conclusions of interest to policy makers and an outlook on subsequent analyses are given.

4.2 A review of constraints analyses

4.2.1 Scope and structure of the review

This literature review is focused exclusively on constraints analyses, as introduced in Chapter 1 (Section 1.6.2). The objective behind this literature review is to gain understanding of how meaningful constraints defining potential EV-households are identified, how different types of data sources can be used, and which deficiencies of constraints analyses are to be either tackled or kept in mind when deriving conclusions.

The first section (4.2.2) introduces so-called travel behaviour studies. They specifically explore the impact of range limitations on EV demand by studying vehicle usage patterns. The second section (4.2.3) presents studies that (partly additionally) explore the impact of recharge infrastructure needs. The methodology and main results of all reviewed studies are outlined. Finally, a discussion compares studies with each other. A final overview table lists all reviewed studies, summarises their main results, and recapitulates key observations with regard to the applied methodology.

4.2.2 Travel behaviour studies

According to Kurani et al. (1994), the first disaggregate demand analyses based on socio-economic data for analysing the potential of EV demand date back to as early as 1982. Such studies are here classified as *travel behaviour* studies. Battery electric vehicle (BEV) sales potential is constituted by households that are able to incorporate a BEV into their vehicle fleet despite the vehicle's range limitation. The main assumption is that such households must at least dispose of two vehicles in order to represent a potential BEV-household. Further, the

households' travel behaviour, which is often analysed on the basis of (one-day) travel diaries, must be in line with the limited range of the BEVs. Other than constraints referring to (multiple) vehicle ownership and vehicle usage behaviour, such as the need for access to overnight recharge infrastructure, are not taken into account. The oldest cited examples of such studies are Kiselewich and Hamilton (1982) and Desphande (1984). An example of a more recent travel behaviour study is Gondor et al. (2007), who explore the usage of 227 vehicles in the St. Louis area, US, over a one day period. Results suggest that an EV-range of 100 miles covers more than 95 % of daily trips.

Greene (1985) proposes a method that avoids the use of single-day surveys by basing his study on a sample of over 2,000 vehicles in the US for which at least 30 consecutive refuelling intervals are reported. Daily travel distributions for each individual vehicle are estimated. Range requirements are then derived. A substantial potential market (20-50 % of all household vehicles) for EVs with ranges in the order of 100 miles is forecasted.

Pearre et al. (2011) analyse range requirements by analysing the GPS driving data of 484 sampled gasoline vehicles in the greater metropolitan area of Atlanta, Georgia, over one to three years. It is found that 9 % of the vehicles in the sample never exceeded 100 miles in one day. These could be replaced by limited-range EVs. The figure increases to 17 % or 32 % in case drivers a willing to adapt their driving behaviour[59] on two or six days respectively per year. Figure 4.1 shows these and further results. The fraction of vehicles that could be substituted by a limited-range vehicle is given as a function of the range of such a vehicle. The four lines represent the fractions in case vehicle owners are willing to make adaptations on zero, two, six, or 25 days per year.

[59] By "adapting driving behaviour" the following options are considered: (i) substitution of the limited-range vehicle with a conventional one (stemming either from the household's fleet or a rental organisation), (ii) recharging during the day or en route, (iii) delaying (a part of) the trip until the next day, or (iv) choice of a different mode of transport.

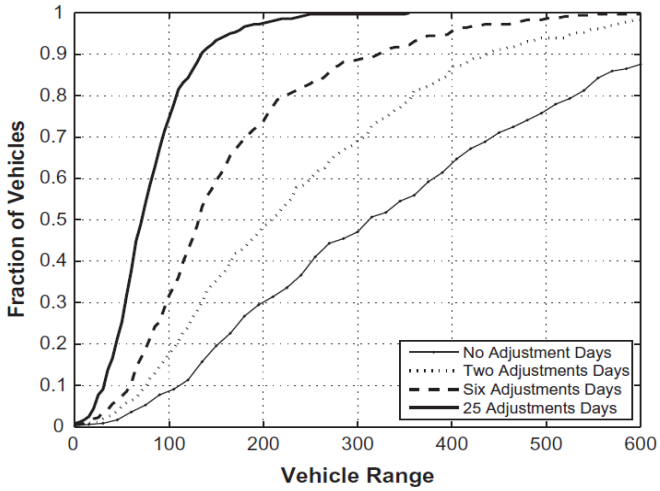


Figure 4.1: Driving success surface by adaptation days (Pearre et al., 2011)[60]

Kurani et al (1994) applies a method based on *interactive, stated lifestyle-preference* interviews. The method incorporates consumer preferences by accounting for attitudes and social processes that are likely to shape vehicle choices. After a household is made aware of its vehicle usage patterns and range requirements[61], it is asked if and how it could incorporate a limited-range vehicle into its fleet. The range of the hypothetical vehicle is gradually reduced in order to derive the minimal vehicle range that the household is willing to accept while bearing the so-called *activity spaces* of the household members in mind. The potential adaptation behaviour that allows the integration of a limited-range vehicle in the household's fleet is analysed. The household is then asked to optimize the usage of its vehicle fleet under hypothetical operating costs of the different vehicle types. Finally, the household is confronted with a selection of limited-range vehicles, and asked if/which one of them it would effectively choose. Altogether 51 interviews were carried out with households who buy new motor vehicles in California. The characteristics of the interviewed households (such as multi-motorisation) correspond to around 200,000-350,000 Californian households per year. 29 households are found to be "pre-adapted" to BEVs – they do not require any change in their travel behaviour in order to integrate a truly limited-range BEV (having a range of (much) less than 100 miles) into their fleet. Fifteen households are "easily

[60] The figure is based on selected 363 vehicles that participated at least 75 % of the surveyed time in the study.

[61] Range requirements are classified into ranges that lie within (i) the "routine activity space", (ii) the "emergency range buffer", and (iii) the distances to "critical destinations". Turrentine (1994) found that the additional range above expected trips (the emergency range buffer) desired by drivers lies at around 20 miles.

adapted" – they switch vehicles or swap vehicles between drivers to accommodate a limited-range vehicle. These households are comfortable with driving ranges between 80 and 100 miles. Seven "non-adapted" households show that their travel behaviour makes it difficult or even impossible to incorporate a BEV into their vehicle fleet. The study by Kurani et al. (1994) is extremely valuable, not only due to the simultaneous investigation of households' travel patterns *and* vehicle preferences, but also due to the explicit recognition of the importance of analysing the whole vehicle *fleet* of a household is explicitly recognised. Kurani et al. (1994) call households that choose different types of propulsion systems for their vehicle fleet *hybrid households*. It is hypothesised that the limited-range of EVs is not an important barrier to its purchase by such a household. Hybrid households are willing to adapt their vehicle usage patterns to the different range limits of their vehicles. This allows them to benefit from the unique advantages of different propulsion systems, such as home recharging in the case of the EV. Vehicles are allocated to travel needs according to the vehicles' operational characteristics. The study does not explore the effect of vehicle costs on potential choice behaviour.

Kurani et al. (1996) build upon the methodology applied in Kurani et al. (1994) in order to carry out a larger scale mail survey that obtains responses from 454 Californian multi-motorised households. Besides information material on different types of EVs and their usage method, the four-stage mail survey requires the completion of a 3-day travel dairy, the mapping of activity locations, and responses to vehicle choice experiments. The *hybrid household hypothesis*, that was formulated based on the findings of Kurani et al. (1994), is tested and confirmed. It is found that by 2020, between 7 and 18 % of annual light duty vehicle sales in California could be battery-powered EVs with ranges of 40-150 miles that go to hybrid households. EVs sold to fleets and other households are in addition to this demand. The choice experiment incorporates price information of the EVs. Up-front EV purchase prices are set to be only slightly higher than those of comparable CVs. This assumption is based on the expectation that EVs are supported by significant purchase subsidies and predominantly leased, which will bring down up-front costs.

Chlond et al. (2012) use 2006-2009 data from the German Mobility Panel that gives information on the day-to-day mobility behaviour during one week for approximately 1,000 households each year. A set of criteria verifies if each reported car could potentially be replaced by an EV. These criteria mainly refer to two conditions: (i) the daily mileage of an EV-qualifying car does not surpass 70 km, and (ii) other reported vehicle usage behaviour allows the conclusion that the car is not used for long-distance trips. Of the total sample of 2,000 cars, 7.5 % were found to qualify for an EV.

4.2.3 Studies exploring the access to recharge infrastructure

Williams and Kurani (2006) introduce a capability constraints approach for exploring the potential for hydrogen-fuel-cell vehicles and other "mobile-energy" technologies (such as plug-in hybrids). Particularly, constraints with regards to "home connection hardware" are defined. They verify whether a household is likely to be able to install appropriate home recharge infrastructure and mainly refer to the dwelling's age, size, and ownership status. Further, constraints on the number of vehicles in a household (limiting EV-qualifying to multi-motorised households) and on the employment status of the household's vehicle members (limiting EV-qualifying households to households with income) are defined. The used data source is the public-use microdata sample of the year 2000 US Census. Results suggest that 5.2 out of 33.9 million Californians live in households that are pre-adapted to mobile-energy-enabled vehicles. Assuming that hybrid households can easily adapt to a ME-enabled vehicle in their fleet (and given the unknown range of fuel-cell vehicles), travel behaviour constraints are not introduced in the analysis.

Biere et al. (2009) introduce the usual constraints that define only those multi-motorised households as EV-qualifying households that dispose of a fixed parking facility in the proximity of their dwelling (which, in case the potential of rechargeable EVs is explored, allows for the installation of recharge infrastructure). Further, the study limits the EV market to households showing vehicle usage behaviour (mainly in terms of annual driven distances and vehicle usage areas) that renders the EV *financially* advantageous over its conventional counterpart. For this purpose a total cost of ownership (TCO) approach is followed. On the basis of 2010 vehicle prices, city BEVs (defined to be BEVs that are equipped with a 20 kWh battery) show to be negligibly more expensive than their conventional petrol counterpart, and around EUR 1,300 cheaper than their diesel counterpart (not counting the costs of the battery). The battery costs of such a city BEV amount to almost EUR 11,920 in 2010, and to EUR 6,520 in 2020. The study is based on a disaggregate data source that reports the mobility behaviour of almost 26,000 households, constituting a fleet of over 33,000 vehicles, on a single day in the whole of Germany in 2002 ("Mobilität in Deutschland 2002"). Average vehicle usage characteristics for defined vehicle user groups are calculated in order to derive the TCO for each vehicle type and user group. Households in the same vehicle user group have the employment status of their reference household member as well as the size of their township, in common. For each vehicle user group showing EV-advantageous vehicle usage behaviour (in an economic sense) the percentage of EV-qualifying households is identified. The study predicts that city BEVs (showing higher urban vehicle usage than other BEVs) become economically advantageous over a conventional vehicle (CV) for all user groups from 2020 onwards. The plug-in

hybrid electric vehicle (PHEV) is for slightly fewer user groups advantageous. However, since PHEVs can also be deployed in mono-motorised households, their market potential augments after applying all selection criteria to over 20 % of the total analysed vehicle fleet. Meanwhile, the market potential for city BEVs shows to be at around 12 % (including those vehicles that can potentially be replaced by either a city BEV or a PHEV). For other BEVs no potential before 2020 is found. This is due to an economic disadvantage of these vehicles compared to their conventional counterpart.

CGDD (2011) works with the ENTD (Enquête Nationale Transports Deplacements 2007-2008) that gives information on over 20,000 French households and their travel behaviour.[62] The potential for BEVs and PHEV is explored by applying a constraints analysis that verifies if a household is multi-motorised (in case the potential for the BEV is explored), and if it has access to a private parking facility. Applying these two criteria, it is found that the potential combined demand for PHEVs and BEVs could increase to 69 %, while solely BEV demand could constitute 20 % of the current private vehicle fleet.

Campbell et al. (2012) propose a constraints analysis with the objective of localising initial EV demand in Birmingham, U.K. Besides the constraints that EV-qualifying households are multi-motorised, home-owners, and housed in detached or semi-detached homes (and are therefore likely to have access to off-road parking that allows for the installation of recharge infrastructure), such EV-qualifying households are further defined as households whose members show higher-than-average levels of education, are aged between 25 and 59 years, have a higher-than-average income level, and drive a car to work. These latter constraints stem from the findings of a literature review about the characteristics of potential early EV adopters. Census data from 2001 is used. Highest potential EV demand is found in the north of Birmingham city centre.

Nesbitt et al. (1992) base their EV demand analysis on the 1985 American Housing Survey. The data source allows the definition of constraints referring to vehicle usage patterns and the household's infrastructure: to be EV-qualifying, households should (i) own their primary place of residence, (ii) have access to a parking space at their primary residence, (iii) dispose in addition to a potential EV of at least one vehicle capable of long-distance trips, and (iv) have at least one vehicle that is not used for commutes longer than 80 miles (round-trip) on a daily basis. Results of the analysis show that almost 30 % of the 1985 US housing stock can be defined as EV-qualifying. The number of potential EV-households drops significantly as an additional income constraint is raised that limits EV demand to households attaining a certain income level.

[62] The ENTD is presented in more detail in section 3.2.

Deloitte (2010) base their constraint analysis on a (partly stated preference) survey carried out with 2,000 current vehicle owners in the US. The defined constraints are the most stringent ones found in the underlying literature review. They refer to (i) the vehicle owner's EV-awareness, (ii) the vehicle owner's will and ability to adapt to (long) vehicle recharging at home, (iii) the vehicle owner's will and ability to adapt to a limited-range vehicle, and (iv) the operational economic benefit of an EV in comparison to its conventional counterpart. Results suggest that none of the surveyed households complies with all constraints in 2010. The "probable" scenario for the year 2020 assuming a "medium" EV purchase price (of $ 35,000), a "medium" vehicle range (of 200 miles), and a "medium" gas price (of $ 3.5/gallon) forecasts that 3.1 % of total automotive sales in the US market (or approximately 465,000 units) will be made up by electric vehicles. The greatest loss of market potential is found to be due to constraint (iv), which verifies the profitability of an EV compared to a CV. Figure 4.2 underneath shows besides the results of the described scenario, also the results for the "aggressive" and the "conservative" scenario. Most important assumptions behind each scenario, as well as the set-up of the defined "purchase funnel", are shown. "Adoption barriers" are what we refer to as constraints.

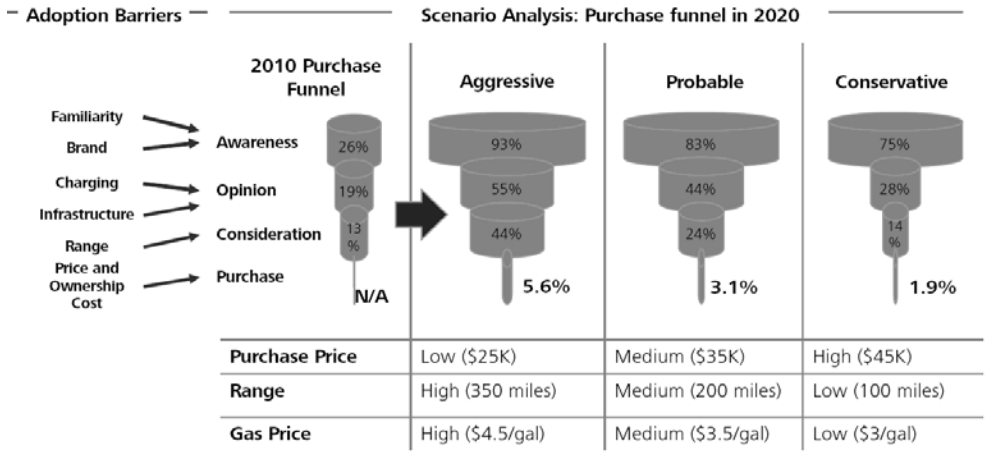


Figure 4.2: Purchase funnel analysis for 2020 market (Deloitte, 2010)

4.2.4 Discussion

In the following section all reviewed studies are discussed in the light of selected topics. First, a timeline of reviewed studies is sketched and their geographic coverage is delineated. Then, a closer look on conclusions with regards to range requirements and the impact of vehicle usage patterns is taken. Next, the definition of infrastructure constraints is analysed. Finally, an overview table

summarises the results, most unique contributions/ideas, but also main deficiencies of each study.

A brief sketch of history

Studies on EV demand applying constraints analyses date back to (at least) the 1980s. Examples of early studies are, for example, Kiselewich and Hamilton (1982) and Desphande (1984). From the 1990s onwards, realistic assumptions on the specifications of the then future EV models were taken. Range limitations and costs are approximately in line with what can be found on today's EV market (e.g. Nesbitt et al., 1992; Kurani et al., 1994, 1996). Results of these studies can serve as valid comparisons with recent studies. However, changing framework conditions over time, such as vehicle ownership rates, housing situations, income levels, or demographics, as well as changes in the specifications of EV models have to be considered when applying the results of older studies onto today's EV market. Nesbitt et al. (1992) is the oldest reviewed constraint analysis that also takes recharge infrastructure issues into account. However, the study by Kaiser and Graver (1980) suggests that these issues had already been explored well before. Studies that *simultaneously* explore a household's potential access to recharge infrastructure *and* a household's capability to integrate a limited-range vehicle into its vehicle fleet without hampering travel needs are rare. The only identified studies that do so are Nesbitt et al. (1992) and Deloitte (2010). The reason for the limited number of studies taking such a comprehensive approach is most likely the often very limited data availability.

Geographic coverage

Reviewed studies mostly explore the US and specifically the state of California. Studies exploring regions in Europe are much more difficult to identify. Only the case of Germany seems to have been explored in more detail. One study specifically explores the case of France. Reasons for this disparity in the number of studies for different regions might again be due to data issues. Data availability appears to be more limited in Europe than in the US. We can, however, not exclude that existing studies (for whichever geographic area) were neglected in the underlying review.

Analysing travel behaviour and range requirements

Many studies take up specific issues concerning the acceptance of, and the range requirements for, limited-range vehicles. In the following the two specific topics of (i) the status of a limited-range vehicle in a households' vehicle fleet, and (ii) the importance of the range of a limited-range vehicle are elucidated. It is shown that discussions on these issues were already being held 20 years ago. Still

valid-appearing conclusions of some aged studies seem to have fallen somewhat into oblivion. Recent studies partly re-discover such old findings.

(i) *The status of a limited-range vehicle in a household's vehicle fleet.* All reviewed household-based constraint analyses restrict EV-qualifying households to households that dispose of at least two vehicles. However, neither all of these studies nor current public discussions suggest that limited-range vehicles are to be considered as the second vehicle of a household. Already the studies of Kurani et al. (1994, 1996) derive this conclusion when studying *hybrid households*. Hybrid households are willing to adapt to a limited-range vehicle in their vehicle fleet in order to benefit from the convenience of home recharging, which is "an important source of value for consumers" (Williams and Kurani, 2006), or from the potential environmental benefit of this type of vehicles. It is found that limited-range vehicles are then likely to become what is often called "first" vehicles – the vehicles that show the highest usage rate within the household's vehicle fleet. Nesbitt et al. (1992) gives an early example of a study that also recognises the possible adaptation behaviour of multi-motorised (hybrid) households. A travel behaviour constraint that implies the verification of the usage of the household's total vehicle fleet is introduced: only households that dispose of at least one vehicle that is not used to commute more than 80 miles on a daily basis qualify for a limited-range EV. Biere et al. (2009) and CGDD (2011), that also recognise the fact of multi-motorised households, ruthlessly omit all travel behaviour constraints (NB: the travel behaviour analysis of Biere et al. (2009) exclusively serves to establish the TCO of the various vehicle types), which is contestable. Further, they both state without demonstration that EVs can only serve as second vehicles. Analyses that are based on single vehicles rather than on household situations and households' vehicle fleets can only neglect the effect of multi-motorised households. Vehicles that are used for long distance trips are automatically excluded from the pool of potential EVs regardless of a household's vehicle configuration. These studies are based on empirical vehicle usage data covering different time frames with different levels of detail. Besides Greene (1985), also the recent studies of Pearre et al. (2011) and Chlond et al. (2012) follow such a debateable approach.

(ii) *The importance of range*. The importance of increasing the range of limited-range vehicles is frequently put into question. This is not solely due to the effect of multi-motorised households as discussed above. Also studies that are based on the analysis of single vehicles seem to justify the scepticism about actual range requirements. Greene (1985) finds "substantial potential market…for vehicles with ranges in the order of 100 miles." Nesbitt et al. (1992) concludes that "driving range, beyond a relatively short distance, is

largely irrelevant to whether people could use a [limited-range] EV on a daily basis", and states that these findings are in line with Desphande (1984) and Kiselewich and Hamilton (1982). Kurani et al. (1994) find that "only in households in which each driver made highly autonomous auto purchase and use decisions did desires for unlimited-range prevail over the practical reality of how and where the household actually travels." Kurani et al. (1996) then details that "any disutility of reduced range is more than offset by the value of home recharging…and possibly zero emissions", and concludes that "So long as the belief persists that EVs must mimic the long range and short refuelling times of gasoline cars, the EV market will be stalled", as well as, "Failure to recognise the market for truly reduced range EVs will unnecessarily delay the introduction of EVs and possibly lock us into an unnecessarily expensive future." Pearre et al. (2011) confirm this impression by concluding that "segmenting vehicle buyers by range needs appears to be a more cost-effective way to introduce electric vehicles than assuming that all vehicle buyers…need currently-expensive large batteries". Also Williams and Kurani (2006) find that the daily range requirements of most Californians are more than met by 200-mile range capabilities. Nesbitt (1992), Kurani (1994) and, moreover, Williams and Kurani (2006) do not neglect the frequently observed differences between *range requirements*, *perceived range requirements* and, most importantly, *range wants* of vehicle owners. Especially mono-motorised households are expected to mostly retain the need for an "unlimited" range vehicle with short refuelling times that satisfy travel desires which lie outside the routine activity space. Deloitte (2010) finds that almost 80 % of vehicle owners expect a minimum range of 300 miles before considering the purchase of an EV – a finding that is in line with numerous other stated preference studies. The contradictory results of these studies with, for example, Kurani (1994, 1996) show the impact of informing and educating households before questioning hypothetical choices.

Exploring a household's infrastructure

The importance of exploring a household's infrastructure with regards to parking infrastructure and the possibility of installing recharge infrastructure is especially recognised in more recent studies. Where data availability allows, private parking infrastructure can be readily studied (see, e.g. Nesbitt et al., 1992; Biere et al., 2009; CGDD, 2011; Deloitte, 2010). Exploring the possibility of connecting an EV to the electricity grid is usually much less straightforward. None of the reviewed studies appears to have access to readily available information on such household data describing the specifications of a parking unit. Hypotheses are frequently proposed for the circumstances under which a household is likely to be capable and willing to install recharge infrastructure at

its parking facility. Williams and Kurani (2006) give an example that defines quite elaborate constraints. It is argued that only those consumers that (i) own their residence, (ii) have access to a parking close to their residence, and (iii) reside in a building structure which is supportive of necessary installations are likely to make the effort to equip their parking with recharge infrastructure. Nesbitt et al. (1992) restricts potential EV-owners to homeowners also owning a garage or carport. Biere et al. (2009) verify the availability of a parking space in a garage or "at home". Campbell et al. (2012) constrain EV-qualifying households to homeowners that live in detached or semi-detached homes. More explicit information on the parking availability does not seem to be available. CGDD (2011) does not define any constraints other than the access to a private parking infrastructure.

The constraint of homeownership in order to verify the possibility of installing recharge infrastructure appears most frequently in reviewed studies. The lack of data does usually not allow specifying any more explicit constraints that analyse whether parking units can be equipped with recharge infrastructure. This observation is valid for all reviewed studies.

Analysing target households

Reviewed analyses also partly explore the characteristics of target households (potential EV households) and compare them to those of the total household population of the region in question. Often, these characteristics are correlated with the definition of constraints. Nesbitt et al. (1992), for example, find that "the potential EV market is wealthier than the general population of American households….". "This comes as no surprise, given that [the] potential EV market is made up of households that own their residence and have more than one vehicle available." They also find that households entirely composed of retirement-age individuals are underrepresented in the target market. Williams and Kurani (2006) show that the household income distribution for the target group leans toward higher incomes, that the target group has a higher average level of education, and that the target group's age distribution tends to be in the 35-55-year range relative to the whole population. Also here, the definition of constraints suggests these findings. An analysis of the identified potential EV households by Kurani et al. (1996) shows that the initial EV market is not necessarily constituted by individuals or households showing pro-environmental values or specific lifestyle choices. Further, "no statistically significant relationships between vehicle choices and households' commute trip distances, longest weekly trips, or distances to critical destinations" are found. Chlond et al. (2012) find that EV-qualifying cars mainly belong to either retired people's households that own only one car, or working households that own two or more cars. Again, the definition of applied constraints that identify cars with low mileage as EV-qualifying vehicles, suggests these results. Moreover, the first

finding is in contrast with findings of Williams and Kurani (2009) and Campbell et al. (2012). The latter study, even *ex ante,* excludes higher age groups by defining only 25-59-year-old individuals as potential EV-owners, and further limits any potential EV owners to individuals with higher education and a "higher professional" or "lower managerial and professional" socio-economic status. The contradictory findings suggest that the definition of constraints allowing only specific age groups to enter into the pool of potential EV households is contestable. Constraints referring to the income, education or socio-economic status of individuals most often suppose that (i) EVs inevitably have higher purchase and/or vehicle usage costs, and that (ii) only higher income individuals (who, in case information on income is not available, are identified either by their level of education, or by their socio-economic status) are likely to acquire EVs. As the results of Chapter 3 suggest, this definition of an economic constraint leaves significant room for improvement: a more holistic TCO approach appears to be more meaningful.

4.2.5 Conclusions

On the significance of constraints analyses

Numerous aspects of vehicle choice behaviour cannot be considered in constraints analyses. These aspects mainly refer to individual tastes and preferences that contribute to the complexity of actual choice behaviour. Especially matters such as vehicle appearance and status, vehicle performance, perceived risk/confidence in a brand, advice from friends or dealers, vehicle comfort etc., often play a decisive role in vehicle choice behaviour. Leaving all these aspects aside, certainty about the actual EV potential cannot be obtained. Out of the reviewed studies, only Kurani et al. (1994 and 1996) propose an extensive methodology that takes preferences and tastes into account. Here, a database that goes beyond any readily available empirical data source is established in a laborious way.

It is arguable that basing an analysis on the potential EV market on empirical data that solely describes easily observable household and vehicle usage characteristics will necessarily lead to an overestimation of EV demand. Tastes and habits that often determine the acquisition of a CV are omitted. Further, the discussion on the range of limited-range vehicles showed that range *wants* often significantly differ from range *requirements*. Even the analysis of observable and well-stated household features, such as travel behaviour and vehicle usage patterns, does not necessarily allow for a reliable conclusion on potential EV demand. The fact that a vehicle that *could* be bought is often far from actually *being* bought certainly limits the validity of constraints analyses.

On the other hand, as Williams and Kurani (2006) recognise, constraints analyses based on typically available empirical data can neither account for the

convenience of home recharging nor for the potential environmental benefit of EVs that are likely sources of value for many households. The fact that households actually prefer limited-range vehicles to CVs due to their specific features is ignored. This might result in an underestimation of potential demand.

One could conclude from this likely simultaneous over- and underestimation of potential EV demand that actual demand will, in fact, be well predicted by constraints analyses. This assumption seems to be somewhat of an oversimplification. We argue that reviewed literature does demonstrate that constraints analyses are a powerful approach to identify potential private vehicle purchasers from a *practical and technical* perspective. Households that conform to EVs' needs and limitations can be identified and can be assumed to constitute the pool of first EV-purchasers. For this reason, constraints analyses can give valuable information for subsequent stated preference surveys with regards to the selection of survey respondents. Further, interesting conclusions for national and regional policy makers, marketing experts and vehicle designers can be obtained. The reliability and meaningfulness of such conclusions will mainly depend on the data availability and the definition of household selection criteria. However, conclusions about potential EV demand should be made with caution.

Results of the studies shown here should be used with caution as they frequently refer to hypothetical, future EV models that were not on the market when the studies were carried out (e.g. Kurani et al., 1994, 1996; Biere et al., 2009). For this reason, price information and/or vehicle characteristics of these vehicles are not necessarily in line with what can be observed on the French market as of 2012.

On surmountable shortcomings

As discussed above, constraints analyses based on empirical household and vehicle usage data comes with certain deficiencies. One apparent shortcoming that does *not* necessarily come with the application of such constraints analyses refers to the definition of an economic constraint. The idea behind the economic constraint definition is to verify if a household is – from a financial viewpoint – actually likely to purchase an EV. Very few of the reviewed studies recognise that this aspect can be explored at all in a constraints analysis. Examples of such studies are Campbell et al. (2012) and Nesbitt et al. (1992). They make the rather brusque supposition that only households with higher incomes are likely EV purchasers.

	Study	Data	Area	Results	Methodology: Unique contribution	Methodology: Main deficiency	
Travel behaviour studies	Greene (1985)	Refuelling behaviour of 2,000 vehicles	U.S.	100-mile-vehicles can replace 20-50 % of household vehicles	Avoidance of single-day travel diaries	Analysis of single vehicles rather than the household fleet	No infrastructure constraints
	Pearre *et al.* (2011)	GPS data of 484 vehicles for 1-3 years	Atlanta, U.S.	9 % of vehicles never exceed 100 miles per day	Impact analysis of possible household adaptations to limited-range vehicles	as above (effect of multi-motorised households is acknowledged)	
	Kurani *et al.* (1994)	Interview data of 51 multi-car households	California, U.S.	29 households can incorporate a limited-range vehicle without making any adaptations	Consumer preferences are accounted for	Analysis based on very small data base	
	Kurani *et al.* (1996)	Mail survey data of 454 households	California, U.S.	150-mile vehicles going to *hybrid households* make up 7-18 % of the annual light duty vehicle sales	Consumer preferences are accounted for	-	
	Chlond *et al.* (2012)	1-week travel diaries of 1,000 households per year	Germany	7.5% of reported vehicles qualify for an BEV	Analysis of characterstics of EV-qualifying households	Analysis of single vehicles rather than the household fleet; defined constraints naturally exclude high-usage vehicles	
Studies (also) exploring access to recharge infra.	Williams and Kurani (2006)	Microdata sample of the 2,000 U.S. census (339,000 individuals)	California, U.S.	15 % of all Californians live in households pre-adapted to 'mobile-energy' vehicles	Constraints verifying possibility of installing recharge infrastructure; detailed analysis of characteristics of found target group	-	No travel behaviour constraints
	Biere *et al.* (2009)	Disaggregate data of 26,000 households in 2002	Germany	In 2020, 12 % of vehicles could potentially be replaced by small city BEVs	Detailed economic constraint based on TCO	Aggregation of disaggregate data to 'user groups' - loss of disaggregate household characteristics	
	CGDD (2011)	Disaggregate data of 20,000 households	France	20 % (69 %) of total private vehicle fleet could be replaced by BEVs (PHEVs)	-	-	
	Campbell *et al.* (2012)	Census data of the year 2001	Birmingham, UK	The areas with the highest density of likely early adopters are identified	Constraints verifying specific characteristics of individuals (e.g., age, education)	Definition of constraints on characteristics of individuals questionable	
	Nesbitt *et al.* (1992)	Household and commuting data of 53,500 households	U.S.	30 % of US households qualify for a BEV	Constraint verifying parking availability; sensitivity analysis of constraints	(Additional) income constraint solely based on up-front costs rather than on ownership costs of the vehicle	
	Deloitte (2010)	Interview data with 2,000 car owners	U.S.	In 2020, 3.1 % of total automotive sales constituted by BEVs	Economic constraint; constraint verifying the EV-awareness of vehicle holders	Study (partly) based on stated preference questions rather than on empirical evidence	

Table 4.1: Overview of reviewed constraints analyses

Results in Chapter 3 reveal that total cost of ownership (TCO) for current EV models does not necessarily surpass the TCOs of its conventional counterpart. Basing a constraint on the household's income level therefore seems highly contestable. It appears to be more plausible to introduce a criterion that checks on the profitability of an EV for a given household by applying a TCO approach as described in Chapter 3. This is likely to result in a more reliable and better-founded forecast of potential EV demand – also if all uncertainties of and hypothesis behind such an approach are not to be neglected. Biere et al. (2009) is the only identified study that incorporates a TCO perspective in its constraints analysis. A very detailed and well-found TCO calculation is carried out. It forms the basis of the economic constraint that contributes to the identification of potential EV households.

4.3 Definition of the constraints analysis

4.3.1 Methodology

Based on previous findings and the insights gained from the literature review, we argue that the condition under which private households potentially create EV demand is fourfold: (i) the household already owns at least one vehicle, (ii) the household can cost-effectively install appropriate EV recharge infrastructure, (iii) the replacement of a household's vehicle by an EV does not interfere with the household's mobility needs, and (iv) the overall economic equation, which is heavily influenced by purchase prices, the household's vehicle usage patterns, policy measures, and economic framework conditions, makes the acquisition of an EV more profitable to a private household than the acquisition of a CV.

Based on the French national transport survey (the Enquete Nationale Transports et Deplacements 2007-2008, or ENTD 2007/08) household selection criteria (or "constraints") are defined. Only households that comply with an EV-type and household-type-specific set of constraints are considered as EV-qualifying. They are seen to be among the first potential customers of EVs as their characteristics allow them to replace (one of) their vehicle(s) with an EV.[63] It should be kept in mind that the definition of constraints verifying the fourfold condition is limited to the given data availability. Certain assumptions have to be made when defining the set of criteria as presented hereafter.

[63] The market potential for EVs thanks to households that decide to acquire an EV as addition to their already existing vehicle fleet is not specifically explored. It is considered to be of only secondary importance.

The specification of EV-type- and household-type-specific sets of constraints is inevitable. This is due to two reasons: First, the different types of EVs analysed in this study, namely battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) show different specifications with regards to their range limitations, as well as with regards to their purchase prices and usage costs. This has to be accounted for when verifying if a household's mobility needs can be met by the selected vehicle type and when analysing the economics of an EV or a CV. Second, as the literature review revealed, members of multi-motorised households largely show the ability to adapt their behaviour to a limited-range vehicle within their fleet. Differentiation of the set of criteria with regards to mono- and multi-motorised households is necessary.

In the following, an overview of the national transport survey (ENTD) will be given first (4.3.2). Next, the definition of the criteria catalogue (the set of household selection criteria, or constraints) is explained (4.3.3). The section is structured in four parts, each part referring to one of the above-introduced conditions that need to be met by households in order to qualify for an EV. All necessary assumptions that are due to the given data availability are elucidated. The last section (4.3.4) gives an overview of the defined set of criteria.

4.3.2 The French National Transport Survey

Overview

The French National Transport Survey (the ENTD) is carried out every 10 years by the French Ministry of Transport and INSEE (The National Institute of Statistics and Economic Studies). The objective of the survey is to gain insight in and understanding of households' transport and travel choices. Besides information on regular, local and long-distance trips, details on households' vehicle equipment and accessibility to public transport are collected. The 2007-2008 survey edition was carried out between April 2007 and April 2008. Data collection was carried out in 6 waves in order to take account of seasonal variability in mobility behaviour. (Setra, 2008)

Survey content

Given the length of the survey, each household was surveyed in two instances. This allowed the distribution of a "carnet véhicule" (a vehicle diary) during the first visit that was then collected during the second visit. The vehicle diary served for registering all trips that were made with the same vehicle during the period of one week. The first visit and the second visit were organised with a time lag of at least 7 days. (Setra, 2008) During the first visit information on the following attributes was collected:

- The household's composition (e.g. household members, income, members' professions, members' level of education)
- The number of its vehicles by type (e.g. cars, motorcycles, bikes)
- Vehicle characteristics and vehicle usage
- Housing (e.g. costs, parking)
- Regular trips (e.g. home-work, home-school) and mobility habits

During the second visit information on the following was collected:

- Local mobility habits (all trips of two selected days of the week preceding the second visit)
- Attitudes towards road security
- Long distance trips during a selected time period for a single selected household member or several selected household members
- Household members' state of health

Number of surveyed households

The following table gives information on (i) the number of surveyed households, (ii) the number of actually existing households in 2008 (according to INSEE, 2011a) and (iii) the derived per mille of surveyed households compared to the actual number of households. Further, the table also shows (iv) the sum of weighted households (applying the weights per household as given in the ENTD) and (v) the deviation of the sum of weighted households to the actual number of households (in %). All these values are shown for the whole of France and, more specifically, for the main study area of this work, the IDF (Île-de-France) region. Here, the same differentiation is made as already motivated in Chapter 3 (Section 3.2.3).

Since the smallest retractable geographic scale of a household's location is a French district ("department"), more precise indications on a household's location are not possible. Nevertheless, a variable reveals the type of the urban setting of a household's location.

	# surveyed HHs	# HHs (INSEE, 2008)	‰ surveyed	Σ weighted HHs	Deviation to # HHs in %
France	**20,178**	**27,270,707**	**0.74**	**26,625,086**	**2.4**
Ile-de-France	5,887	4,897,765	1.20	4,971,010	-1.5
Paris	*1,118*	1,148,845	0.97	1,163,041	-1.2
Petite Couronne	*1,973*	1,809,102	1.09	1,843,461	-1.9
Grande Couronne	*2,796*	1,939,818	1.44	1,964,507	-1.3

HH – household; Source: ENTD 2007/08

Table 4.2: Number of surveyed and total households per area

Table 4.2 shows that the per-mille of households that were surveyed varies across the geographic areas in question. This over- (or, respectively under-) representation of households of certain areas impedes a valid aggregation of

results on national or regional scale (as the IDF region). Further, an over-representation of multi-motorised households and households in the rural area is identified (Setra, 2008). Due to these inconsistencies in data collection, all following analyses are based on weighted households according to the ENTD. The sum of weighted households per area and the deviation of these sums to the actual number of households in % (both given in Table 4.2) show that weighted households reflect the actual number of households well when regarding the whole of France or the IDF region. Slight deviations might be due to a change in the actual number of households during 2007-2008.

4.3.3 Defining constraints

This section serves to explicate the definition of criteria that verify if the 4-fold condition as described in Section 4.3.1 is met by a household in question. Figures explore the repartition of households in the light of the discussed criterion. This allows obtaining an idea of the impact of a defined household selection criterion on the potential number of EV-qualifying households.

It is to be kept in mind that a household has to comply with a whole set of selection criteria before entering the pool of EV-qualifying households. In the following, when describing a single selection criterion, a household is named a *potential* EV-qualifying household when complying with the constraint in question. The same household becomes an actual EV-qualifying household in case it also complies with all other constraints of the *set* of criteria specific to the household's level of motorisation and to the explored EV type (BEV or PHEV).

(i) Vehicle ownership criterion

The first selection criterion verifying whether a household is a potential EV-qualifying household is the *vehicle ownership criterion*. It checks if a household is already in the possession of at least one vehicle. The assumption is made that only households already owning at least one private vehicle will be likely to purchase an EV. This criterion definition is in contrast to all reviewed studies that consider only multi-motorised households (households with two or more vehicles) as potential EV households. Given the fact that also non-motorised households, or households that decide to complete their already existing fleet with an EV, can constitute a potential EV market, we argue that the inclusion of mono-motorised (besides multi-motorised) households in the analysis leads to more reliable results. In contrast to multi-motorised households, mono-motorised households are subject to a more stringent set of vehicle usage criteria (as described in the following).

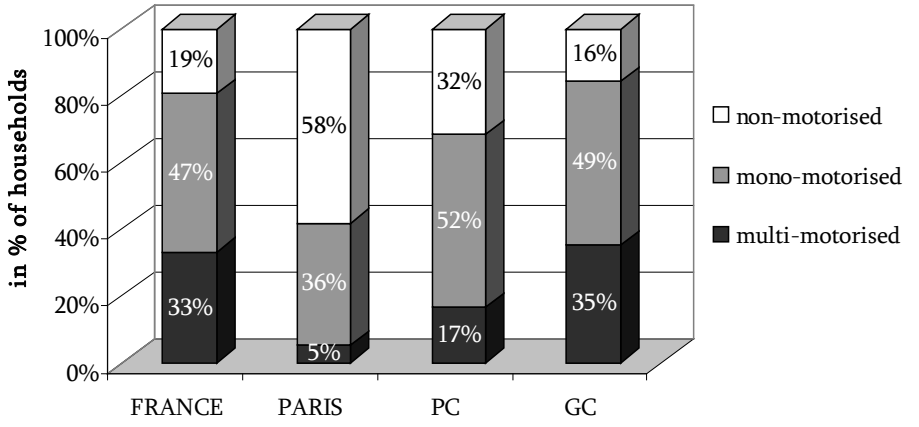
For completeness, Table 4.3 shows the vehicle ownership criterion. There is no application condition to this criterion – it is applied to all households analysed in the study.

Criterion #	Description	Application condition
1	HH is motorised	none (applied to all HHs)

HH - household

Table 4.3: Vehicle ownership criterion

Figure 4.3 depicts vehicle ownership rates in France and, more specifically, for the main study area of our analysis (Paris, the Grande Couronne (GC), and the Petite Couronne (PC)). Paris shows by far the lowest vehicle ownership rate. Only 5 % of households are multi-motorised. The ownership rates increase in the PC and GC areas. It can also be noticed that the values for the GC area resemble the ones for the whole of France.



Source: ENTD 2007/08

Figure 4.3: Motorisation of households in France

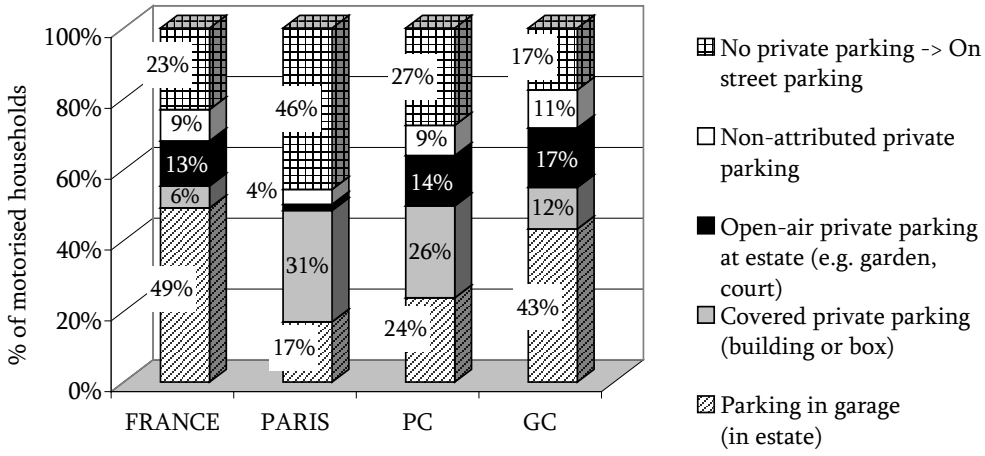
(ii) Infrastructure criteria

The motivation for defining infrastructure criteria comes from the fact that EV batteries need to be recharged. Since public recharge infrastructure is (for the time being) neither readily nor sufficiently available for assuring convenient overnight battery charging, the acquisition of an EV comes with the need of private recharge infrastructure at home. This entails the access to a private parking space where such recharge infrastructure can be installed. The installation of such infrastructure will frequently be – certainly so in the upcoming years – the responsibility of and to the costs of the households themselves.

The objective of defining infrastructure criteria lies in identifying households that are potentially willing and capable of installing such

infrastructure at their private parking unit in the most reliable way given the data availability of the ENTD.[64]

Private parking at home. The first infrastructure criterion verifies if a household has access to a privately owned or rented parking facility with exclusive usage rights[65] at his residence. The following figure gives information on the availability of private parking spaces of motorised households per selected geographic region. An impression of the categorisation of parking facilities as defined in the ENTD 2007/08 can be gained.



Source: ENTD 2007/08

Figure 4.4: Private parking availability per type and region

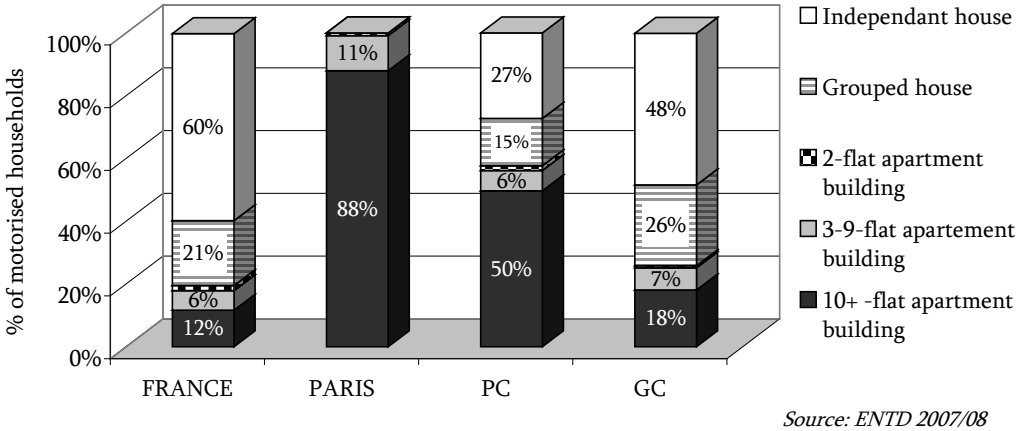
The figure shows that the parking situation in Paris is more precarious than in the PC or the GC area. Decreasing population densities come along with increasingly accessible covered or open-air private parking facilities. 46 % of motorised households in Paris need to park their vehicle(s) on street. In the GC area, almost the same percentage of motorised households can park their vehicle in their garage. The repartition of parking facilities in the whole of France resembles the GC area the most. However, the parking situation in the GC seems to be slightly more constrained than that on the national average. The private parking criterion determines that only households that have access to either 'open-air private parking at the estate', 'covered private parking', or

[64] Thanks to the French national development plan for clean vehicles (MEDDE, 2010), which renders the installation of electricity outlets at parking spaces of new dwellings obligatory since 2012, an increasing number of households will have access to private recharge infrastructure in the future. In the course of 2012 the number of households for which this is already the case can be neglected.

[65] meaning that the parking is 'attributed' and not 'non-attributed' to a specific household (as defined in the ENTD 2007/08)

'parking in a garage' qualify as potential EV households. The case that households might decide to specifically rent a parking space (that is either already equipped with recharge infrastructure or, more likely, to be equipped with recharge infrastructure) in order to appropriately park and recharge an EV is, in theory, imaginable. Nevertheless, such households are excluded from the analysis given that an economic advantage in terms of TCO of an EV will be very unlikely for such households (see results of the scenario analyses of Chapter 3). Vehicle purchasers without private parking facilities are expected to refrain from an EV purchase.

Recharge infrastructure installation at private parking. The second infrastructure criterion verifies if a household can install recharge infrastructure at his private parking facility. The ENTD 2007-2008 asked its interviewees to state whether there is an electricity outlet "in the proximity of" the household's private parking facility. An explicit definition of the term "proximity" was not given though. In view of this ambiguity of the term, it is decided not to use this information for defining the recharge infrastructure criterion. Alternatively, the information on the housing type is used for an approximation of whether or not a household is likely to install recharge infrastructure. Before the exact definition of the criterion is given, the following figure shows the housing situation in the specified study area. It can be seen that basically all motorised households in the city of Paris reside in apartment buildings with 3 or more flats. This percentage drops to 56 % in the PC area and to 25 % in the GC area. In the whole of France such households make up 18 % of the motorised household population. On this national level the independent housing is dominant.



Source: ENTD 2007/08

Figure 4.5: Housing type per region

The recharge infrastructure criterion constrains EV-qualifying households to households that reside in either independent or grouped houses (with *any* type of attributed, private parking facility), or apartment buildings that have access to

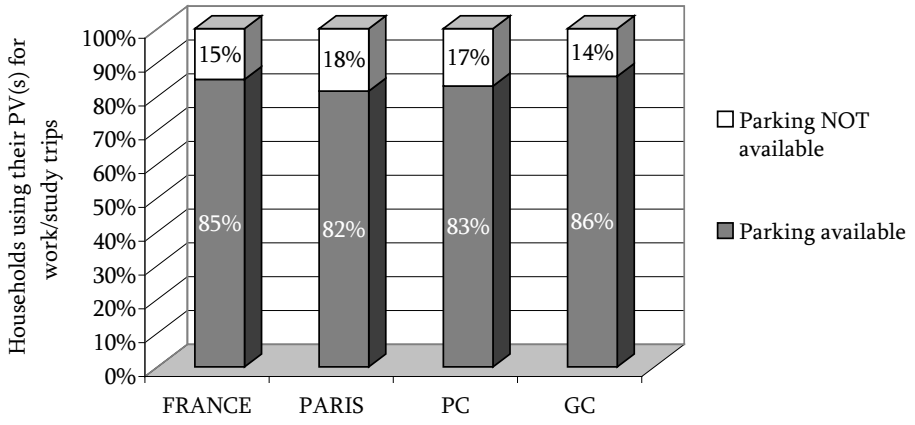
covered parking (in a building, box, or garage). It is assumed that private parking places that conform to these configurations are in a close-enough distance to an electricity outlet that allows a recharge infrastructure installation with sufficient ease.

It is decided that not only homeowners, but also home tenants are potential EV-qualifying households. This is in contrast to what has been found in literature. The motivation behind this decision is twofold. First, the information on whether households own their residence does not necessarily reveal whether a household also owns its parking facility. This latter information would, however, be the more reliable one for indicating whether the installation of recharge infrastructure by a household is likely or not. Second, also households that rent parking spaces might decide to install infrastructure at their own cost in case an overall financial advantage of the acquisition of an EV (entailing the installation of infrastructure) over the one of a comparable CV can be achieved. The economic criterion, which is introduced later in this section, assesses if such an advantage is likely for a given household. A preliminary exclusion of these households due to the ownership status of their residence does not seem appropriate. It is also important to mention that within the upcoming years the administrative procedures necessary for obtaining the permission for recharge infrastructure installations at co-owned or rented property will progressively be facilitated. The "right for a socket" ("la droit à la prise") defined in an official decree released in July 2011[66] be here only mentioned. For a more detailed discussion on the juridical aspects of recharge infrastructure installations in France see Sadeghian et al. (2012). In the light of decreasing juridical hurdles and installation costs, that do not necessarily render the overall EV acquisition unprofitable, the decision of not categorically excluding home (and parking infrastructure) tenants from potential EV purchasers appears to be justified.

Parking at work. This household selection criterion verifies if parking facilities are available at the destination of frequent trips (as, e.g. trips to work, to university or school) in case a household's vehicle is used for this type of trips. At least one of the vehicles that are found to be used for such trips is required to have access to a parking facility at the destination. In case there are no vehicles in a household's vehicle fleet that are used for this type of trips, the household is directly selected as potential EV-household. The motivation for this criterion comes from the assumption that the access to parking facilities at such destinations will be reassuring for an EV user. The energy consumption for the trip can be more reliably forecasted; no uncertainty with regards to possible cruising in the search of a parking space has to be taken into account. Further,

[66] Décret n 2011-873 of 25 July 2011 with regards to installations dedicated to the charging of electric and plug-in hybrid electric vehicles

assuming that parking places at destinations such as work will increasingly be equipped with recharge infrastructure, the vehicle user is in the position to recharge his vehicle during the day if necessary. This reassurance might render an EV purchase more likely. The following figure reveals that this seemingly restrictive criterion does, in fact, not exclude many households from the pool of EV-qualifying households. Only 14 – 18 % of households that use their vehicle(s) for the defined trips do not have access to parking at the destination. Since this criterion is in relation to range anxiety that comes with limited-range vehicles, the criterion is not applied when exploring the potential for PHEVs.



Source: ENTD 2007/08

Figure 4.6: Parking availability at the place of destination of regular, frequent trips (in % of households using their private vehicle(s) for such trips)

The following table gives an overview of the set of defined infrastructure criteria and reminds the application conditions of each criterion.

Criterion	Description	Application Condition
2	HH has access to private, attributed home-parking	none (applied to all HHs)
3	HH is likely to be willing to and capable of installing recharge	none (applied to all HHs)
4	At least one of the HH's vehicles used for frequent trips can be parked at the destination	Only applied to HHs that carry out frequent trips with their private vehicle; only applied when exploring BEV demand

Table 4.4: Summarising the set of infrastructure criteria

(iii) Vehicle usage criteria

The motivation behind the definition of selection criteria with regards to vehicle usage is to identify households for which the limited range of a BEV does not interfere with the travel needs of the households' members. Since the

range of the PHEV is not necessarily inferior to the one of a CV, vehicle usage criteria are only applied if investigating the number of BEV-qualifying households. Currently announced autonomies of BEVs are in the range of 120-200 km. These values have to be taken with caution. Electricity consumption heavily depends on the auxiliary energy usage of the vehicle (for heating, lighting etc.) as well as on driving styles, usage areas, and the efficiency of regenerative braking.

The general assumption behind the definition of vehicle usage criteria is that only those (multi-) mono-motorised households that do not use (all of) their vehicle(s) for trips exceeding 120 km are likely to consider the replacement of (one of) their vehicle(s) by a BEV. Trips of up to 120 km lie within the range of most announced BEV models that are to be launched (or have recently been launched) on the French market.[67]

Further, the hybrid household hypothesis, as introduced in Section 4.2.2, is applied. The hypothesis postulates that multi-motorised households disposing of vehicles with different propulsion systems are willing to adapt their vehicle usage behaviour in order to make the most of the benefits of each vehicle type. Hybrid households considerately choose the vehicle which fits the needs of a certain trip the best. The value of home recharging of EVs is acknowledged, and limited-range vehicles are usually easily integrated in the household's fleet. The defined vehicle usage criteria are only applied to mono-motorised households that do not have the option to fall back onto an "unlimited"-range vehicle in case their only vehicle is replaced by a BEV. The only exception is the first criterion, which is described hereafter.

The definition of vehicle usage criteria is restrained to the data availability of the ENTD. We refrain from using trip diaries since these only register the vehicle usage behaviour during the very limited period of a single week. Alternatively, it is tried to find more generally valid indications on whether the use of a current household's vehicle is conform to the range limitations of a BEV.

Return-trips to frequent destinations (e.g. to the place of work). The first vehicle usage criterion verifies if trips to frequent destinations lie within the range of a BEV. More explicitly, it is defined that the sum of daily return-trips is to lie within the range of 120 km. This way it is verified that, e.g. also employees who return home for lunch and carry out the return-journey home-work-home twice a day do not run into range problems. In case of multi-motorised households, at least one vehicle of the household's fleet has to comply with the defined criterion. Only this way can a household enter the pool of EV-qualifying households.

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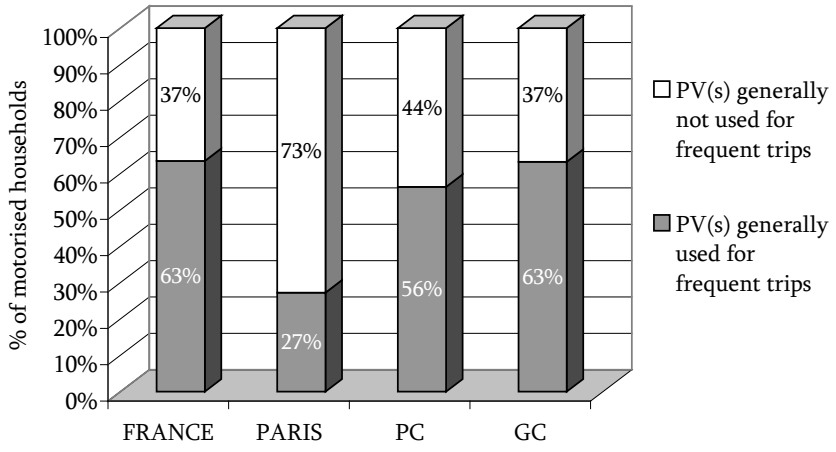
[67] See, e.g., the specification of Renault's BEV models as given in chapter 3.

Figure 4.7 gives information on the percentage of motorised households that use at least one of their vehicles for trips to frequent destinations, such as to work. Figure 4.8 shows then the repartition of these households with regards to potential range problems. In case of multi-motorised households, range problems are faced if *all* of a household's vehicles are used for trips lying outside the defined critical range.

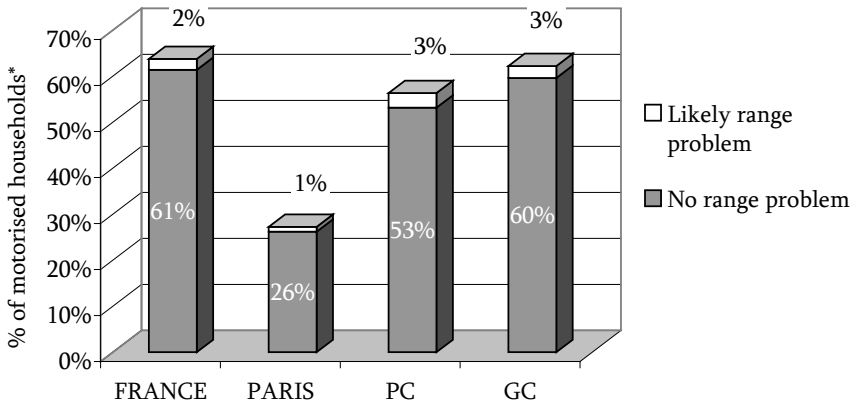
In the city of Paris, altogether 27 % of motorised households use their vehicle(s) for the same frequent trips. On the national level this percentage raises to 63 %, which equals the one of the GC area.



**All shown households have at least one member that uses a household's vehicle for trips to a frequent destination*

Source: ENTD 2007/08

Figure 4.7: Motorised households' vehicle usage for recurrent destinations per region (PV-private vehicle)



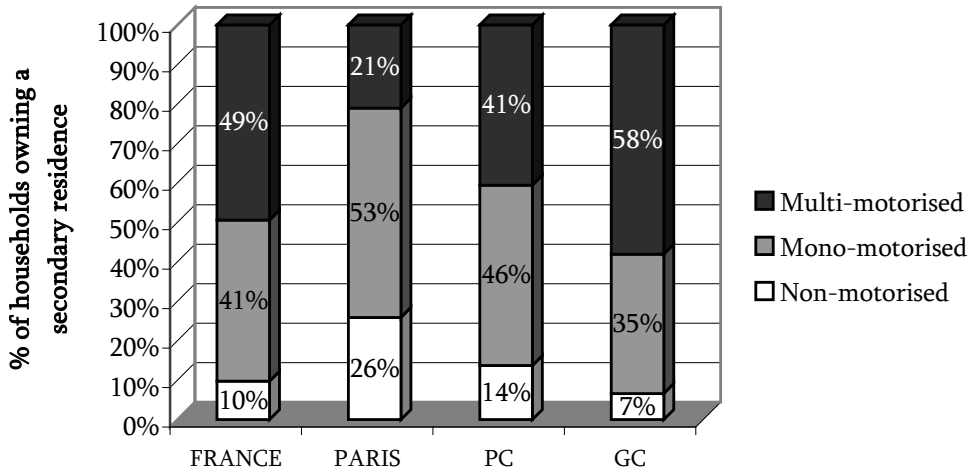
**All shown households have at least one member that uses a household's vehicle for trips to a frequent destination*

Source: ENTD 2007/08

Figure 4.8: Motorised households potentially confronted with range problems with regards to a recurrent destination (PV-private vehicle)

Figure 4.8 shows that the percentage of households that would actually face range problems in case (one of) their vehicle(s) was to be replaced by a BEV is very low in all areas. The reduction of the number of potential EV-qualifying households due to this criterion is expected to be low.

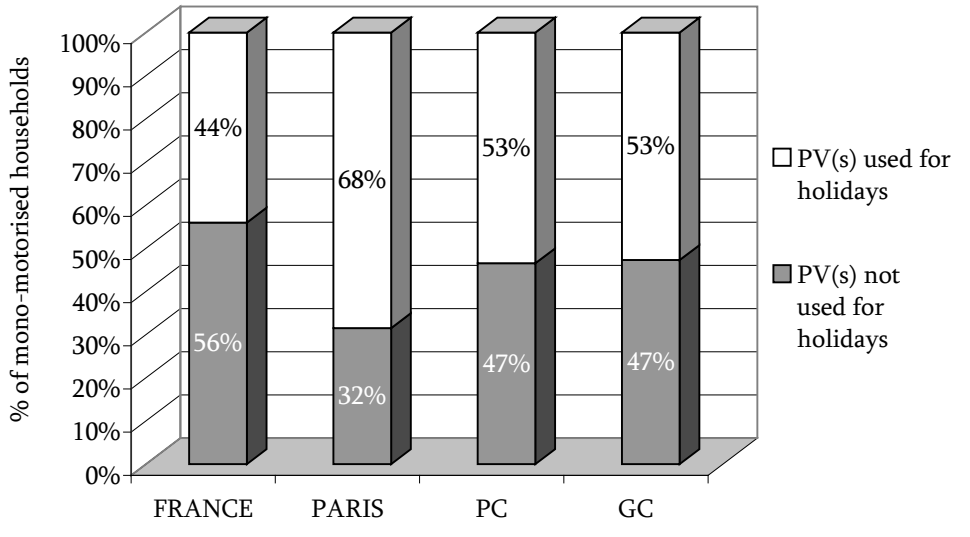
Trips to secondary/occasional residences. The ENTD 2007-2008 gives information on the existence of secondary residences (also "holiday residences") and occasional residences, their location, and the transport mode used by household members to get to them. The defined selection criterion verifies if one-way trips to this type of residences lie within a 120 km distance of the primary residence. Since neither the exact location of a household's residences nor the exact distance between these is known, the range requirement is estimated. For this purpose, we calculate the average distance between the districts (the French departments) where the residences in question are located. The ENTD 2007-2008 reveals that (i) 19 % (11 % | 9 %) of motorised households in Paris (the PC | the GC) own a *secondary* residence and face range problems when using their private vehicle to get there, and (ii) 0.2 % (0.1 % | 0.8 %) of motorised households in Paris (the PC | the GC) own an *occasional* residence and face range problems when using their private vehicle to get there. The numbers of the national average resemble the numbers of the GC area. The much lower found percentages with regards to occasional residences stem from the fact that much fewer households dispose of occasional residences than of secondary residences. Paris shows with 35 % the highest percentage of motorised households that own a secondary residence (compared to 15 % in the GC area). For occasional residences, these percentages lie in the range of 2-4 %. The defined household selection criterion is only applied to mono-motorised households, hereby making the assumption that hybrid households fall back on their conventional vehicle(s) in case the trip length lies outside the BEV range (as postulated by the hybrid household hypothesis). The following figure gives information on the motorisation rates of households disposing of a secondary residence. It can be seen that the motorisation rates of such households varies with the residential zone.



Source: ENTD 2007/08

Figure 4.9: Motorisation rate of households with secondary residences

Holiday trips. A criterion with regards to holiday trips determines that mono-motorised households that use their vehicle for holiday purposes are excluded from the pool of potential BEV-households. Also here, the hybrid household hypothesis is applied. Multi-motorised vehicles are not concerned by the selection criterion.



Source: ENTD 2007/08

Figure 4.10: Motorised households' vehicle usage for holiday trips (PV – private vehicle)

Figure 4.10 reveals that around 50 % of mono-motorised households used their vehicles for holiday trips in the investigated year of the underlying survey. The percentage for France lies above the ones for the PC and GC areas. Only in Paris, mono-motorised households appear to use their vehicle significantly less

for holiday trips. Given these generally rather high percentages, it can be expected that the number of mono-motorised EV-qualifying households drops significantly due to this criterion.

The following table gives an overview of the defined set of vehicle usage criteria and reminds the application conditions of each criterion.

Criterion #	Description	Application Condition
5	Return trips to frequent destination of at least one of the HH's vehicles within BEV range	Only applied to HHs that carry out these trips with their private vehicle; only applied when exploring BEV demand
6	Trips between home and secondary/occasional residence within BEV range	
7	Private vehicle is not used for holiday purposes	Only applied when exploring BEV demand

Table 4.5: Summarising the set of vehicle usage criteria

(iv) Economic criterion

The economic criterion verifies if the acquisition of an EV is economically more advantageous than the acquisition of a CV. It is assumed that only households for which this is the case are likely to equip themselves with an EV. The economic advantage is verified by applying the TCO model as introduced in Chapter 3. The model calculates vehicle purchase and usage costs throughout the whole ownership period of the vehicle. TCO calculations are largely based on the reference scenario as introduced in Chapter 3 (Section 3.3.1). Household-specific parameter values only then differ from the reference scenario in case actual values can be retrieved from the ENTD 2007-2008. This way not only the verification of the above introduced selection criteria, but also the calculation of TCO that serve as basis for the last constraint is carried out on a disaggregate, household basis. The information retrieved from the ENTD that serves TCO calculations refers to:

- the *residential zone of the household in question,* assuming that it remains the same over the ownership period of the vehicle;
- the *annual driven distance of the vehicle that is to be replaced,* assuming that the new vehicle will be used in a similar way over the vehicle's ownership period. NB: In case of multi-motorised households, the assumption is made that the vehicle to be replaced is the one that shows the highest annual driven distance (in case information on more than one vehicle is available); further, we assume

that the annual vehicle usage does not change with the event of vehicle replacement[68];

- the *vehicle type of the vehicle that is to be replaced*, assuming that the household in question replaces its vehicle with a similar type of vehicle – either a sedan or compact car[69];
- the *fuel type of the vehicle that is to be replaced,* assuming that the household in question replaces its current vehicle with a vehicle running on the same fuel as the existing one (in case a CV is chosen)[11];
- the *average annual income of the household in question* that allows for deducing possible income tax reductions, assuming that this income only changes with the inflation rate as applied in the TCO model;
- the *share of the annual driven distance that is due to professional reasons* and that also allows for deducing possible income tax reductions, assuming that it remains the same over the ownership period of the vehicle.

As mentioned when the set of infrastructure criteria was defined, TCO calculations also comprise the costs of infrastructure installation. As stated in Chapter 3 (Section 3.2.4), these costs are very approximate. A detailed calculation of infrastructure installation costs, which are specific for each household, is not feasible given the data availability of the ENTD. Fiscal policy measures that show effect on the single vehicle by altering vehicle purchase

[68] These assumptions can certainly be contested: motorisation rates, and, with it, vehicle usage patterns are likely to change in the upcoming years (e.g., due to increasingly accessible public transport services). This can entail general increases or decreases of annual driven distances carried out by a household's vehicle in question (see current trends and a discussion on the development of motorisation rates as well as on resulting changes in vehicle usage patterns in chapter 5, section 2.2). Further, the specific event of vehicle replacement, i.e., the replacement of a CV by an EV, may to lead to changes in the usage of the private vehicle: In order to avoid potential range problems with a BEV, some trips that have traditionally been carried out with the CV might be avoided, while others might be carried out with a different mode of transport (or with the remaining CV in case of a multi-motorised household). This results in a decreased annual vehicle usage of the vehicle to be replaced. On the other hand, the lower running costs of EVs when compared to CVs might lead to increased every-day usage of the vehicle in question.

[69] Also this assumption is contestable given (i) that households might increasingly prefer smaller, more fuel-efficient vehicles, also as an effect of increasingly stringent environmental policy, and (ii) the increasing uptake rate of diesel vehicles, due to lower fuel prices (at least in the past). See current trends and a discussion in this regard in chapter 5, section 2.2.

and/or usage are integrated in the TCO model. Again, for completeness, the following table shows the definition of the economic criterion.

Criterion #	Description	Application Condition
8	TCO of the EV are less than the TCO of a comparable CV	none (applied to all HHs)

Table 4.6: The economic criterion

4.3.4 Summarising the criteria catalogue

Table 4.7 gives now an overview of all defined criteria. The last two columns of Table 4.7 show which household type and which EV type is concerned by the defined criterion. For an exact definition of all criteria see the section above.

Criterion Category	Criterion *n*	Criterion Description	Concerned HH type	Concerned EV type
Vehicle Ownership	1	HH is motorized	all	BEV, PHEV
Infra-structure	2	Private parking at home available	all	BEV, PHEV
	3	Recharge infrastructure installation possible	all	BEV, PHEV
	4	Parking at work available	all	BEV
Vehicle Usage	5	Return-trips to frequent regular destinations within EV range	all	BEV
	6	Trips to secondary/occasional residences within EV range	mono-motorized	BEV
	7	Holiday trips not carried out with the private car	mono-motorized	BEV
Economics	8	TCO EV < TCO CV	all	BEV, PHEV

Table 4.7: Overview of criteria catalogue

A total of 8 criteria for the 4 introduced categories are defined. Due to the hybrid household hypothesis, criteria 6 and 7 are only applied to mono-motorised households. Criterion 5 is also applied to multi-motorised households: there needs to be at least one vehicle in a household's fleet that is not used on a frequent basis for trips that lie outside the range of a BEV. When exploring the potential PHEV demand, the set of criteria is largely relaxed due to the vehicle's range that is comparable to the one of a conventional vehicle.

4.4 Application and results

This section shows besides final results also the incremental application of the before defined constraints (4.4.1). This way an idea of the significance of single

household selection criteria can be obtained. Next, the Île-de-France region is explored in more detail in order to identify the effect of territorial characteristics on potential EV demand (4.4.2). Subsequent scenario and sensitivity analyses (4.4.3-4.4.4) explicate the household selection criteria's effect on the final results. Finally, the characteristics of EV-qualifying households are explored by confronting them with the motorised and total French household population (4.4.5).

4.4.1 Results for France

Table 4.8 shows the incremental application of household selection criteria as defined in Section 4.3. Shown percentage values give the rates of households that comply with the selection criterion as specified in the regarded line, as well as with all selection criteria that are stated above. The first part shows the application of the constraints analysis when identifying BEV-qualifying households. Since the set of criteria is specific to a household's motorisation, one column shows the incremental results for mono-motorised households, while the other one shows the results for multi-motorised households. The second part shows the constraints analysis when identifying PHEV-qualifying households. Since a PHEV's range is considered to be the same as the one of a comparable conventional vehicle, a differentiation of the set of criteria per household type can be omitted. The table quickly reveals the differences in the sets of selection criteria for the different household and EV types.[70] When applying the last criterion, the economic selection criterion, a differentiation according to the acquisition type of the vehicle's battery is made. As Chapter 3 showed, the economics behind these options can be significantly different, which results in different compliance rates of households with this criterion. The second-to-last line of the table gives the resulting total of EV-qualifying households per EV type; the last line shows the total of these by avoiding the double counting of households that qualify for both EV types. All shown percentage values are in reference to the total number of households in France, as obtained by the weights of the ENTD 2007-2008.

The application of the first criterion shows again (as in Section 3.3) the already identified motorisation rate of households in France: 47.0 % of households are single-motorised, 33.2 % are multi-motorised. The subsequent set of infrastructure criteria reveals that the availability of a private parking space at home is more likely for multi-motorised households than for single-motorised households. The percentage of potential EV-qualifying households is reduced by 7.2 % (to 26.0 %) in case of multi-motorised households. In the case

[70] See section 3.4, table 7 for an overview of the EV type and household type specific sets of selection criteria.

of mono-motorised households it is reduced by 17.0 % (to 30.3 %). Further, in case households dispose of a private parking, they appear to be frequently able to equip it with according EV recharge infrastructure – especially so in case of multi-motorised households. The criterion of having access to a parking place at the frequent destination of the vehicle (e.g. at work) does not appear to be very stringent for either household type. When exploring potential PHEV-qualifying households, this criterion is the first one that is not applied.

Looking at the results when applying vehicle usage criteria reveals that this type of criteria does not significantly reduce potential EV demand. The exception is criterion 7 (the holiday criterion) that is only applied to mono-motorised households. Potential PHEV households are exempted from all defined vehicle usage constraints.

The TCO criterion entails an extreme reduction of potential EV households. While 34.7 % (12.3 % + 22.4 %) of French households are seen as potential BEV households before the application of the TCO constraint, only 0.5 % is considered so afterwards. In case the vehicle's battery is hired – which reflects the economically more advantageous battery acquisition type on the French market (see Chapter 3) – the EV potential is "only" reduced to 3.5 % of households. The impact of this last criterion is underlined when identifying PHEV-qualifying households: here, the previously found potential of 50.8 % of French households is almost completely eradicated due to the TCO constraint. The total percentage of identified EV-qualifying households is practically exclusively made up by BEV-qualifying households.

FRANCE

Set of household selection criteria			HHs complying with criteria 1 to n (if applied to the defined EV type and HH type)		
			BEV		PHEV
Criterion Category	Criterion *n*	Criterion Description	mono-motorised	multi-motorised	mono- or multi-motorised
			(all in % of the total household population)*		*(in % of the total HH pop.*)*
Vehicle Ownership	1	Household motorised	47.0	33.2	80.2
Infra-structure	2	Private parking at home available	30.3	26.0	56.3
	3	Home recharge infra. installation possible	25.9	24.9	50.8
	4	Parking at frequent destination available**	23.4	22.6	n.a.****
Vehicle Usage	5	Return-trips to frequent destination within EV range	23.1	22.4	n.a.****
	6	Trips to secondary/occasional residences within EV range	21.7	n.a.****	
	7	Holiday trips not carried out with the private vehicle	12.3		
Economics	8	TCO EV < TCO CV (Battery purchase | Battery hire)	0.2 | 1.3	0.3 | 2.2	0.0 (0.006)
Total EV-qualifying HHs per type			**0,5 | 3,5**		**0.0 (0.006)**
Total EV-qualifying HHs***					**0.5 | 3.5**

Reading aid (exemplary): Taking the line of criterion *n*=5: 23.1 % of the total household population in France complies with criteria 1 to (including) 5 and is mono-motorised; 22.4 % complies with the same set of criteria and is multi-motorised; for the identification of PHEV-qualifying households, criterion 5 (among others) is not applied (n.a.) - the previously found percentage of potential PHEV-qualifying households is not further reduced and immediately subject to criterion 8. 0.5 % of the total household population corresponds to all BEV-specific selection criteria. This percentage rises to 3.5 % in case the vehicle's battery is hired.

* 26,625,086 HHs according to the survey (weighted)

** assuming that it increasingly comes along with recharge infra. availability that reduces range anxiety

*** NB: HHs that qualify for a BEV *and* a PHEV are counted once

**** n.a. - criteria not applied

Source: ENTD 2007-2008 and the author's calculations based on the conceived TCO model

Table 4.8: Identification of EV-qualifying households (HHs) based on the incremental application of selection criteria (France)

4.4.2 Results per area

This section examines the Île-de-France region in more detail. Different residential zones show diverse compatibility with the needs and limits of EVs. This section investigates these findings in more detail. First, Table 4.9 gives the results for the total IDF region in the same way as this was done in Table 4.8 for the whole of France.

Île-de-France

Set of household selection criteria			HHs complying with criteria 1 to n (if applied to the defined EV type and HH type)		
			BEV		PHEV
Criterion Category	Criterion *n*	Criterion Description	mono-motorised	multi-motorised	mono- or multi-motorised
			(all in % of the total household population)*		*(in % of the total HH pop.*)*
Vehicle Ownership	1	Household motorised	47.0	21.4	68.4
Infra-structure	2	Private parking at home available	30.9	17.0	47.9
	3	Home recharge infra. installation possible	23.9	15.4	39.3
	4	Parking at frequent destination available**	20.7	13.1	
Vehicle Usage	5	Return-trips to frequent destination within EV range	20.4	12.8	n.a.****
	6	Trips to secondary/occasional residences within EV range	18.2	n.a.****	
	7	Holiday trips not carried out with the private vehicle	7.7		
Economics	8	TCO EV < TCO CV (Battery purchase | Battery hire)	0.1 | 1.5	0.3 | 1.8	0.0
Total EV-qualifying HHs per type* **			**0.4 | 3.3**		**0.0**
Total EV-qualifying HHs				**0.4 | 3.3**	

Reading aid (exemplary): Taking the line of criterion *n*=5: 20.4% of the total household population in France complies with criteria 1 to (including) 5 and is mono-motorised; 12.8% complies with the same set of criteria and is multi-motorised; for the identification of PHEV-qualifying households, criterion 5 (among others) is not applied (n.a.) - the previously found percentage of potential PHEV-qualifying households is not further reduced and immediately subject to criterion 8. 0.4% of the total household population corresponds to all BEV-specific selection criteria. This percentage rises to 3.3% in case the vehicle's battery is hired.

* 4 971 010 HHs according to the survey (weighted)

** assuming that it increasingly comes along with recharge infra. availability that reduces range anxiety

*** NB: no households are found that qualify for a PHEV

**** n.a. - criteria not applied

Source: ENTD 2007-2008 and the author's calculations based on the conceived TCO model

Table 4.9: Identification of EV-qualifying households (HHs) based on the incremental application of selection criteria (IDF)

Comparing the results for the IDF region with those for the whole of France shows that there is a similar percentage of households that qualify for EVs. Whereas in the whole of France 3.5 % of households comply with all defined selection criteria (when looking at the battery hire option), this is 3.3 % of households in the IDF region. These similar results only emerge after the application of the last, economic criterion. Comparing intermediate percentage values shows that households in the IDF region are, on average, less adapted to an EV uptake than the average household on the national level. In the whole of France, 34.7 % (12.3 % + 22.4 %, see Table 4.8) of households are shown to be BEV-adapted (they comply with constraints 1-7); in the IDF region BEV-adapted households make up 20.5 % of the total households population (7.7 % + 12.8 %, see Table 4.9). Also in the IDF region, the number of potential PHEV households is found to be negligible due to the imposed economic constraint.

Table 4.10 now shows the results per defined residential area (for Paris, the Petite Couronne and the Grande Couronne). For a quicker interpretation of the results, Figure 4.11 graphs the main findings thereafter. It can be seen that the household motorisation rate in the Grande Couronne area is by far the highest, at 84 % (all households that remain after application of constraint 1). Also, infrastructure constraints (constraints 2-4) are the least stringent in the Grande Couronne area. Here, parking availability seems to be a far less stringent criterion than in the denser Petite Couronne area or in the city of Paris. After also applying vehicle usage constraints, remaining households make up 7 % of Parisian households, 17 % of households in the Petite Couronne area, and 31 % of households in the Grande Couronne area. These results show that vehicle usage constraints are also less stringent in this least dense, Grande Couronne area. This is mainly due to the high percentage of multi-motorised households that can be found in the Grande Couronne area. Finally, applying the last, economic constraint as well shows surprising results. In spite of the criterion's stringent nature, the percentage of Parisian households qualifying for an EV is not further reduced. All households that are found to comply with selection criteria 1-7 also show an EV-favourable TCO comparison. In the two other areas, the stringent nature of the TCO criterion becomes apparent.

Set of household selection criteria		HHs complying with criteria 1 to n (if applied to the defined EV type and HH type) per area								
		Paris			Petite Couronne			Grande Couronne		
Criterion Category	Criterion *n*	BEV		PHEV	BEV		PHEV	BEV		PHEV
		mono-motor.	multi-motor.	all	mono-motor.	multi-motor.	all	mono-motor.	multi-motor.	all
		(all in % of the area's total HH pop.)*			*(all in % of the area's total HH pop.*)*			*(all in % of the area's total HH pop.*)*		
Vehicle Ownership	1	36.5	5.4	41.9	51.7	16.6	68.3	48.9	35.4	84.3
Infra-structure	2	21.7	5.4	27.1	34.3	12.1	46.4	33.1	29.4	62.5
	3	16.7	4.0	20.7	26.0	10.8	36.8	26.2	26.8	53.0
	4	16.0	3.4		22.2	9.2		22.2	22.6	
Vehicle Usage	5	15.9	3.3	n.a.**	21.7	9.0	n.a.**	21.8	21.9	n.a.**
	6	12.1	n.a.**		19.8	n.a.**		20.4	n.a.**	
	7	3.6			8.3			9.5		
Economics ***	8	0.2 | 3.6	0.1 | 3.3	0.0	0.1 | 0.7	0.2 | 0.7	0.0	0.1 | 1.0	0.6 | 2.0	0.0
Total EV-qualif. HHs (in % of*)			**0.3 | 6.9**			**0.3 | 1.4**			**0.7 | 3.0**	

Reading aid and description of single criteria: see previous table on France or on the Île-de-France

* Paris: 1,163,041 HHs, Petite Couronne: 1,843,461 HHs, Grande Couronne: 1,964,507 HHs; all according to the survey (weighted)

** n.a. - criteria not applied (previously found % is immediately subject to criterion 8)

*** Battery purchase option | Battery hire option

Source: ENTD 2007-2008 and the author's calculations based on the conceived TCO model

Table 4.10: Identification of EV-qualifying households (HHs) per area

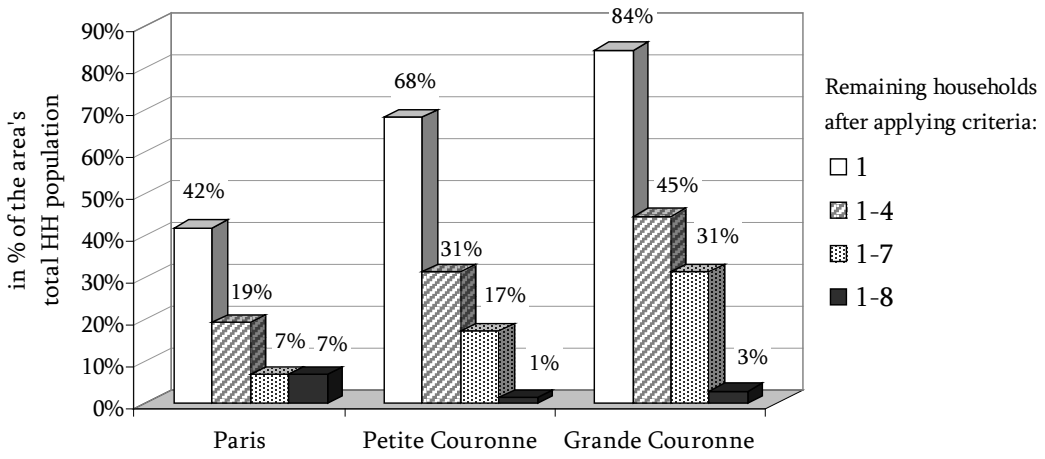


Figure 4.11: Incremental results per residential area

The most evident reason for this finding is the financial impact of parking policies in Paris. As will be later shown, it does not take much make a TCO comparison between different vehicle types that favours BEVs. In the city of Paris, the necessary financial incentive appears to be the EV-favourable parking policy that is in place (and that is assumed to be maintained during the vehicle's 7-year ownership period). According to the hypotheses behind the TCO calculation model (see Chapter 3, Section 2.4), parking costs of a Parisian vehicle owner amount, on average, to just over EUR 900 per year. During the assumed vehicle ownership period of 7 years, an EV user is therefore estimated to save EUR 6,300 compared to a CV user. The financial impact of Paris' parking policy is sufficient to compensate for the economic household selection criterion effect that is observed in other regions: in the Petite Couronne area, or Grande Couronne area, where costs for public parking are generally lower, the impact of free EV-parking on public premises is insufficient for balancing the economic selection criterion effect (i.e., annual parking costs for parking on public grounds are assumed to amount to just above EUR 220 per year in both of these regions). The effect of the economic criterion is evident. It reduces the number of potential EV households from 17 % to 1 % in the Petite Couronne area, and from 31 % to 3 % in the Grande Couronne area.

4.4.3 Scenario analysis

Scenario analysis allows the identification of the potential number of EV-qualifying households in case constraints are overcome thanks to technological, institutional, and/or behavioural changes. Table 4.11 gives an overview of scenarios that are developed for this purpose. Next to the already above-presented "fully-constrained" base scenario, which applies all defined selection criteria, 7 alternative scenarios are developed. Each of them relaxes one or more selection criteria. The only criterion that is not relaxed in any of the scenarios is

the first one that specifies that only already motorised households can qualify for an EV.

Scenarios 2, 3, and 4 explore the exclusive impact of either infrastructure criteria, vehicle usage criteria, or the economic criterion. Scenario 2, which only applies the set of infrastructure criteria (it relaxes all vehicle usage constraints as well as the economic constraint), refers to a situation where neither the limited range of BEVs nor their TCO pose any purchase barrier for private households. At least one of the following settings, from today's point of view rather than in theory, appears to be a necessary condition for justifying a complete relaxation of all vehicle usage constraints:

i) A dense net of battery swap stations has been put into place that eliminates range anxiety due to the quick exchange of depleted batteries for charged ones being made possible.
ii) Efficiently working and easily accessible vehicle hire services that are (especially) dedicated to owners of limited-range vehicles have been developed. They enable the substitution of a BEV with a CV in case long-distance trips are to be carried out.
iii) Technological advancements allow for BEV range that is similar to that of a CV, and for battery recharging that does not take longer than the refuelling of a CV.

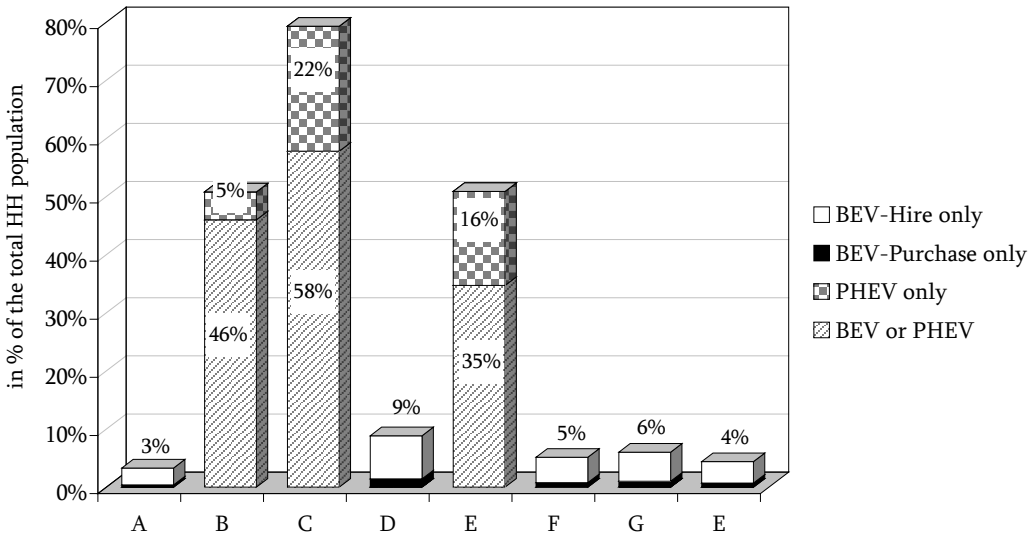
Justifications for the relaxation of the economic criterion could be either; significant EV price decreases, EV-favourable market conditions, high purchase subsidies, or any other type of policy intervention that ensures an economic advantage of a BEV purchase over a CV purchase (refer to Chapter 3 for an analysis of possible economic levers). Also, if these (combined) framework conditions are hypothetical from today's point of view, exploring a scenario that postulates this gives an insight into the possible impact of policy measures or institutional changes regarding new service provision. Scenario 3 relaxes the economic constraint as well as all infrastructure constraints. This postulates well-established public recharge infrastructure that enables EV owners to carry out overnight recharging without having access to truly private parking or recharge facilities at their own cost. Also condition i) and certainly condition iii), as mentioned above, would contribute to make scenario 3 a realistic one. Nevertheless, such a reality appears to be quite farfetched from today's point of view. However, the afore-mentioned policy measure put in place in Amsterdam (see Chapter 3, Section 3.2.4) is to be kept in mind: it foresees the free-of-charge provision of an EV-adequate parking facility for every EV owner. Also if such a measure is certainly an exception, it demonstrates where the suppression of the here-defined infrastructure constraints would already be justified. Finally, scenario 4 explores the sole impact of the economic constraint by relaxing all infrastructure and vehicle usage constraints.

Scenarios 5 to 7 apply two out of the three criteria categories. Also, although remaining somewhat hypothetical, these scenarios are seen to be more realistic than the previous ones. Finally, scenario 8 only relaxes selection criterion 7. It hereby postulates the availability of vehicle rental services that focus on the demand for CVs of BEV owners for holiday purposes. Taking the rather realistic assumption that such services are successfully developed and accepted by BEV owners, the relaxation of the holiday criterion is justified. Scenario 8 is therefore seen to be the most realistic scenario from today's point of view.

Figure 4.12 gives the results of the sensitivity analysis. As before, the percentage values displayed refer to the total household population in France. The results of each scenario are represented by one bar. Each bar differentiates households into those that qualify exclusively for a BEV, those that qualify exclusively for a PHEV, and those that qualify for either one of these two EV types. Since all households that qualify for a BEV with a battery purchase option are found to also qualify for a BEV with a battery hire option, only the percentage value of the latter one is shown. The proportion of those households that would also qualify for the battery purchase option is indicated in the figure.

Set of household selection criteria			Applied selection criteria per scenario							
			A	B	C	D	E	F	G	H
Criterion Category	*n*	Criterion Description	fully constr.	infra. constraints only	vehicle usage constraints only	economic constraint only	vehicle usage + infra. constraints	infra. + economic constraint	vehicle usage + economic constraint	all but holiday constraint
Vehicle Ownership	1	Household motorised	•	•	•	•	•	•	•	•
Infra-structure	2	Private parking at home available	•	•			•	•		•
	3	Home recharge infra. installation possible	•	•			•	•		•
	4	Parking at frequent destination available	•	•			•	•		•
Vehicle Usage	5	Ret.-trips to frequent dest. within EV range	•		•		•		•	•
	6	Trips to second./occas. resid. within EV range	•		•		•		•	•
	7	Holiday trips not with private vehicle	•		•		•		•	
Economics	8	TCO EV < TCO CV	•			•		•	•	•

Table 4.11: Overview of scenario definitions



Source: ENTD 2007/08 and the author's calculations based on the conceived TCO model

Figure 4.12: Resulting EV-qualifying households per modelled scenario

The results immediately reveal that applying the economic criterion reduces the percentage of EV-qualifying households significantly – no matter which other selection criteria are applied in the same scenario (see scenarios 1, 4, 6, 7, and 8). Remaining households qualify for a BEV[71] – for a large part only for the economically more advantageous battery hire option. Scenario 4 shows that the applying the economic criterion leaves 9 % of French households as potential (B)EV households. The economic criterion can be easily identified as the most stringent in the defined criteria catalogue.

Looking at the results of scenarios 2 and 3 reveals that the set of infrastructure criteria is more stringent than the set of vehicle usage criteria: while the application of infrastructure criteria leaves 51 % of households as potential EV-qualifying households altogether, this increases up to 80% when applying the vehicle usage criteria. This is due to the fact that the latter scenario finds all motorised households (80 %) as PHEV-qualifying. Given that PHEV-qualifying households are subject to less selection criteria in comparison to BEV-qualifying households, both scenarios show that a non-negligible number of households only qualify for a PHEV.

Scenarios 2 and 5 give the same total percentage of EV-qualifying households. This is explained by the fact that the additional constraints in scenario 5 are only applied for identifying BEV-qualifying households. This

[71] The percentage of households that also qualify for a PHEV remains negligible in all scenarios not relaxing the economic constraint.

results in a reduction of BEV-qualifying households, while the total number of EV-qualifying households remains the same as in scenario 2.

Scenario 8 demonstrates the possible impact of adequate vehicle hire services focusing on the demand for CVs of mono-motorised EV households for holiday purposes. The scenario shows that relaxing the holiday constraint results in a 1 % increase in the number of BEV-qualifying households (or an increase of 266,250 households).

4.4.4 Sensitivity analysis

In the following section, the extremely restrictive economic constraint is explored in more detail. As defined in Section 4.3.3, the TCO criterion limits EV-qualifying households to those for which the term $TCO_{CV} > TCO_{EV}$, or $(TCO_{CV} - TCO_{EV}) > 0$, is valid. Given this strict definition, the economic criterion is likely to under- (or, alternatively, over-) estimate the number of EV-qualifying households. This is due primarily to:

i) An expected imprecision in TCO calculations due to the significant amount of hypotheses and assumptions underlying the calculation model (see Chapter 3). Actual TCO values are likely to differ from the estimated ones.
ii) A probable imprecision of stated household or vehicle usage characteristics as found in the underlying data source, the ENTD 2007-2007, which can result in incorrect TCO values for a specific household.
iii) A possible unawareness of or insensitivity to (future) TCO of different vehicle types: even in the case where TCO do constitute a decision criterion in the vehicle purchase process, vehicle purchasers are prone to basing these on only rough or imprecise calculations. It is seen to be improbable that the decision is based on such a strict criterion as introduced in the underlying study.

Given the probable imprecise TCO values on the one hand, and a rather "flexible" definition of an economic criterion by actual vehicle purchasers on the other hand, the importance of exploring the sensitivity of the number of EV-qualifying households to the economic criterion becomes evident. For this purpose, the following two figures show the percentage of households that qualify for an EV as a function of what is called the "TCO gap". The TCO gap, G, is defined by $G = TCO_{CV} - TCO_{EV}$. This implies that an increase in the assumed accepted TCO gap comes with a higher number of identified EV-qualifying households. Figures 4.13 and 4.14 show the percentage of EV-qualifying households for an assumed accepted TCO gap G ranging from EUR -5,000 to + 10,000. While Figure 4.13 represents the results when exploring BEVs with the battery purchase option, Figure 4.14 represents those when looking at BEVs with the battery hire option. Both figures also show the percentages of

households qualifying for a PHEV. It can quickly be seen that their potential remains negligible over the whole TCO gap value-range. The lower part of each figure gives a more detailed view on TCO gap values lying in the interval EUR $[-2000,+2000]$.

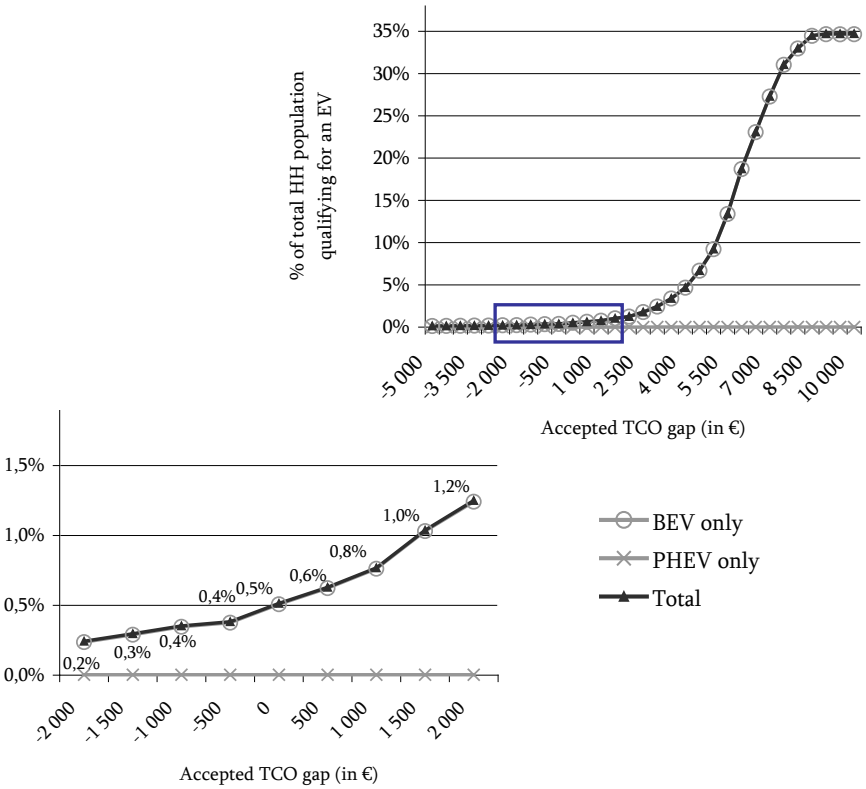


Figure 4.13: EV-qualifying HHs as a function of the TCO gap (BEV battery purchase)

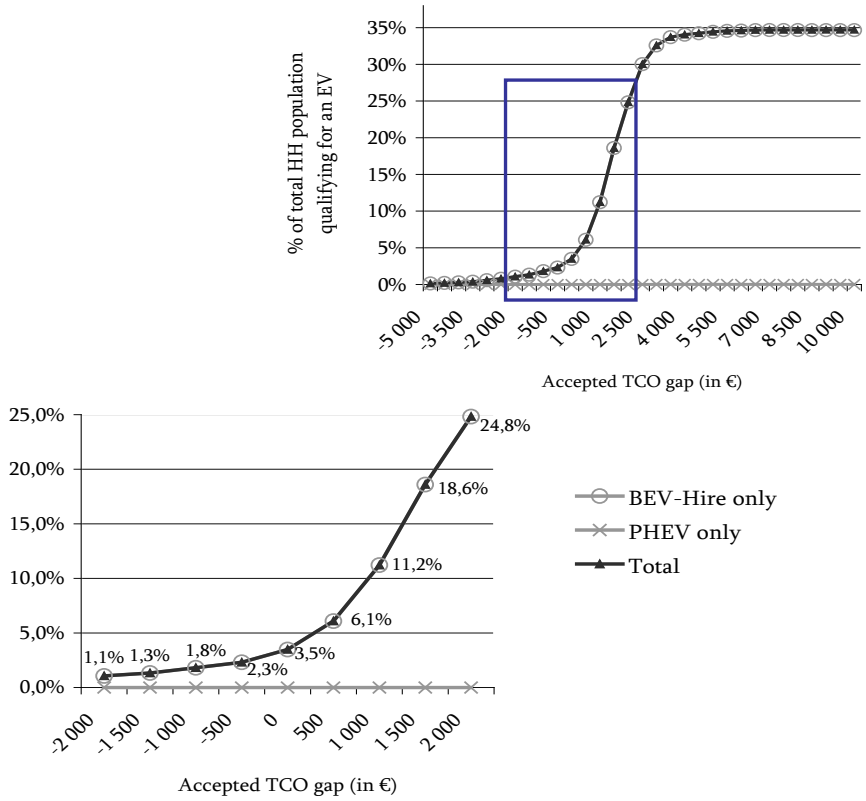


Figure 4.14: EV-qualifying HHs as a function of the TCO gap (BEV battery hire)

Furthermore, both figures show that the chosen TCO gap value-range of EUR $[-5000,10000]$ suffices for the coverage of the whole spectrum of possible identifiable BEV-qualifying households. Since the analysis shown here is based on the fully constrained scenario (scenario 1 as defined in Table 4.9), the maximal attainable percentage of BEV-qualifying households amounts to 34.7 % (= 12.3 % + 22.4 %, see Table 4.8). Looking at both figures, the comparatively high sensitivity of results when exploring the battery hire option becomes evident. While an assumed accepted TCO gap in the range of EUR $[-2000,+2000]$ only entails a resulting percentage range of $[0.2\%,1.2\%]$ in the case of a battery purchase, the same TCO gap value-range provokes resulting percentages in the range of $[1.1\%,24.8\%]$. In particular, the latter results for the battery hire option underline the fact that the reduction of the number of BEV-qualifying households due to the economic criterion is to be seen with caution. Only a subtle relaxation of this criterion provokes an enormous increase of the number of BEV-qualifying households. Also, it is important to note that results for both battery acquisition options are more sensitive to changes to the TCO gap if the latter one is positive rather than negative.

It should be kept in mind that the displayed percentages result from TCO calculations that assume a purchase subsidy of EUR 5,000. Displayed figures give an idea of the impact of removing this subsidy. For both battery acquisition options, the number of identified BEV-qualifying households would tend towards zero. The exact impact of a newly defined purchase subsidy (taking effect at time instant t=0 of the vehicle ownership period) deviates from the results shown here that explore the impact of an assumed accepted TCO gap (at the end of the assumed vehicle ownership period). See Box 1 for a specific example.

Box 1 – Effect of a EUR 7,000 purchase subsidy

The "Plan Automobile" (MRP, 2012) released in July 2012 increases the French EV purchase subsidy from the former level of EUR 5,000 to a level of EUR 7,000. This raise results in an increase of the percentage of households that qualify for an EV from 0.5 % to 1.5 % in case the of battery purchase option, or from 3.5 % to 28.2 % in case of the battery hire option. NB: The difference between these results and the results found when assuming an accepted TCO gap of EUR 2,000 stems from the differing assumptions on at which specific time instance the EUR 2,000 TCO reduction occurs.

4.4.5 Characteristics of EV-qualifying households

This section examines EV-qualifying households against (i) the total household population, and (ii) motorised households using selected characteristics. This way, possible distribution differences of these selected household characteristics can be identified. In the following analysis, all households that qualify for a BEV with the battery hire option are considered as BEV-qualifying households.

The first figure (Figure 4.15) shows the age distribution[72] of the different household populations. It is observed that the age distribution of potential BEV households tends to higher age categories relative to the total but also to the motorised household populations. With regards to the total household population, only the 70+ age group is slightly underrepresented among the EV-qualifying households. A similar move is observed when comparing households' monthly income levels (Figure 4.16): on average, a potential BEV household has a higher income than the average French motorised household, which has, in turn, a higher income than the average French household. Given the definition of household selection criteria, these observations are not surprising. Multi-vehicle households that have access to private parking infrastructure (which is, by definition, the case of BEV-qualifying households) are expected to show, on average, higher income levels than the total household population. Given that higher income levels often come with higher age, the observed age shift is not surprising.

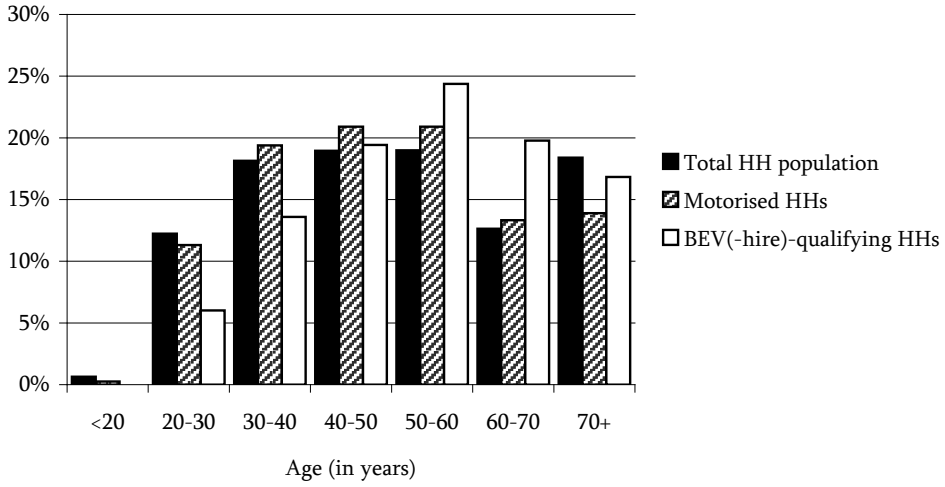


Figure 4.15: Household distribution by age of the reference person (in years)

[72] The age regarded here is the one of the 'reference person' of a household in question, as defined in the ENTD 2007-2008).

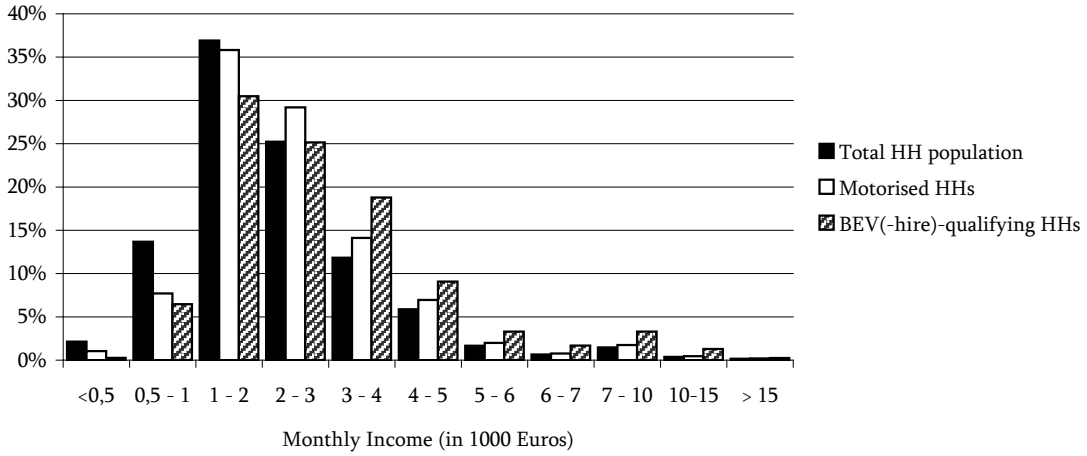


Figure 4.16: Household distribution by monthly household income (income in EUR 1,000)

Figure 4.17 shows the distribution of households by the number of vehicles they own. It has to be kept in mind that the number of vehicles is a filter criterion for the identification of BEV-qualifying households. Non-motorised households do not appear in the pool of BEV-qualifying households. Figure 4.17 shows that multi-motorised households are overrepresented in the BEV-qualifying household population.

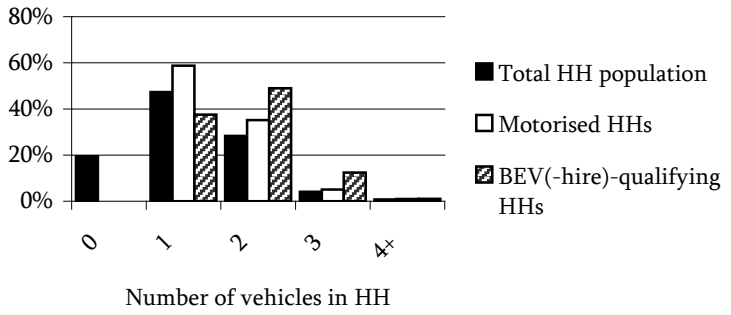


Figure 4.17: Household distribution by number of vehicles

Figure 4.18 shows the location of households according to the type of residential area. Comparing BEV-qualifying households with the total and motorised household population, the following is observed:

- BEV-qualifying households are *over*represented in predominantly rural areas, in (multi) polarised urban areas and in Paris.
- BEV-qualifying households are especially *under*represented in urban centres and the suburbs of Paris.

The rather contradictory results regarding urban centres (overrepresentation of BEV-qualifying households in Paris, underrepresentation of these households in urban centres) most likely stem from deficiencies of the TCO model when applied to the whole of France. While the Paris region is modelled on a more adequate level of detail (i.e., per defined residential zone), the region "rest of France" (whether rural or urban areas) is defined by the same territorial parameter values as the Grande Couronne area (see Chapter 3, Section 3.2.3). This is likely to lead to distortions in results, especially so when keeping in mind that varying parking costs within the "rest of France" area are not accounted for in this simplified approach. Economic advantages of BEVs in urban centres other than the IDF region, where BEV-favourable parking policies can have a decisive impact on the TCO comparison, are neglected. An underrepresentation of BEVs in these areas is the result. Figure 4.18 also shows the distribution of households that comply with all but the economic selection criterion 8. These *BEV-adapted* households (named here) show BEV-adequate infrastructure and vehicle usage patterns, while verifying BEV-favourable TCO is neglected. The distribution of these BEV-adapted households shows the following: predominantly rural areas are by far the most adapted for the take up of BEVs. Households in such areas are overrepresented when compared to the total household population. Also overrepresented are households in (small and large) polarised and multipolarised urban areas. The highest under-representations are found in large urban centres, in the Paris' suburbs and in Paris itself. Leaving the economic criterion aside, these results give a more coherent picture of the readiness of diverse residential zones for the take up of BEVs.

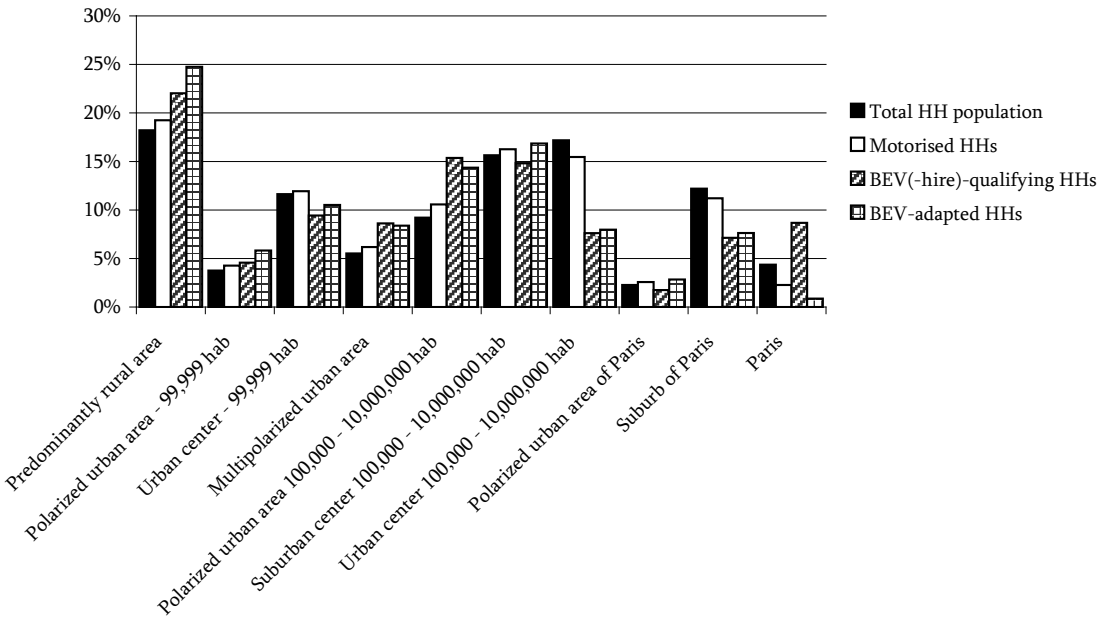


Figure 4.18: Household distribution by residential zone

Figure 4.19 shows the household distribution by the annual driven distance of the household's 'first' vehicle (the vehicle that is stated in the ENTD 2007/08, or the one that shows the highest annual driven distance). It can be seen that the distribution for BEV(-hire)-qualifying households largely resembles the one of the total French household population. It tendency towards lower annual driven distances can be observed. This confirms the findings of the previous chapter: the TCO of the BEV with a battery hire option is superior to the one of its conventional counterpart in case the annual driven distance surpasses a certain threshold and the monthly battery hire costs become more significant.

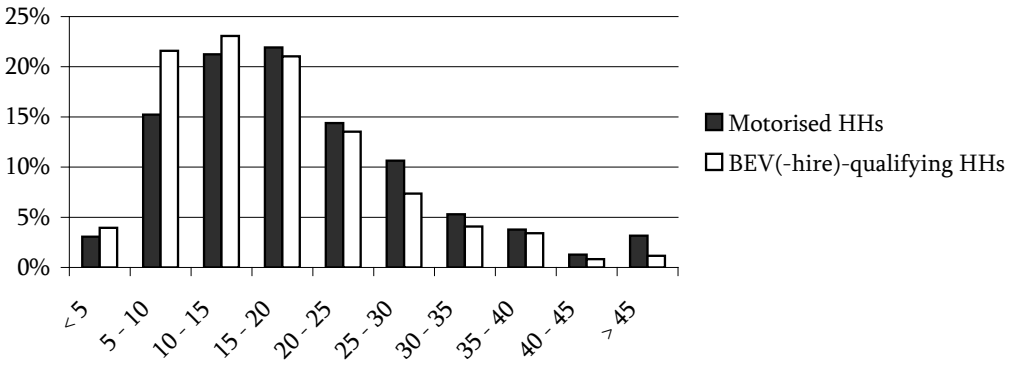


Figure 4.19: Household distribution by annual driven distance (in 1,000 km)

4.5 Discussion of results

4.5.1 Summary of results

The following list summarises major findings of the constraints analysis :

- In the whole of France, around 3.5 % of households are found to qualify for an EV. This potential is identified when assuming that battery hire is the accepted business model. Assuming battery purchase as the only offered battery acquisition type, the percentage drops to 0.5 %. The number of identified PHEV-qualifying households is found to be negligible.
- The defined economic constraint, based on a TCO comparison of the different vehicle types, shows to be, by far, the most stringent household selection criterion. The sole application of this criterion identifies 9 % of the total household population as potentially EV-qualified. The sole application of the set of infrastructure constraints still identifies 51 % of households as potentially EV-qualifying; the sole application of the set of vehicle usage constraints identifies 80 % as potential EV-qualifying households. Vehicle usage constraints appear to be the least stringent. This stems in particular

from the fact that multi-motorised households are only subject to a subset of the defined vehicle usage criteria.

- Results are shown to be extremely sensitive to the definition of the economic criterion. By assuming an accepted TCO gap of only EUR 2,000, the percentage of BEV-qualifying households (adhering to the battery hire option) raises from 3.5 to 24.8 %. This identified sensitivity helps put the estimated potential for BEVs into perspective. PHEV potential, on the other hand, appears to be largely insensitive to the exact definition of the economic criterion.
- On average, EV-qualifying households are richer, older and more motorised than the total household population. Given the definition of EV-qualifying households, these findings are not surprising.
- Analysing the residential zones of EV-qualifying households and taking a close look at the Île-de-France region shows that predominantly rural areas are the most adapted for EVs. Both, adequate access to (parking) infrastructure and adequate vehicle usage behaviour are more frequently found here than in other areas.
- Thanks to EV-favourable parking policies that are naturally more effective in dense urban areas, dense urban areas can finally turn out as most adapted and attractive zones for an EV purchase of a private household when taking economic considerations into account. The environmental advantages of EVs with regards to local emissions are here capitalised the most, which justifies such local measures in dense areas. Given the often severe restrictions of public space in dense areas, the provision of parking and recharge infrastructure will, however, have its limits. With EVs' current technological development, certain EV penetration thresholds will be difficult to exceed. Shared EV services, such as Autolib in Paris (see Chapter 2, Section 2.3.2), might be the most adequate solution for introducing EVs in dense urban areas.

4.5.2 Comparison with reviewed literature

Comparing findings of the underlying study with what has been found in reviewed literature is not straightforward. Either different geographic scope, different units of analysis (vehicles instead of households), or different study approaches prevent a direct comparison of results. For this reason in the following section, results from the underlying study are only compared to those of the studies that allow a (partially) valid comparison. The significance of each comparison is put into question by stating the most important and obvious differences between the two presented studies. This contributes to understanding the possible origins of inconsistent or differing results.

CGDD (2011) that is based on the same dataset as the underlying study finds that 20 % of the private vehicle fleet could be replaced by BEVs and 69 % by

PHEVs. The approach used by the study does not comprise a financial selection criterion (although a detailed TCO analysis foregoes the constraints analysis). For this reason, the most comparable results of the underlying study are those of scenario 5 that gives the percentage of households complying with infrastructure and vehicle usage criteria. 35 % of French households are here found to comply with the needs and limitations of a BEV; 51 % comply with those of a PHEV (see Figure 4.12). Differences are explained by the fact that CGDD (2011) (1) only considers vehicles in multi-motorised households as potential EVs, (2) does (for this reason) not define any vehicle usage selection criteria, and (3) defines infrastructure selection criteria differently than this is done in the underlying study (i.e., only cars that can be parked at private parking spaces at home and the place of work qualify for an EV; the possibility of installing recharge infrastructure is not investigated).

Williams and Kurani (2006), who find that 15 % of Californian households are pre-adapted to limited-range vehicles, base their analysis exclusively on infrastructure constraints. Results are comparable to scenario 2 of the underlying study (see Figure 4.12). It shows that 46 % of French households comply with defined infrastructure criteria. The most evident explanation for this difference in findings is the differing geographic scope of the two studies. The access to parking and recharge infrastructure is certainly not comparable in these two very different geographic areas. The large percentage difference that shows French households to be much more adapted to an EV-uptake (with regards to infrastructure access only) is certainly also due to the very stringent set of criteria that is defined by Williams and Kurani (2006). Criteria do not only take parking infrastructure but also the building size and age into account. Nesbitt et al. (1992) defines less stringent infrastructure criteria than Williams and Kurani (2006), but takes vehicle usage behaviour into account. 30 % of US households are found to qualify for a BEV. Making the more valid comparison between Williams and Kurani (2006) and Nesbitt et al. (1992) (both studies are carried out for the/within the US) shows the possible impact of the infrastructure criteria definition.

Biere et al. (2009), the only study also incorporating an economic criterion based on a TCO comparison, finds that 12 % of the private vehicle fleet in Germany could be replaced by small city BEVs by 2020. Taking the seemingly valid assumption that identified EV-qualifying households in the underlying study will only acquire one EV, the resulting percentage can be apportioned to the private vehicle fleet in France.[73] This way, the identified 3.5 % of French households qualifying for a BEV represent 3 % of private vehicles in France that could be replaced by a BEV with the battery hire option. It can be seen that the

[73] According to CCFA (2011c) this vehicle fleet comprised 33 million vehicles in 2008.

estimated potential in France is much lower than in Germany. Again, the most obvious reason for this difference is the differing geographic scales of the two studies. These entail different policy settings, market conditions, vehicle usage behaviours and infrastructure accessibility. Next, Biere et al. (2009) take 2020 as the reference year. All cost calculations are based on assumed future framework conditions that are assumed more EV-favourable than the current ones. Further, Biere et al. (2009) specifically explore the potential for small city BEVs. This reference vehicle type comes with lower costs than the reference EV models underlying this study.

The most obvious finding that is in line with the findings of the literature review is the little impact that range limitations have on the number of EV-qualifying households (see, e.g. Greene, 1985; Nesbitt et al., 1992; Kurani et al., 1994). Also, in our study the set of vehicle usage criteria is identified to be the least stringent.

4.5.3 Critical review of methodology

Results from this chapter should not be presented without critically reflecting on the methodology and the limitations of the chosen approach.

As mentioned in this chapter's introduction, the applied methodology results in the identification of all those households that *could* buy an EV from a technical and practical perspective. However, it remains unexplored whether these households *would* actually buy an EV if they actually were in a vehicle purchase process. Not only is the understanding of the total cost of ownership lacking, but also the awareness of new vehicle technologies and their potential advantages. Further, a household's actual vehicle behaviour is often only little comprehended, which frequently underlies unfounded range anxiety. These issues suggest that the EV potential identified here will not necessarily materialise. Individual tastes and preferences (i.e., due to vehicle appearance and status, vehicle performance, perceived risk/confidence in a brand, advice from friends or dealers, or vehicle comfort) are neglected. Further, the demand for second-hand vehicles is completely ignored in the underlying analysis. From a financial point of view, EV offers that are currently available are most certainly not competitive with second-hand vehicles. The TCO comparison of a newly-purchased EV with a second-hand CV will, in most cases, result in a financial advantage for the CV. Considering that around 60 % of newly-purchased vehicles in France are bought second-hand (INSEE, 2011b), the number of identified EV-qualifying households in this study appears to be too optimistic.

On the other hand, the number of households that would buy an EV in spite of identifiable (financial) disadvantages also remains unexplored in this study. The possible effect of potential environmental benefits or time savings (thanks to the possibility of home recharging) on the EV take up rate is not accounted for. In addition, the EV demand in currently non-motorised households remains

unexplored. This allows for some confidence that the actual number of EV-qualifying households could also surpass the potential identified here. Sensitivity analysis shows that the reduction of the number of potential EV households due to the economic criterion is significant. The criterion's definition proves to result in an extremely conservative estimation of the number of EV-qualifying households. The fact that EV purchasers might actually accept a (slight) TCO disadvantage in order to benefit from the often overlooked advantages of EVs (as mentioned above) is not accounted for. Further, it has to be kept in mind that the study only estimates the number of EV-households under 2012 framework conditions. Carrying out the same analysis for a later point in time is likely to result in more optimistic EV forecasts. Changing framework conditions, such as increasing petrol prices (as argued in Chapter 3), enhanced accessibility to recharge infrastructure, behavioural changes or technological advancements, as they can be assumed for the future, are likely to lead to more EV-favourable results. Under such settings, it might become justified to relax or soften certain household selection criteria as they were introduced in the base scenario of this study. The sensitivity analysis carried out gives an impression of results that are possibly attainable in the future.

Results of the underlying study should be interpreted as a 2012 snapshot of the households' adaptability to an EV and the vehicles' financial attractiveness for these households. Understanding of how potential demand can possibly be increased is created by identifying the most promising demand-increasing levers. Characteristics of EV-qualifying households are discovered and their likely location is identified. Deriving conclusions about actual demand based on findings obtained here would be premature. The questions of *when* actual purchase decisions will be made and *under which future framework conditions* they will occur have not been investigated. Only such analyses would allow meaningful demand forecasts.

4.6 Conclusion

4.6.1 Summary of applied methodology

This chapter first gives a comprehensive literature review on constraints analyses that aim to estimate the number of vehicles that could potentially be replaced by an EV in a defined geographic region. Studies are categorised into those that specifically explore vehicle usage behaviour (mostly carried out with the help of vehicle-based data) and those that are more focused on analysing the availability of EV-necessary infrastructure (carried out on household-based data). As well as the results, main deficiencies and unique contributions of each study are highlighted. The Literature review especially shows that the definition of an economic constraint is neglected in most studies. Based on these and other

findings, and given the data availability underlying this study, constraints that help identify EV-qualifying households are defined. The set-up criteria catalogue comprises household selection criteria with regards to a household's (1) motorisation, (2) access to parking and recharge infrastructure, (3) vehicle usage behaviour, and (4) specific TCO of each vehicle type. The underlying study bridges the gap between financial and solely constraints-based analyses.

4.6.2 Application results

The application of the constraints analysis on the French National Transport Survey (ENTD) 2007-2008 database reveals that, under current settings and given the partly very stringent definition of constraints, the number of EV-qualifying households is quite moderate. It lies at around 3.5 % of the total household population. The number of identified PHEV-qualifying households is negligible. Sensitivity analysis shows that technological, behavioural or institutional changes have the potential to increase the estimated number significantly. Especially the stringent definition of the economic constraint suggests that estimated numbers can be seen as conservative values. The discussion of results underlines that obtained findings should not serve as a basis for EV demand forecasts. Rather, they have to be understood as a snapshot of the current compliance of French households with EVs. They allow for the identification of the most EV-adapted regions, as well as the most effective (policy) levers that have the potential to increase the number of EV-qualifying households.

Given the high sensitivity of the results to the economic criterion, financial policy measures have an important effect on the potential EV-uptake. This conclusion is only valid if noted uncertainties concerning TCO calculations are ignored and the assumed accepted TCO gap of potential EV buyers tends towards zero. Relaxing the TCO criterion by allowing a TCO gap shows that the number of potential EV buyers can be expected to be significantly higher than what is identified by the most stringent base scenario defined here. Policy measures directed towards the provision of private parking and recharge infrastructure seem to be a more evident lever from today's point of view.

4.6.3 Shortcomings and outlook

The most evident and surmountable shortcoming of the proposed analysis is the missing time component. Without an analysis of when and under which framework conditions identified EV-qualifying households will actually be in the process of a vehicle purchase, demand forecasts for EVs cannot be made. The reason for this is that the impact of policy measures, market trends and vehicle advancements cannot be estimated. The following chapter introduces the necessary time component in the study presented here and works with scenario

analysis in order to account for the many uncertainties concerning future developments. This allows for the estimation of actual vehicle demand over time. The other identified main deficiency of this study is the disregard of the market for second-hand CVs (as already discussed in Chapter 3). This market is expected to be (along with the market for new CVs) in fierce competition with the market for new EVs. Further deficiencies refer to those that concern the underlying TCO calculation model. These were progressively introduced and discussed in Chapter 3.

Chapter 5
Forecasting the EVs' potential up until 2023

5.1 Introduction

5.1.1 Context and objectives

Chapter 4 introduced a constraints analysis that identifies the number of French households that qualify for an electric vehicle (EV). Such "EV-qualifying" households were defined to be households that:

i) are motorised
ii) have access to EV-adequate household infrastructure (i.e. access to private parking infrastructure where EV recharging infrastructure can be installed)
iii) show vehicle usage behaviour that is line with the range limitations of current EV models, and
iv) show household and vehicle usage characteristics that make the acquisition of an EV financially more advantageous than the purchase of a comparable CV (conventional vehicle).

The analysis was carried out for the year 2012. All framework conditions with regards to introduced policy measures, economic trends and vehicle specifications referred to the actual situation in that year. Policy measures were kept at their 2012 settings over the modelled ownership period of the vehicle, whereas economic trends (notably fuel and electricity prices) changed according to underlying energy price forecasts over the ownership period.

In this chapter, we now explore the development of the number of EV-qualifying households over time. The applied methodology is as described in Chapter 4 and as applied to the year 2012. Forecasts on the development of framework conditions allow us to obtain results until the year 2023. The framework conditions that change over time mainly alter the expected costs of vehicle purchase and ownership. These are the basis for the economic household selection criterion as applied in the constraints analysis introduced in Chapter 4. We explore the effectiveness of policy measures over time and identify the most reasonable settings of policy measures that could encourage private EV uptake, while not giving unsustainable excess financial support.

Due to the many uncertainties related to underlying parameter forecasts, we develop scenarios that reflect both the worst and the best case conditions as well as the most realistic conditions (from our point of view) under which EVs will develop. Again, the analysis is carried out for France; a focus is put on the Île-de-France (IDF) region (see Chapter 2, Section 2.2.3, for a description of this study area).

The outlook on the development of the number of EV-qualifying households serves then as basis for subsequent approximate EV demand estimations.

5.1.2 Outline of the chapter

The chapter is structured as follows: Section 5.2 (Methodology) shows how the static constraints analysis (as introduced and applied in Chapter 4) creates the basis for forecasting the number of EV-qualifying households. We outline all necessary underlying hypotheses that make such an outlook feasible and critically discuss them in view of currently observed trends. Section 5.3 (Scenario building) then gives an overview of the scenarios that are developed and explored in the following section. Settings of selected parameters are specified and supported by the findings of the reviewed literature. Section 5.4 (Resulting EV-qualifying households till 2023) gives then the number of EV-qualifying households over time and per scenario. We identify the essential and most promising policy measures that have the potential to encourage EV uptake. For this purpose we develop several sub-scenarios with adapted policy measures. In Section 5.5, we estimate potential EV sales to the identified EV-qualifying households and discuss the results in the light of the underlying methodology. Section 5.6 gives a summary of the methodology and main results. Shortcomings are stated and an outlook on the subsequent chapter is given.

5.2 Critical review of underlying hypotheses

5.2.1 Overview of the applied methodology

The applied methodology for identifying EV-qualifying households over time is the one introduced in Chapter 4. With the help of the ENTD (the Enquête Nationale Transports et Déplacements) and the TCO (Total Cost of Ownership) calculation model (as introduced in Chapter 3) EV-qualifying households are identified by applying the previously introduced constraints analysis. This methodology is applied to each year up until 2023. Changing framework conditions are taken into account by altering values of input parameters to the TCO model. The relaxation of certain household selection criteria in the applied constraints analysis reflects enhanced accessibility to recharge infrastructure and/or behavioural changes over time.

Following this methodology for obtaining a forecast on the number of EV-qualifying households over time comes with several underlying assumptions. These are outlined in the following and critically discussed in view of currently observed trends.

5.2.2 Underlying hypotheses vs. observed trends

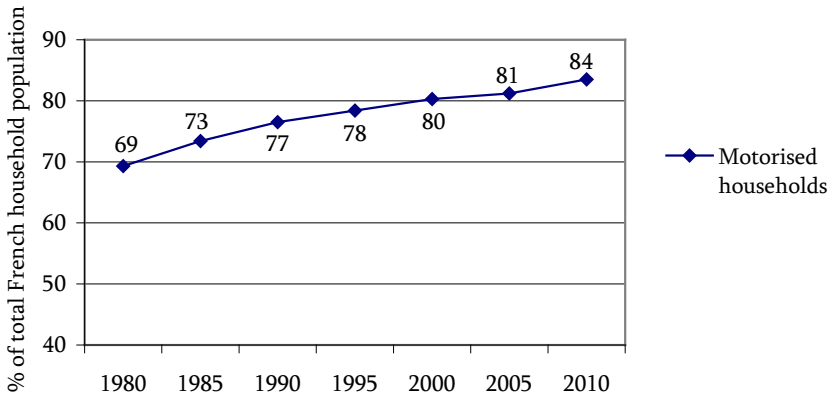
The underlying methodology relies on many hypotheses that are necessary for making a forecast on the number of EV-qualifying households. Firstly, they refer to household characteristics that are retrieved from the data set of the ENTD 2007/08 and used for the definition of the set of household selection criteria as applied in the constraints analysis. Secondly, these hypotheses refer to the numerous parameter values describing framework conditions (and, again, household characteristics) necessary for TCO calculations that create the basis of the economic selection criterion in the constraints analysis.

In the following, assumptions behind household characteristics that are retrieved from the ENTD are discussed. These are assumed to stay unchanged over time. Other parameter values, which are assumed to change over time and/or per developed scenario, are discussed in the subsequent section when the different scenarios are introduced.

The households' level of motorisation

This parameter is used for the first household selection criterion in the constraints analysis that limits potential EV-qualifying households to already motorised households. Figure 5.1 shows the motorisation rate of French households over time. It can be seen that the motorisation rate increased by 15 % over the last 3 decades. In case this tendency continues in the future, the assumption of a stable motorisation rate over time is prone to underestimate the

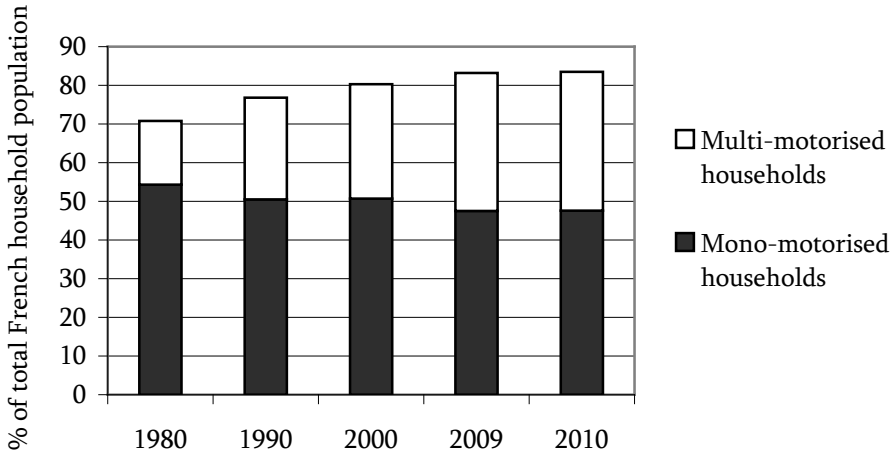
number of potential EV-qualifying households until 2023. Figure 5.2 further shows that it is especially multi-motorised households that increase in their number. Such a continuous development could also result in underestimations, given that multi-motorised households are by the definition of this study more prone to enter the pool of EV-qualifying households. On the other hand, Figure 5.2 gives reason to assume constant or even declining motorisation rates over the next years. Between the years 2009 and 2010 no increase can be observed. While this could be explained by the economic crisis that entailed reduced automobile sales, it could also be interpreted as first sign of stagnating motorisation rates or even demotorisation. The latter is especially predicted for urban areas where the evolving mobility system increasingly integrates and offers alternative modes of transport (such as public but also individual transport means such as shared 2-, 3-, and 4-wheelers) that render private car ownership less interesting. Furthermore, urban public policies render private car ownership in dense urban settings increasingly expensive, which contributes to demotorisation trends of private households. Such trends have already been identified in big cities of established industrial nations (Roland Berger, 2011a). France is likely to show similar motorisation trends given that the surface area and the population of urban areas have been continuously increasing over the last decade[74].



Source: CCFA (2011b)

Figure 5.1: Household motorisation in France over time

[74] Between 1999 and 2010 the urbanised surface area in France has increased by 19 %; the population in urbanised areas has increased by 5 % (NB: the development of the number of households in urbanised areas is not identified) (INSEE, 2011c).



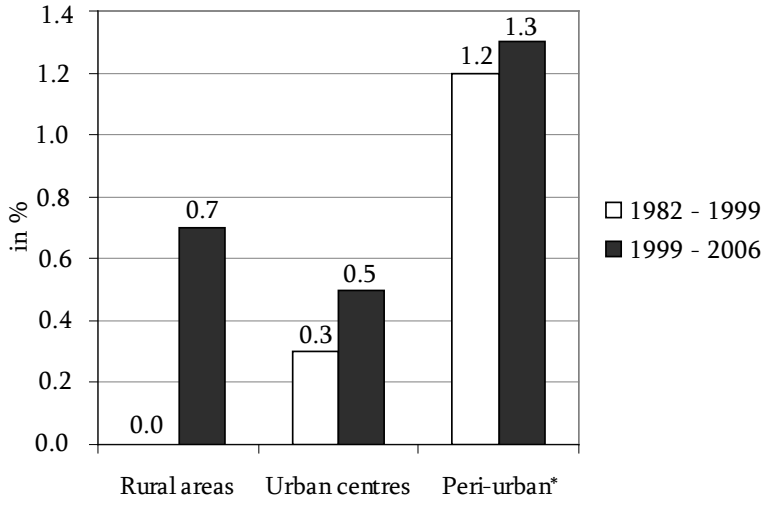
Source: INSEE (2010)

Figure 5.2: Household motorisation in France over time

The households' access to private parking infrastructure

The information on whether a household has access to a private parking infrastructure, and whether this can be equipped with recharge infrastructure is retrieved from the ENTD 2007/08. It helps define the respective household selection criteria in the constraints analysis. We assume that French households show on average the same characteristics with regards to the availability of parking infrastructure over the whole forecast period until 2023.

Data on the past development of parking availability could not be identified. Figure 5.3 however, depicts the annual population change per area. It can be seen that the population in peri-urban surroundings increased disproportionately when compared to rural areas and urban centres during the last two decades. Between 1999 and 2006 the population of rural areas increased at a higher rate than that of urban centres. Assuming that (i) private parking space availability in rural and peri-urban areas is higher than the one in urban centres (as partly shown in Chapter 4), (ii) changes with regards to the populations' location distribution continue to follow observed trends, and (iii) changes in household sizes do not vary across the different residential areas, the households' access to private parking facilities can be expected to increase over the next decade.



**Area immediately adjoining an urban area between the suburbs and the countryside*
Source: INSEE (2009b)

Figure 5.3: Annual population change per zone in France

The assumption that, on average, the households' access to private parking facilities remains constant over time is therefore likely to slightly underestimate the number of future EV-qualifying households.

Trip purposes and lengths of trips

In the constraints analysis, trip lengths for various types of trips (notably home-work trips and trips to secondary or occasional residences) are verified in order to check whether the household in question is prone to run into range problems should a limited-range vehicle be accommodated in the household's fleet. Data on how the lengths of each of these specific trips carried out with the private vehicle and for a specific purpose develop over time could not be identified. The following table shows observed trends concerning car usage for home-work trips and their associated lengths. It also gives information on the overall share of trips carried out with the private motorised vehicle.

	1982	1994	2008	Av. annual increase (1994-2008)
Average trip length to work (km)	9	12	15	1.61
Car share for home-work trips - men* (%)	52	67	70	0.26
Car share for home-work trips - women* (%)	48	57	69	1.32
Share of trips carried out with private motorised vehicle				
rural and weakly urbanised areas (%)		74	76	0
agglomerations (%)		56	55	-0.13

** use of vehicle as vehicle driver; only employed individuals with habitual working place considered*

Source: CGDD (2010), INSEE (2009c)

Table 5.1: Evolution of work trip characteristics in France

It can be seen that the average trip length to work increased moderately from 1982 to 2008. The assumption that households' trip lengths of home-work trips remain constant over the regarded time frame does not seem to be in significant conflict with these observations.

The share of home-work trips that are carried out by car changed only slightly during the period from 1994 to 2008. The car share of women's home-work trips increased more than that of men. In case motorisation rates decline (as suggested above) the car share for these trips can even be expected to remain constant or to decline in the upcoming years, which would be in slight contrast to the observations shown in Table 5.1. We therefore postulate that the assumption of a constant remaining share of usage for home-work trips up until 2023 is not in significant conflict with observed trends.

Further, the table shows that the overall share of trips carried out with the private motorised vehicle changed only moderately between 1994 and 2008. Also the assumption that the purposes of trips carried out with the private vehicle remain constant over time does therefore not appear to be in conflict with this data (NB: The data source does not give explicit information on the development of the share of trips carried out with motorised vehicles per single trip purpose).

Table 5.1 shows that slight decreases of car usage in agglomerations can be observed. This observation is in line with expected demotorisation trends in urbanised areas, where alternative modes of transport have been gaining increasing importance.

The annual driven distance with the private vehicle

The annual driven distance of a household's 'first' vehicle is used for TCO calculations. It is assumed that this annual distance (i) is the one that will be driven by the vehicle to be purchased, (ii) does not change over the ownership period of the vehicle, and (iii) does not increase or decrease for the household population in question up until 2023. Assumptions with regards to (i) and (ii) have already been discussed in Chapter 4 when the economic criterion of the constraints analysis was introduced and discussed. Applying the constraints analysis for each year up until 2023 also entails, however, assumption (iii), which means that the annual driven distances of households in 2023 are the same as in 2012 (and therefore according to what is observed in the underlying data source of the ENTD 2007/08).

Table 5.2 shows the development of average annual driven distances with the private vehicle for the time period from 1990 to 2010 in France. It can be seen that the average distance per vehicle decreased by 6.6 % over the regarded 14-year timeframe. The average annual driven distance per household (meaning the distance driven with the totality of the household's private vehicle fleet) decreased by 3.6 %. This weaker decrease of the driven distance per household

is explained by the increasing motorisation of motorised households, as observed in the same time frame (a trend that was shown in Figure 5.2).

in km	1994	2008	% change
per vehicle	13,942	13,020	-6.6
per household	20,950	20,186	-3.6
Nb of vehicles per motorised household	1.50	1.55	3.3

Source: CGDD (2010)

Table 5.2: Average annual driven distance with the private vehicle in France

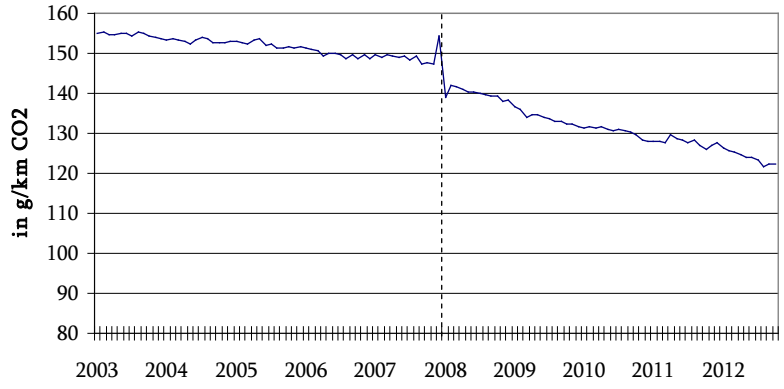
The numbers given in Table 5.2 suggest that the development of annual driven distances per vehicle will depend on the motorisation rate of households. Since we expect decreasing motorisation rates (at least in urbanised areas – as explained above) the development of annual driven distances per vehicle could be subject to a change, i.e. they could remain constant or even slightly increase in the upcoming years. For this reason, the assumption that future annual driven distances per vehicle remain constant is not seen to be in severe conflict with what has been discovered here. However, the replacement of a CV with an alternative fuel vehicle or with an EV specifically, might even result in increasing vehicle usage due to decreasing vehicle usage costs (as a result of increasing energy efficiency).

The households' preference for a certain vehicle type

The calculation of the total cost of vehicle ownership (TCO) for a household in question necessitates an assumption with regards to the vehicle type that the household is prone to purchase. As stated in Chapter 4, it is assumed that the preference of a certain vehicle type is in line with the household's "first" vehicle as stated in the ENTD 2007/08. Either a compact or a sedan vehicle type can be chosen by the household in the fictive vehicle purchase process. The assumption that households' preferences with regards to the vehicle type stay the same over the next decade is in conflict with what is expected. Increasingly stringent public policy measures on the CO_2 emissions of new motorised vehicles suggest that French car purchasers will increasingly tend to buy energy efficient, small vehicles. The French fee and rebate system (the bonus/malus system that has been put in place in January 2008) continuously favours such energy-efficient vehicles by both putting supplementary tax burdens on energy inefficient vehicles and by offering purchase subsidies to energy efficient vehicles. While from 2008 to 2011 all vehicles that emitted less than 60 g/km CO_2 were still eligible for a EUR 5,000 purchase bonus, this bonus is only offered for vehicles that emit less than 50 g/km from 2012 (since August 2012 this bonus has been increased to EUR 7,000 for vehicles emitting less than 20 g/km CO_2). Similar, but even more stringent conditions have been set for the malus (fees) that is (are) to be paid: in 2008, a fee of EUR 2,600 had to be paid for all vehicles that

emitted more than 250 g/km CO_2; in 2012, this fee was increased to EUR 3,600 and applied to all vehicles that emit more than 230 g/km CO_2 (MEDDE, 2012).[75] Maintaining such increasingly stringent policy measures is expected to result in increasing sales of energy efficient vehicles.

Figure 5.4 shows the development of the average CO_2 emissions of newly bought private cars in France over time. The effect of the introduction of the bonus/malus system can be clearly seen at the end of 2007/the beginning of 2008, when average CO_2 emissions were subject to a significant increase and an even more significant decrease straight afterwards. The increasingly rigorous bonus/malus system as well as the efforts of vehicle manufacturers to offer increasingly energy efficient vehicles[76] seems to be reflected by the continuous emissions decrease over the last 10 years.



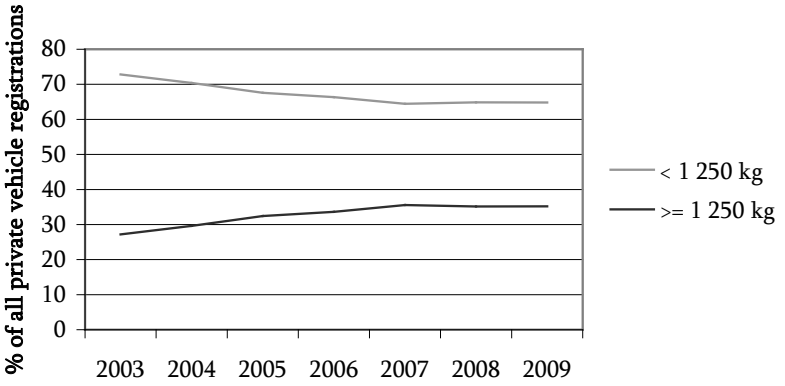
Source: CGDD (2012d)

Figure 5.4: Average CO_2 emissions of newly bought private cars in France

However, these emission reductions have not resulted in a remarkable change of the sales share of lighter vehicles until 2009 (Figure 5.5). This suggests that reduced emissions were rather due to improvements of the energy efficiency of the motor and/or its adjacent systems, the vehicles' tires, or the vehicles' aerodynamics. Neither vehicle downsizing (which results in the reduction of a vehicle's weight) nor increased preferences for smaller vehicles seem to have played an important role in lowering average CO_2 emissions.

[75] See annex A.1 for a complete overview of the French bonus/malus system since 2008.

[76] Which can be (partly) seen as the result of the EU's increasingly stringent emission standards (see chapter 1, section 3.1) (EC, 2009a).



Source: CGDD (2012c)

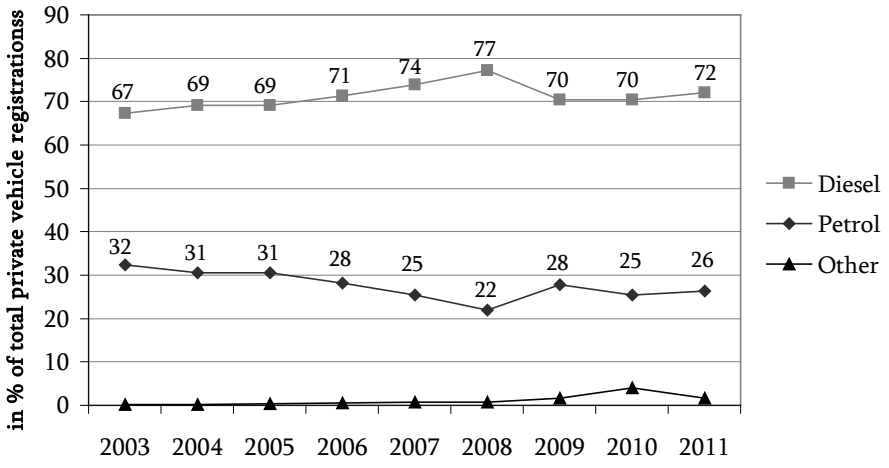
Figure 5.5: % share of newly registered private vehicles per weight category in France

We expect, however, that reductions of the average vehicle weight will increasingly be observed in case the fee and rebate system gets increasingly rigorous, and once vehicle manufacturers approach the limits of other emission reduction measures. There will be an increasing trend towards small, energy efficient vehicles. Our underlying assumption that households' preferences for a certain vehicle type will remain constant over time is therefore in conflict with this expectation. This might result in slight underestimations of the number of future EV-qualifying households. This is due to the fact that we observed a higher cost competitiveness of small, rather than big, EVs with their conventional counterparts (see the break-even analysis of Chapter 3).

The households' preference for a certain fuel type

Also the alleged preference of a household for a certain fuel type serves as input information for the TCO calculations. As it was done with the presumed preference for a certain vehicle type, we assume that a household's "first" vehicle (as stated in the ENTD 2007/08) gives information on which fuel type is preferred in case a CV is bought. We assume this preference to stay the same up until 2023.

Figure 5.6 shows that the percentage shares of private vehicle registrations per fuel type remained on similar levels during the last decade. A slight continuous increase in favour of Diesel vehicles can be observed. Registrations of diesel vehicles are, with a 70 % share of all vehicle registrations, largely dominant. For 2007 and 2008 (the year when the French emission-based fee and rebate system was introduced) outliers are observed.

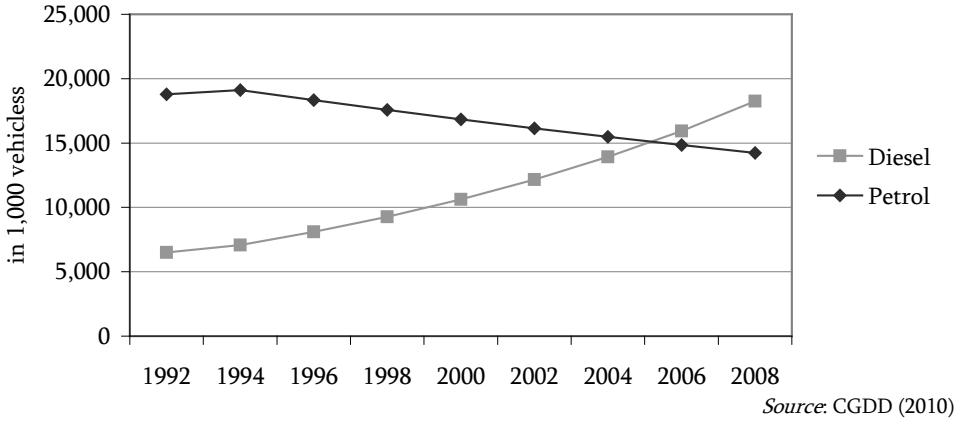


Source: CGDD (2012e)

Figure 5.6: Vehicle registrations per fuel type over time

Our assumption of constant vehicle preferences is, however, based on France's private vehicle fleet as observed in the ENTD 2007/08 (and not on vehicle sales in that year). Figure 5.7 shows that the sales distribution as depicted in Figure 5.6 resulted in a significantly increasing share of diesel vehicles in the French household vehicle fleet during the last two decades. Assuming a (nearly) constant diesel vehicle sales share over the next decade, the observed trend with regards to the whole fleet can be expected to flatten.

Given these findings, the assumption that supposed fuel type preferences (based on the 2007/08 vehicle fleet) remain constant over time will therefore underestimate potential diesel vehicle sales. This entails an overestimation of EV-qualifying households as EVs were found to be financially more competitive to (compact) petrol vehicles than to (compact) diesel vehicles (see the break-even analysis of Chapter 3).



Source: CGDD (2010)

Figure 5.7: Evolution of the French household vehicle fleet by fuel type

5.2.3 Summary and critical discussion

Summarising, it can be said that the underlying hypotheses, which assume household and vehicle usage characteristics to be constant over time, do not appear to severely contradict observed trends of the past. The assumption that these tendencies remain unchanged until 2023 is expected to result in both slight over- and underestimations of the future number of EV-qualifying households. Assumptions made with regards to fuel type preferences and households' level of motorisation are seen to result in overestimations, while assumptions with regards to vehicle type preferences and private parking facilities appear to result in underestimations. Assumptions behind the development of annual driven distances and trip purposes are seen to be largely in line with observed trends of the past.

Nevertheless, as already briefly touched upon in the discussion of future motorisation rates, there is no evidence that observed trends of the last decade are a legitimate basis for assumptions on future developments. On the contrary, they appear short-sighted in view of recent developments. In the last couple of years first indications of changing mobility behaviour in the developed world can be identified – Goodwin (2012) shows that such changes were even already observable during the years preceding the economic crises. This suggests that we are heading towards, or have even already reached the 'peak car' in the developed world. Assuming stagnation or even a decrease of car ownership rates and car usage (see discussion above and Goodwin, 2012) appears to be legitimate.

Potential triggers for such changes, which might result in significant changes of our mobility system in the upcoming decades, are manifold:

- saturation of the existing system (e.g. reflected by congestion);
- rising environmental awareness of travellers;
- increasing energy dependence of our transport system;
- ascending emissions stemming from the transport sector;
- technological advancements;
- changing cost structures of existing transport modes for both transport providers and users;
- new multimodal and integrated mobility offers;
- an ageing, but mobile remaining population;
- rising accessibility, awareness and acceptance of, and advancements in information and communication technologies,

are all factors that will further result in, or alternatively cause, increasingly stringent environmental and industrial policies on the local, national and international level, which will also contribute in altering our mobility system. Car ownership and use is expected to become increasingly less interesting. How fast new mobility habits will actually develop remains unclear and will depend on the inertia of the whole mobility system (see, e.g. Lenz, 2011; Académie des

Technologies, 2012). From this perspective, public policies will have a crucial role.[77]

Fundamental changes in mobility behaviour that might already emerge until 2023 are largely ignored in the underlying study – especially since private vehicle usage (i.e. the annual distance driven) is assumed to stay constant over time and within the vehicle ownership period (the latter one even implying a look into the future up until 2030).

5.3 Parameter forecasts per scenario

This section outlines specific assumptions on parameter values that are mainly necessary for TCO calculations. They define if and at which speed EVs will become financially advantageous over CVs. Since there are many uncertainties concerning how vehicle characteristics and market trends will develop over time, different scenarios have been established. These do not intend to represent precise predictions of the future. Rather, they give an impression of possible realities, given today's lack of data with regards to future developments of framework conditions. Once the introduced scenarios are assessed, sub-scenarios are developed that specifically explore the impact of policy measures. These are presented in the subsequent results section (5.4), after the results of the base scenarios presented here have been obtained.

In the following, an introduction to the scenarios is given. The basic methodology of how they were developed is explained. Next, the more detailed assumptions on the precise development of each parameter value until the end of the forecasting period are stated. Partly, only their development with regards to the "base value", the parameter's value as of 2012 is given. Chapter 3 gives information on how such base values were defined. Annex 5.2 to 5.5 give a comprehensive overview of all forecasted parameter values.

5.3.1 Scenario overview

Altogether 3 base scenarios are developed:

The **"baseline" scenario** gives from our perspective the most realistic forecast of future developments. All input parameters are estimated as realistically as possible. Estimations are either based on observed developments of the past or on a comprehensive literature review. Government incentives are assumed to largely run out by 2023. Vehicle technologies are supposed to progress for both EVs and CVs in a similarly realistic way. Energy prices follow "medium" price forecasts as they were already introduced in Chapter 3.

[77] See the discussion on the role of public policies in chapter 1, an overview of the portfolio of public policy measures in chapter 2.

The **"EV+" scenario** reflects a situation where most framework conditions develop to the advantage of the EV. The scenario is built around the baseline scenario but underlying assumptions categorically assume (slightly) more EV-positive developments. Public policy measures are maintained for a longer time period; vehicle technologies mainly develop to the advantage to the EV; fuel prices follow the "high" scenario, while electricity prices increase in a more moderate way than what was assumed in the baseline scenario.

The "CV+" scenario reflects a situation where framework conditions develop in favour of the CV. Also this scenario is built around the baseline scenario, but categorically assumes more CV-advantageous developments. Technological developments are in favour of the CV; public policy measures rapidly decrease from 2012 onwards. Fuel prices follow the "low" forecast scenario, while electricity prices increase more than in the baseline scenario.

The EV+ and CV+ scenarios can therefore be seen as extreme-case scenarios.

5.3.2 Forecasting vehicle development

The parameters that describe the vehicles' development and that are integrated in our TCO model are i) the EV's battery price, ii) the vehicle price per vehicle type, iii) the energy consumption per vehicle type, and iv) the vehicles' range (in case of the battery electric vehicle, the BEV). We assume a continuous and gradual evolution of all these parameters reflected by annual changes of the parameter values. Especially in the case of the EV models, this does not reflect the actual market availability of this type of vehicle. It is expected that market availability remains quite limited throughout the next years. However, we judge results obtained by introducing gradual developments to be more realistic than results that would be derived from introducing sudden technological advancements in the forecasting tool.

Battery price

Battery price forecasts were developed according to findings in literature. Table 5.3 gives an overview of reviewed studies and their battery price forecasts. Price forecasts are given in USD/kWh on a battery pack level. Attention is drawn to the fact that the values shown are not directly comparable. While all stated studies give forecasts for Lithium-Ion batteries, not all refer to batteries of the same size/capacity or the exact technology (according precisions are frequently not even stated in the sources). Several studies differentiate price forecasts for BEVs and PHEVs (as battery packs of PHEVs (plug-in hybrid electric vehicles) are less generic in terms of power requirements) (Element Energy, 2012), and develop different scenarios that refer to different EV penetration scenarios.

BatPac (2011) is the only study that explicitly states that battery prices will, above all, depend on production levels. Price forecasts of BatPac (2011) can only be obtained after having defined the annual production level of a battery producer. Further, it can be seen that battery prices per kWh depend on the capacity of the battery. IEA (2009c), Roland Berger (2011), and Zero Emission Vehicles (2010) fail to state which battery capacities underlie price forecasts. All studies forecast significant battery price decreases between 2015 and 2025. Element Energy (2012) and BatPac (2011) forecast that more significant price decreases will take place in the first half of this period (from 2015 to 2020). Starting values (the price level in 2015) vary, however, significantly. Assuming that a battery producer has a production level of 10,000 batteries per year in 2015, BatPac (2011) forecasts a battery price of below 400 USD/kWh. The low price scenario of Zero Emission Vehicles (2011) results in a similar price level. All other studies and scenarios foresee higher prices: they range from 417 USD/kWh (see the EV push scenario of Element Energy, 2012) to 952 USD/kWh (see the high price scenario of Zero Emission Vehicles, 2010). Assumed underlying production levels are not stated.

Our forecasts are based on a battery price level of 570 USD/kWh (or 450 EUR/kWh as of 12 November 2012). In comparison to the reviewed studies, this price level appears to be a medium price for the year 2015. It has therefore been decided to keep this price level until 2015 (for both BEVs and PHEVs) in the baseline scenario. After that, the BEV (PHEV) battery prices are assumed to fall by 7 % (6 %) per year until 2020. From 2020 to 2025 prices are assumed to fall by 6 % (5 %) per year. The differences between BEV and PHEV price developments shall reflect the expected higher price levels of PHEV battery packs. The annual price decreases are approximately in line with the medium/baseline scenarios that were identified in the literature review. Only BatPaC (2011) battery price levels appear to be significantly lower.

The EV+ and CV+ scenarios are built around the baseline scenario. They vary annual price changes as well as the assumption of when first price decreases begin after the starting value of 570 USD/kWh in 2012. Table 5.4 gives a complete overview of assumed battery price developments per EV type and scenario. Prices for battery hire are assumed to evolve in the same manner as battery purchase prices.

Study	Scenarios	Price Forecast in USD/kWh (on battery pack level)						Average annual decrease in %				Notes
		BEV			PHEV			BEV		PHEV		
		2015	2020	2025	2015	2020	2025	2015 - 2020	2020 - 2025	2015 - 2020	2020 - 2025	
BCG (2010)	*low price*	-	360	-	-	-	-	-	-	-	-	Values for a 15 kWh battery
	high price		440									
Element Energy (2012)	*EV push*	417	245	202	696	439	380	10.1	3.8	8.8	2.8	Values for a 30 kWh BEV battery or a 12 kWh PHEV battery; scenarios represent different EV uptake and technology development speeds
	baseline	483	318	225	798	523	435	8.0	6.7	8.1	3.6	
	niche EV	517	399	291	853	639	512	5.0	6.1	5.6	4.3	
IEA (2009c)	*low price*	470	350	-	570	420	-	5.7	-	5.9	-	Time intervals approximate; values for a 150km range BEV
	high price	620	530		755	645		3.1		3.1		
Roland Berger (2011)	-	-	-	265	-	-	-	-	-	-	-	Achievable costs in the 'long term'
Zero Emission Vehicles (2010)	*low price*	349	292	-	-	-	-	3.5	-	-	-	(EUR-USD conversion as of 14/11/2012)
	medium	580	381					8.1				
	high price	952	571					9.7				
Batt.Capacity / Batt.Production		*10,000/y*	*50,000/y*	*100,000/y*	*10,000/y*	*50,000/y*	*100,000/y*					Model results for LiNiMn batt., diff. pack unit production levels, and diff. battery capacities; % values based on assumption that modelled production volumes materialise for a batt. manufacturer in question
BatPaC (2011)	*10 kWh*		-		478	366	335	-	-	5.2	1.8	
	15 kWh	369	288	266	368	287	265	4.8	1.6	4.9	1.6	
	20 kWh	323	256	238		-		4.5	1.4	-	-	

Table 5.3: Battery cost forecasts found in literature

Scenario	BEV								
	EV+			Baseline			CV+		
Year	*annual % change*	*Cost in USD/kWh*	*ratio with 2012 value*	*annual % change*	*Cost in USD/kWh*	*ratio with 2012 value*	*annual % change*	*Cost in USD/kWh*	*ratio with 2012 value*
2012	-	570	1.00	-	570	1.00	-	570	1.00
2013	0.05	542	0.95	0.00	570	1.00	0.00	570	1.00
2014	0.05	514	0.90	0.00	570	1.00	0.00	570	1.00
2015	0.05	489	0.86	0.00	570	1.00	0.00	570	1.00
2016	0.08	450	0.79	0.07	530	0.93	0.05	542	0.95
2017	0.08	414	0.73	0.07	493	0.86	0.05	514	0.90
2018	0.08	381	0.67	0.07	458	0.80	0.05	489	0.86
2019	0.08	350	0.61	0.07	426	0.75	0.05	464	0.81
2020	0.08	322	0.57	0.07	397	0.70	0.05	441	0.77
2021	0.06	303	0.53	0.06	373	0.65	0.05	419	0.74
2022	0.06	285	0.50	0.06	350	0.61	0.05	398	0.70
2023	0.06	268	0.47	0.06	329	0.58	0.05	378	0.66

Scenario	PHEV								
	EV+			Baseline			CV+		
Year	*annual % change*	*Cost in USD/kWh*	*ratio with 2012 value*	*annual % change*	*Cost in USD/kWh*	*ratio with 2012 value*	*annual % change*	*Cost in USD/kWh*	*ratio with 2012 value*
2012	-	570	1.00	-	570	1.00	-	570	1.00
2013	0.04	547	0.96	0.00	570	1.00	0.00	570	1.00
2014	0.04	525	0.92	0.00	570	1.00	0.00	570	1.00
2015	0.04	504	0.88	0.00	570	1.00	0.00	570	1.00
2016	0.07	469	0.82	0.06	536	0.94	0.04	547	0.96
2017	0.07	436	0.77	0.06	504	0.88	0.04	525	0.92
2018	0.07	406	0.71	0.06	473	0.83	0.04	504	0.88
2019	0.07	377	0.66	0.06	445	0.78	0.04	484	0.85
2020	0.07	351	0.62	0.06	418	0.73	0.04	465	0.82
2021	0.05	333	0.58	0.05	397	0.70	0.04	446	0.78
2022	0.05	317	0.56	0.05	378	0.66	0.04	428	0.75
2023	0.05	301	0.53	0.05	359	0.63	0.04	411	0.72

Table 5.4: Assumed Lithium-Ion battery price developments per scenario and EV type

Vehicle price

Vehicle price forecasts for the CV were based on observed price developments of new vehicles in the past. A regression analysis was carried out on the price indices of new automobiles in France from 2000 to 2012 (see Figure 5.8) in order to obtain price forecasts for the baseline scenario. Figure 5.8 reveals that prices increased from 2000 onwards. This general increase was subject to severe monthly fluctuations. Since the aim was not to reflect such monthly fluctuations in our forecasts, the regression analysis was carried out on the annual averages of the shown price indices only. The resulting average annual price increase amounts to

$$a_{CV} = 0.94\,\%$$

For the CV+ and the EV+ scenario we assume an annual price increase of $(a_{CV} \cdot 50\%)$ and of $(a_{CV} \cdot 150\%)$ of the baseline scenario's value.

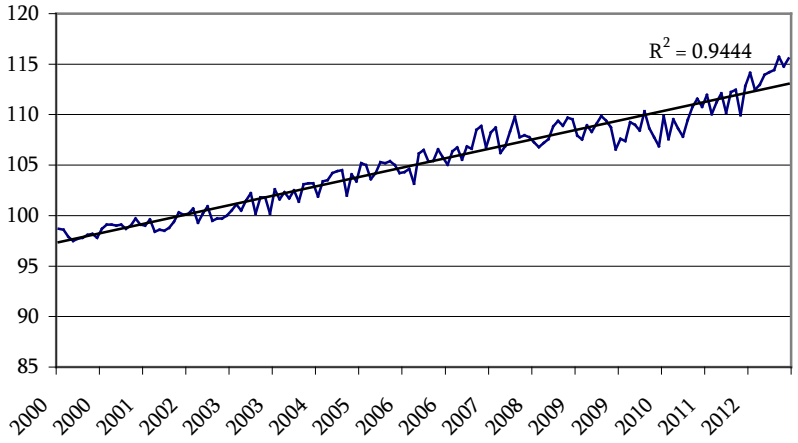


Figure 5.8: Price index of French automobiles
(base year is 1998 with an index of 100)

The price forecasts for the **BEV** are based on the CV's forecasts, although EV prices will still be largely dependent on the still uncertain future demand of these vehicles as well as on demand-dependent economies of scale and learning curves in the production processes. It is assumed that 50 % of the CV's price increases are due to developments of the combustion engine, while 50 % are due to developments of vehicle tires, of the vehicle's chassis, of used materials etc. These latter advancements are assumed to be the same for the BEV excluding i) its battery, and ii) the electronics and electric parts that are due to the electrification of the vehicle's traction chain (as, e.g. the electric motor). We assume that the BEV's value due to the electrification of the traction chain amounts to 20 % of the total vehicle's value (excluding its battery). This signifies that the "remaining" parts of the BEV amount to 80 % of the vehicle's value (without the battery). The annual price change of the BEV (without its battery) therefore amounts to

$$a_{BEV} = \frac{a_{CV}}{2} \cdot 80\% + b \cdot 20\%$$

for the baseline scenario, where b gives the annual price change of the vehicle's electric parts. The latter is still subject to significant learning effects in the production processes and is assumed to be -1% (based on CAR (2011) that gives annual cost reductions due to scale volumes of electrical machines for automotive applications). This results in

$$a_{BEV} = 0.17\%$$ [78]

For the CV+ and the EV+ scenarios we assume only moderate changes of the annual price increases with regards to the baseline scenario. We assume an annual BEV price change of $(a_{BEV} \cdot 120\%)$ for the CV+ scenario, and of $(a_{BEV} \cdot 80\%)$ for the EV+ scenario.

For the **PHEV** the same methodology as for the BEV is applied. The value of the PHEV (without its battery) is repartitioned onto the parts that conform to the CV, and onto the vehicle's parts that stem from the electrification and hybridisation of the vehicle. Since the hybridisation of the vehicle is assumed to carry a higher value than the sole electrification of the vehicle in the BEV's case, we accord 40 % of the vehicle's value (without its battery) to the new hybrid technology in the vehicle. This 40 % is subject to the annual price change b, as was the case for the electrification technology, since similar learning effects and effects of economies of scales are assumed. Contrary to the assumptions made for the BEV, this 40 % gives a likely realistic estimate of the actual value share of the hybridisation (the PHEV's value (without its battery) is 40 % higher than the sedan, diesel CV's value). Since the hybrid technology proved to be financially less viable from the client's perspective, we assume that all prospective production cost decreases are passed on to the client. The PHEV's 60 % value share that is conform to the CV technology is subject to the same annual price decrease as the CV, namely to a_{CV}. The total annual price change for the PHEV in the baseline scenario is therefore given by

$$a_{PHEV} = a_{CV} \cdot 60\% + b \cdot 40\%$$

which amounts to

$$a_{PHEV} = 0.16\%.$$

For the CV+ and EV+ scenarios the same changes as for before for the BEV are assumed: the PHEV price changes by an annual rate of $(a_{PHEV} \cdot 120\%)$ for the CV+ scenario, and of $(a_{PHEV} \cdot 80\%)$ for the EV+ scenario.

Table 5.5 gives an overview of the assumed annual price changes per vehicle type and scenario as well as the resulting price ratio with the 2012 vehicle price.

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[78] We actually assume that the value ratio of the BEV of 80-20 underestimates the value share of the electric parts/electronics of the vehicle that are due to the electrification of the traction chain. The value difference between the CV (without its combustion engine motor) and the BEV (without its battery) is higher than 20 % of the BEV's value. It actually amounts to almost 60 % of the BEV's value. This deliberate underestimation shall reflect that we do not assume that all prospective price decreases (due to learning effects and economies of scale) will get passed on to the client: rather, they are used to cover investments in research and development.

	CV (Vehicle incl. motor)			**BEV** (Vehicle excl. battery)			**PHEV** (Vehicle excl. battery)		
Scenario	**EV+**	**Baseline**	**CV+**	**EV+**	**Baseline**	**CV+**	**EV+**	**Baseline**	**CV+**
Annual change (%)	1.40	0.94	0.47	0.14	0.17	0.21	0.13	0.16	0.19
Year	*resulting price ratio with 2012 value*								
2012	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2013	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2014	1.03	1.01	1.01	1.00	1.00	1.00	1.00	1.00	1.00
2015	1.04	1.02	1.01	1.00	1.01	1.01	1.00	1.00	1.01
2016	1.06	1.03	1.02	1.01	1.01	1.01	1.01	1.01	1.01
2017	1.07	1.04	1.02	1.01	1.01	1.01	1.01	1.01	1.01
2018	1.09	1.05	1.03	1.01	1.01	1.01	1.01	1.01	1.01
2019	1.10	1.06	1.03	1.01	1.01	1.01	1.01	1.01	1.01
2020	1.12	1.08	1.04	1.01	1.01	1.02	1.01	1.01	1.02
2021	1.13	1.09	1.04	1.01	1.02	1.02	1.01	1.01	1.02
2022	1.15	1.10	1.05	1.01	1.02	1.02	1.01	1.02	1.02
2023	1.17	1.11	1.05	1.02	1.02	1.02	1.01	1.02	1.02

Table 5.5: Vehicle price forecasts per vehicle type and scenario

Price forecasts of different vehicle types are difficult to find in literature. One exception is CE Delft (2011). CE Delft's baseline scenario shows similar CV price developments (+ 2.5 % every 5 years) to our baseline scenario. PHEV and BEV price developments are assumed to be same and do not differentiate vehicle price and battery price developments. A 2.5 % price decrease every 5 years is assumed in the baseline scenario. Taking the combined effect of BEV price and battery price developments until 2020, our assumptions result in a 4.3 % price decrease every 5 years in the baseline scenario, which is rather in line with CE Delft's "EV breakthrough" scenario until 2015, where a 5 % price decrease is assumed. Thereafter a price decrease of 15 % is assumed for the EV breakthrough scenario. CE Delft's price forecasts lack, however, any argumentation behind the assumed values.

Energy consumption

The forecasts for the energy consumption of **CVs** are based on projections of Bodek and Heywood (2008). They give expected fuel consumption levels for European petrol and diesel vehicles up until the year 2035, which result from gradual annual efficiency improvements. This allows the estimation of approximate potential fuel consumptions of each powertrain technology at any point in time up until 2035. For the time period from 2012 until 2023, a potential fuel consumption reduction of 19 % and 18 % for petrol and, respectively, diesel vehicles can be found. These numbers reflect the technical potential – the possible level of fuel consumption that can reasonably be achieved if future vehicle characteristics (e.g. acceleration, top speed, and weight) were kept at the same level. Analysis of historic data on vehicles'

performances, vehicles' fuel economies, and vehicles' weights gives information on how the technical potential for reductions in fuel consumptions was utilised in the past. Bodek and Heywood (2008) show that the level of what they call emphasis on reducing fuel consumption (ERFC)[79] varies significantly per country. In the time period from 1995 to 2006 the average ERFC for France's new petrol (diesel) vehicles was 68 % (64 %). In Germany, the according value amounts to only 54 % (22 %). These values are significantly higher than what has been observed for the US, where the ERFC of petrol vehicles over the same time period was less than 10 %.

Our fuel consumption development scenarios evolve around the identified 19 % (18%) technical reduction potential for petrol (diesel) vehicles. In the baseline scenario, we assume that the ERFC value starts at 75 % in 2013. After that, it is subject to an annual increase of 1 % up until 2023 – irrespective of any utilised or non-utilised fuel reduction potential of the years before. This assumption is based on the expectation of increasingly stringent policy measures with regards to vehicle emissions. These will force vehicle manufacturers to increasingly exploit the technical fuel reduction potential for actual fuel economy improvements rather than for increases in vehicle performance. In the EV+ scenario, we assume that the ERFC value slightly decreases to what has been found in the period from 1995 to 2006: the ERFC value amounts to 60 % and shows an annual increase of only 0.5 % up until 2023. In the CV+ scenario we assume that the ERFC value starts and remains at 90 % up until 2023.

Taking the advertised diesel consumption levels of the Renault Clio (4.0 l/100 km) and the Renault Fluence (4.5 l/100 km) as the basis for forecasting future consumption levels[80], we obtain 2020 consumption levels of 3.5 and 4.0 l/100 km in the baseline scenario. These translate to CO_2 emission levels of 94 and 106 gCO_2/km[81]. Such emission levels are just in line or, respectively, just above the European Union's target of average emissions of 95 gCO_2/km of a manufacturer's car fleet (EC, 2009a). It is therefore expected that the baseline scenario gives a quite realistic forecast of future vehicle consumption levels.

[79] %ERFC = realised fuel consumption reduction / possible fuel consumption reduction assuming constant vehicle size and performance

[80] NB: These are not the values used in the TCO calculation model which differentiates between urban, peri-urban, and urban/peri-urban usage of the vehicles and takes values according to results of real-life vehicle test drives.

[81] According to conversion factors as obtained from http://www.unitjuggler.com/convert-fuelconsumption-from-lper100km-to-gperkmdiesel.html (accessed 2 December 2012).

	CV - Petrol			CV - Diesel		
Red. Potential 2012-2023	19%			18%		
	EV+	**Baseline**	**CV+**	**EV+**	**Baseline**	**CV+**
ERFC Value	60%	75%	90%	60%	75%	90%
Annual increase	0.5%	1.0%	0.0%	0.5%	1.0%	0.0%
Year	*resulting fuel consumption ratio with 2012 value*					
2012	1	1	1	1	1	1
2013	0.99	0.99	0.98	0.99	0.99	0.98
2014	0.98	0.97	0.97	0.98	0.97	0.97
2015	0.97	0.96	0.95	0.97	0.96	0.95
2016	0.95	0.94	0.93	0.96	0.94	0.94
2017	0.94	0.93	0.92	0.94	0.93	0.92
2018	0.93	0.91	0.90	0.93	0.91	0.91
2019	0.92	0.90	0.89	0.92	0.90	0.89
2020	0.91	0.88	0.87	0.91	0.89	0.88
2021	0.90	0.87	0.86	0.90	0.87	0.86
2022	0.88	0.85	0.84	0.89	0.86	0.85
2023	0.87	0.84	0.83	0.88	0.84	0.84

Table 5.6: Fuel consumption forecasts per fuel type and scenario

In the baseline scenario, the electricity consumption of the **BEV** is assumed to fall to 85 % of the starting value in 2012. This reflects an average annual electricity consumption reduction of 1.5 %, which is a more optimistic than the 1.0 % that is assumed in the "most realistic" scenario of CE Delft (2011). In the EV+ scenario we assume that the electricity consumption levels drop to 75 % by 2023, which signifies an average annual change of 2.6 %. For the CV+ scenario we assume that no reduction in electricity consumption can be achieved by 2023.

Fuel and electricity consumption forecasts for the petrol and electricity mode of the **PHEV** are according to the forecasts of the petrol CV and, respectively, the BEV.

Range

Closely related to the topic of electricity consumption is the range of the BEV. The higher the energy efficiency of the vehicle and its battery, the higher is the range of the BEV, given that the battery capacity is kept at the same level. For the baseline scenario we assume that the above forecasted increasing energy efficiency of BEV comes in hand with slight reductions of the batteries' capacity. Only this way the battery price decreases, as they were forecasted for the baseline scenario (see above), can be realised. The range of the vehicle therefore remains at (the rather conservative value of) 120 km. For the CV+ scenario, we assume that the assumed constant energy consumption of the BEV over time (see above) does neither allow for reductions in the batteries' capacity, nor for increased autonomies. Also here, the vehicle's range therefore remains at

120 km. Only in the EV+ scenario an increase in the range can be achieved: the increased energy efficiency goes not to the cost of the battery's capacity (and price) reduction, but can actually be converted to an increased cruising range of the vehicle. Battery price decreases as forecasted above can be achieved without any reductions in the battery capacities.

5.3.3 Forecasting market trends

The parameters used for describing future market trends and that are integrated in our TCO model are i) energy prices, ii) the EV maintenance cost share (compared to the CV's maintenance costs), iii) insurance cost reduction for BEVs, and iv) the market interest and inflation rate.

Energy prices

Since the objective of this forecast is to foresee the number of EV-qualifying households until 2023, and purchased vehicles are assumed to be hold for a period of 7 years, energy price forecasts need to be developed until the year 2030.

As already introduced in Chapter 3, **fuel price forecasts** are obtained from the Annual Energy Outlook 2011 of the US Energy Information Administration (EIA, 2011) and translated to the French context by using data of passed French price developments, hereby assuming a constant EUR-$ exchange rate. Since exact values up until 2023 were already stated in Chapter 3, we content ourselves with the visual representations of assumed fuel prices per scenario in Figures 5.9 (for petrol prices) and 5.10 (for diesel prices). Shown values comprise French taxes as according to the baseline policy scenario (see Section 5.3.4 hereafter). Values for the years 2020 and 2030 are stated explicitly.

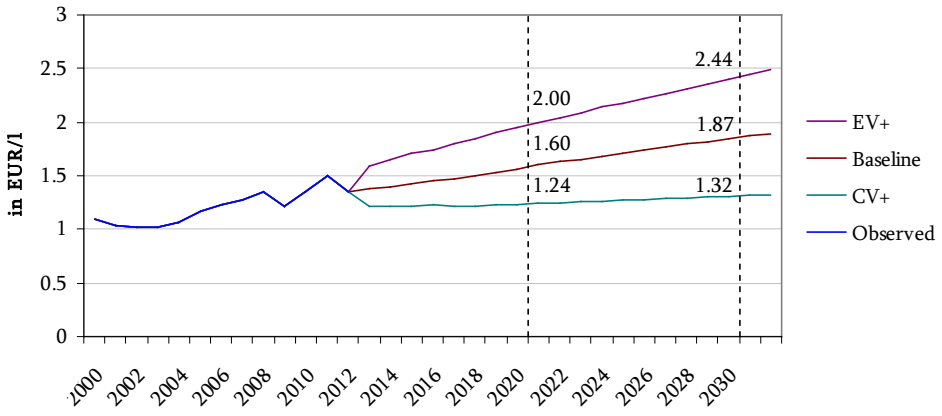


Figure 5.9: Petrol price forecasts per scenario

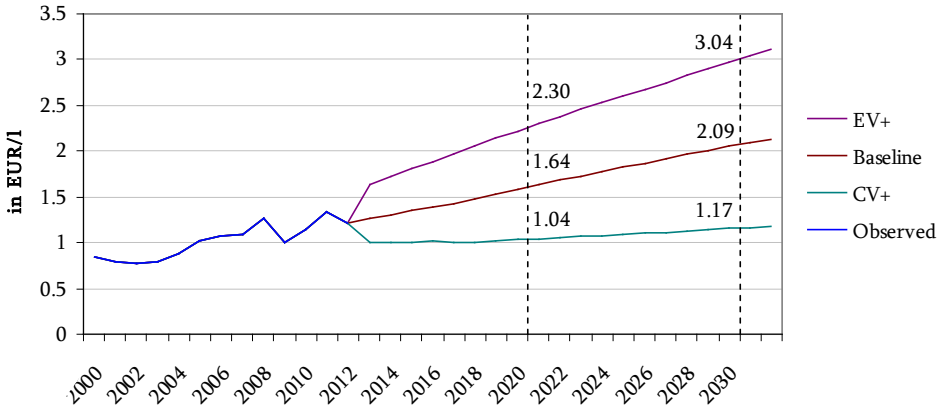


Figure 5.10: Diesel price forecasts per scenario

French fuel prices of the first half of 2012 (petrol: 1.59 EUR/l, diesel: 1.41 EUR/l; DGEC, 2012) suggest that we are currently following the EV+ scenario (meaning the high fuel price scenario). Whether this trend is ongoing remains to be observed.

The motivation behind **electricity price forecasts** was already given in Chapter 3. We assume a continuous price increase for all 3 scenarios due to the awaited increasing investments in renewable energies (Sénat, 2012). For the baseline scenario an annual price increase of 4 % until 2030 is assumed; for the EV+ and the CV+ scenarios we assume an annual price increase of 3 % and, respectively, 7 %. A commission of the French Senate on electricity prices (Sénat, 2012) expects a 50 % increase of 2011 French electricity prices by 2020. This expectation is line with the baseline scenario.

shows the electricity prices per scenario including all taxes (hereby assuming the baseline electricity taxation scenario – see Section 5.3.4).

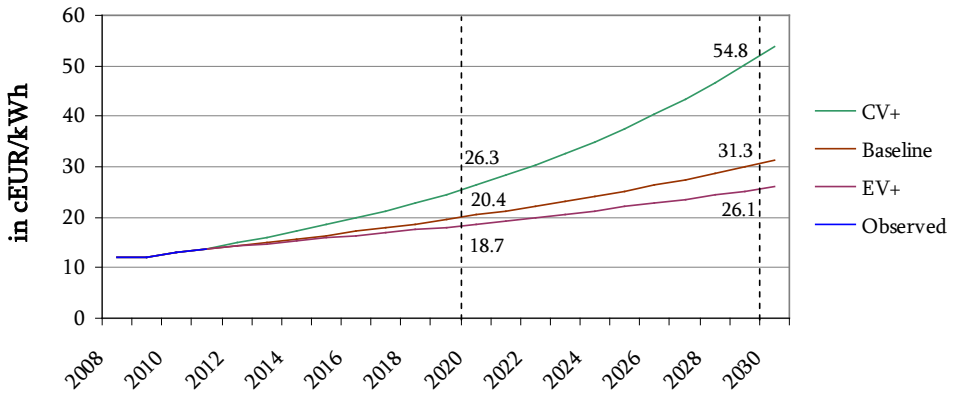


Figure 5.11: Electricity price forecasts per scenario

BEV maintenance cost share

The BEV maintenance costs are defined as share of the maintenance costs of the BEV's conventional counterpart. A vehicle's maintenance costs mc_t^Y in year t (of the total vehicle ownership period T) of a vehicle bought in year Y are assumed to be the same for all $t \in [0,T]$:

$$mc_{t+1}^Y = mc_t^Y, \forall t \in [0,T-1] \text{ and } Y \in [2012,2023].$$

A vehicle bought at a later point in time (in a different base year Y) is subject to inflated maintenance costs, so

$$mc_t^{Y+1} = mc_t^Y \cdot r^Y, \forall t \in [0,T] \text{ and } Y \in [2012,2022]$$

where r^Y gives the inflation rate of year Y. As we assume constant maintenance cost over the vehicle ownership period, the real discount rate is applied for discounting maintenance costs to the base year Y, the year of vehicle purchase (as stated in Chapter 3, Section 3.2.4; see *market interest and inflation rate* later in this section, for the assumed development of the discount rate over time).

Vehicle manufacturers show continuous efforts towards decreasing vehicle service costs of BEVs with the objective of eventually attaining a cost share of 50 % (according to discussions with Renault). A German study (Cars21, 2012f) estimates that today's small BEVs attain already a 65 % cost share over a usage period of 8 years. We therefore assume decreasing BEV maintenance cost shares in all scenarios. Again, these are built around the reference scenario as introduced in Chapter 3. For vehicles bought in 2012, a maintenance cost share with regards to conventional vehicles of 80 % is assumed. In the baseline scenario, this share is assumed to fall to 60 % for vehicles bought in 2023. For the EV+ and CV+ scenarios, this latter value falls to 50 %, and 70 % respectively. Table 5.7 reveals how these cost shares develop over time.

	EV+	Baseline	CV+
2012	80	80	80
2013	77	78	79
2014	73	76	78
2015	70	74	77
2016	67	72	76
2017	65	70	75
2018	62	68	74
2019	59	67	73
2020	57	65	73
2021	54	63	72
2022	52	62	71
2023	50	60	70

Table 5.7: BEV maintenance cost share per scenario
(in relation to a comparable CV, in %)

The maintenance costs of CVs are assumed to stay constant over the vehicle ownership period (as described above, they only change with the inflation rate from one vehicle purchase year to the next). Refer to Chapter 3, Section 3.2.4, for the base values of CV maintenance costs for the year 2012.

Insurance cost reduction for BEVs

In the reference scenario of Chapter 3, a BEV insurance cost reduction of 20 % was assumed. This value was based on observed offers (as of 2012) of French insurers that actively support the uptake of BEVs. Similar to the BEV maintenance costs, the annual insurance costs (ic) are also assumed to stay the same over the vehicle ownership period T for a vehicle bought in year Y:

$$ic_{t+1}^{Y} = ic_{t}^{Y}, \forall t \in [0, T-1] \ and \ Y \in [2012, 2023].$$

As was the case for maintenance costs, a vehicle bought at a later point in time is subject to inflated insurance costs, so to

$$ic_{t}^{Y+1} = ic_{t}^{Y} \cdot r^{Y}, \forall t \in [0, T] \ and \ Y \in [2012, 2022]$$

where r^{Y} gives the inflation rate of year Y. Although we assume constant insurance costs over the vehicle ownership period, insurance costs are discounted with the nominal discount rate to the year of vehicle purchase. This shall reflect assumingly decreasing insurance costs over time (as it often is the case if no insurance claims have been made).[82]

It is expected that preferential BEV insurance offers (as observed in 2012) will only hold for a limited amount of time. For the baseline scenario we assume that all EV-preferential insurance tariffs have been suppressed by 2022. In the CV+ scenario they do so by 2017; in the EV+ they do so only after 2023. See Table 5.8 for assumed BEV insurance cost shares per year and scenario.

[82] See chapter 3, section 2.4, for a discussion of the discount rate, and the following section for assumptions on its development over time.

	EV+	Baseline	CV+
2012	20	20	20
2013	19	18	16
2014	18	16	12
2015	17	14	8
2016	16	12	4
2017	15	10	0
2018	14	8	0
2019	13	6	0
2020	12	4	0
2021	11	2	0
2022	11	0	0
2023	10	0	0

Table 5.8: BEV insurance cost reduction
(in % of the insurance costs of a comparable CV)

Market interest and inflation rate

Chapter 3, Section 3.2.4, gives an explanation of how the market interest rate is used for discounting future costs to the year of the vehicle purchase. The nominal discount rate, applied to inflated cost forecasts (such as energy prices), is equivalent to the market interest rate. The real discount rate, applied to non-inflated cost forecasts (such as maintenance costs), is the market interest rate minus the inflation rate. For all scenarios we assume constant inflation and market interest rates over time. The values shown in Table 5.9 are therefore valid for the whole time frame from 2012 to 2030 (the assumed last year of vehicle ownership of a vehicle bought in 2023). Again, the forecast scenarios defined here are built around the reference scenario as introduced in Chapter 3. The baseline scenario takes the same values as the reference scenario in Chapter 3. The EV+ scenario is built in such a way that resulting discount rates are lower than the ones of the baseline scenario (this way, the cost advantage of EVs that potentially materialises over the vehicle usage period is less discounted). The nominal discount rate in the EV+ scenario amounts to 5.5 % (being the market interest rate); the real discount rate amounts to 3.5 % (= 5.5 – 2.0 %), given the assumed higher level of the inflation rate. It was decided to keep the market interest rate for the CV+ scenario as in the baseline scenario, as the baseline scenario appears to be a rather conservative value (e.g. ITF (2012) builds its scenarios around a 4 % discount rate, one scenario is modelled with a 8 % discount rate). The inflation rate is assumed to be 1.4 % which results in a rather high remaining real discount rate of 5.1 %.

(in %, 2012 - 2030)	EV+	Baseline	CV+
Market Interest Rate	5.50	6.50	6.50
Inflation Rate	2.00	1.73	1.40

Table 5.9: Assumptions for the market interest and inflation rate per scenario

5.3.4 Evolving perceptions of BEVs

As mentioned in Section 5.2, the forecast on the number of EV-qualifying households is largely based on the assumption that household characteristics as well as vehicle usage behaviour remains the same within the next decade. However, certain perceptions of the limited-range BEVs could evolve. This refers to the fact that potential BEV users might get less and less sensitive to the range restrictions of BEVs. The reasons behind such a potentially decreasing sensitivity are seen to be mainly threefold[83]: Firstly, vehicle users might increasingly understand their actual vehicle usage behaviour and recognise that most (or even the totality) of their trips carried out on a daily basis do (does) actually lie(s) within the range of a BEV. As a result, expectations with regards to the provision of public (and even private) parking and recharge infrastructure might decrease. Such developments could be due to increased efforts undertaken by policy makers and/or other e-mobility stakeholders who create awareness for electric vehicles and their usage among vehicle owners. Secondly, an increased presence of public (and private) recharge infrastructure over time could give more and more comfort to vehicle users. These latter ones become increasingly aware of recharge possibilities throughout the day and are, in consequence, more willing to take the "risk" to have to recharge their potential BEV away from their home. Thirdly, increased presence, accessibility and flexibility of (short-term) vehicle rental services can cause increased acceptance of such services as a fall-back option for trips out of the BEV's range. As a consequence, the range issue of the BEV might be perceived less of a hindrance to a potential BEV purchase.

The definition of the constraints analysis (as introduced in Chapter 4, Section 4.3) allows for taking such potential attitude changes into account. Some of the household selection criteria that are applied in the constraints analysis can be relaxed. We do so in different ways for the definition of the baseline, EV+ and CV+ scenarios. The following table gives information on which household selection criteria are relaxed and by which year per defined scenario. The notes of the table recap the meaning of the selection criteria in question. Refer to

[83] A first discussion on reasons and possible effects of such changing attitudes were already presented in section 4.2 of chapter 4, where a sensitivity analysis of household selection criteria was carried out.

Chapter 4, Section 4.3.3, for a more detailed information on the household selection criteria and the set-up of the constraints analysis.

	EV+	Baseline	CV+
2012	7	none	none
2013	7	none	none
2014	7	none	none
2015	4, 7	7	none
2016	4, 7	7	none
2017	4, 7	7	none
2018	4, 7	7	none
2019	4, 7	4, 7	none
2020	4, 7	4, 7	none
2021	4, 6, 7	4, 7	none
2022	4, 6, 7	4, 7	none
2023	4, 6, 7	4, 7	none

Household selection criterion (HSC) 4: Access to parking facilities at a frequent destination (such as work), HSC 6: Trips to occasional or secondary residences lie in the BEV's range, HSC 7: Holiday trips are not carried out with the private vehicle.

Table 5.10: Suppressed household selection criteria per scenario

For the **CV+ scenario**, we assume that there are no recognisable changes in the perception of BEVs within the next decade. We do not suppress any household selection criteria in the constraints analysis over the whole forecasting period. For the **baseline scenario**, we assume that vehicle holders become increasingly comfortable with the use of a BEV: from 2015 onwards, also those mono-motorised households that use their private vehicle for holiday purposes qualify for a BEV (household selection criterion 7 is therefore suppressed). For holiday trips (that usually surpass the limited range of a BEV) these households either fall back on a vehicle rental service for pursuing this trip with a CV, or they still decide to use their BEV as they are comfortable with relying on public battery recharge infrastructure. The latter case could either be fast charging points or battery swap stations – taking the hypothesis that such infrastructures will have already been built up in a sufficiently dense way by that year. From 2019 onwards, we assume that also those infrastructure demands that evoke from every-day vehicle usage get less stringent: a parking place at the vehicle user's frequent destination (such as work), where recharge infrastructure will increasingly be deployed, is not a precondition for a household to get equipped with a BEV. Range needs and vehicle usage behaviour are sufficiently comprehended by then. Thanks to the public recharge infrastructure net that has been deployed by then, potential BEV users do not see the need of assured access to additional recharge infrastructure at the work place. For the **EV+ scenario**, we take similar assumptions as for the baseline scenario. Assumed

changing perceptions of recharge infrastructure requirements do, however, evolve earlier. Household selection criterion 7 is already suppressed by 2012; household selection criterion 4 is suppressed by 2015. Further, from 2021 onwards, also household selection criterion 6 is suppressed. Occasional but repetitive trips (such as to occasional or secondary residences) do not necessarily need to lie within the range of the BEV. Also for such trips, potential BEV holders rely on public recharge infrastructure.

A specific assumption on whether a potential mono-motorised BEV household that faces a trip lying outside the vehicle's range i) completely avoids the trip, ii) falls back on a CV rental service, or iii) decides to carry out the trip with its BEV (hereby relying on public recharge infrastructure) is not taken. For this reason, the annual driven distance that is assumed to be attained by the BEV is not adapted in any of the scenarios. As a consequence, vehicle usage costs remain the same. The potential extra costs of a CV rental are not taken into account either, which is certainly a deficiency in the underlying assumptions. More precise assumptions on how a mono-motorised BEV household behaves in case an out-of-range trip is to be carried out would allow for the necessary adaptations in the TCO calculations.

5.3.5 Expected policy measures

Given that policy measures focused on the uptake of EVs will be largely dependent on the actual EV sales numbers, forecasts on policy measures are difficult to make before having an idea of how EV demand is likely to evolve. On the other hand, evolving EV demand will be heavily dependent on policy measures – at least in the first years after the recent and ongoing EV market launch. In order to tackle this interrelation, we start by taking very hypothetical policy assumptions. On the basis of these, the future number of EV-qualifying households is derived. In a second step, these policy measures are then adjusted to values that prove to be more reasonable given their observed effect.

In the baseline scenario, we assume policy measures that appear to be likely from today's point of view. Today's policy measures are kept at a similar level for a certain period of time before they are incrementally reduced. It is assumed that increasing EV demand will render them more and more redundant as well as less and less viable from a financial perspective. In the EV+ scenario, policy measures are supposed to be maintained for a longer period of time, and at a higher level of financial EV support. In truth, such a scenario is rather unlikely: the more EVs will become (financially) viable thanks to advantageous framework conditions, the less policy support will be necessary to support their successful uptake. Assuming an increased uptake in the EV+ scenario, policy measures will become financially unviable at a much faster pace than in the other scenarios. Nevertheless, to give an idea of the possible bandwidth of the potential number of EV-qualifying households, we decide to develop extreme

scenarios: the EV+ scenario is backed with EV-favourable policy measures, while the CV+ scenario is back with much less EV-favourable policy measures. Despite the extreme character of the EV+ and CV+ scenarios, we judge all assumed sets of policy measures to be reasonable from today's point of view (i.e. in none of the scenarios extreme values for purchase subsidies or energy taxations are assumed).

The purchase subsidy

The purchase subsidy (the bonus that is credited to the EVs under the French bonus/malus system) is one of the most influential policy measures. As Chapters 3 and 4 have shown, its level of EUR 5,000 (up until July 2012), or, respectively, EUR 7,000 (since August 2012) has important impact on the TCO comparison of an EV with its comparable conventional counterpart. Further, given the fact that the purchase subsidy is an up-front policy measure, its perceived financial effect on the customer is even higher than would be the case with a recurring financial benefit of the same magnitude (see Chapter 2, Section 2.4.4). All scenarios start with the same purchase subsidy of EUR 7,000 in year 2012. After that, the subsidy is supposed to be incrementally reduced until no purchase subsidy is anymore credited. The speed, according to which the magnitude of the purchase subsidy falls, is dependent on the scenario. See Table 5.11 for the exact values per year and scenario. The results section (5.4) then shows how the purchase subsidy is gradually adjusted to what we believe to be the more reasonable values.

	EV+	Baseline	CV+
2012	7,000	7,000	7,000
2013	7,000	7,000	7,000
2014	5,000	5,000	5,000
2015	5,000	5,000	5,000
2016	5,000	2,500	0
2017	5,000	2,500	0
2018	2,500	2,500	0
2019	2,500	2,500	0
2020	2,500	0	0
2021	2,500	0	0
2022	0	0	0
2023	0	0	0

Table 5.11: Assumed purchase subsidy per year and scenario (starting values)

Other policy measures

The **registration cost exemption** is assumed to be a measure that is accorded with the purchase subsidy. As long as a purchase subsidy (in whatever magnitude) is accorded to an EV, the EV is also exempted from any registration costs.

The **fuel taxation** scenarios define the annual increase of the French TICPE (the tax on petroleum products). In all fuel price scenarios (see Section 5.3.3), the TICPE is supposed to evolve according to what has been observed in previous years. TICPE changes defined refer to *additional* increases that are not in line with expectations that are based on historic data. For the baseline scenario, we do not assume any additional TICPE increases. Consequently, also for the CV+ scenario we do not assume any TICPE increases, but also no decreases. In the EV+ scenario we assume a moderate TICPE increase of 1 % every three years, starting with the first increase in 2014.

The **infrastructure usage costs** are assumed to stay the same (except for annual changes according to the inflation) until 2030. The baseline scenario takes the value of the 2012 reference scenario as introduced in Chapter 3: 0.26 cEUR/km. In the CV+ scenario this value amounts to 1 cEUR/km; in the EV+ scenario it is assumed that all costs for public infrastructure are carried either by public authorities or by any other stakeholders that invest into publicly accessible recharge infrastructure. The private user is free of any charges.

Infrastructure installation costs amount to EUR 590 in the baseline scenario. Also in the CV+ scenario we do not assume any higher value. In reality, infrastructure installation costs will vary from case to case and depend on the household's infrastructure. In the EV+ scenario, it is assumed that private recharge infrastructure installation costs are covered by the public authorities, e.g. in the form of tax credits.[84] There are no infrastructure installation costs for the private user.

In Chapter 3, three different **EV parking policy** scenarios were introduced. They range from (1) no EV parking policy (no preferential rights or costs for EVs), and (2) free public parking for EVs, to (3) free public and private parking for EVs (in case no private parking facility is available at the household in question). Since we do not develop any scenario in which the household selection criterion with regards to the access to private parking infrastructure is relaxed, parking policy scenario (3) is redundant for the underlying analysis: all EV-qualifying households have access to private parking infrastructure – parking policy scenario (3) has the same impact on these users as parking policy scenario (2). In the baseline and the EV+ scenario, we assume that parking policy scenario (2) is maintained up until 2018. In the CV+ scenario, this policy measure is only kept up until 2015.

[84] See chapter 2, section 4.4, for a discussion of measures supporting the deployment of (private) recharge infrastructure.

5.4 Resulting EV-qualifying households till 2023

The focus in this result section is on findings with regards to the BEV with a battery hire option. Chapter 3 and 4 found that this vehicle technology and business model is, for the time being, the financially most viable one on the French market. Also findings of this forecast analysis will confirm this financial advantage of the battery hire option over the battery purchase option.

In the following, the results per defined scenario are presented first (5.4.1). Next, variations of these scenarios with regards to underlying policy measures are developed (5.4.2). This way, a set of financial policy measures that should assure a reasonable number of EV-qualifying households during the upcoming decade is identified. The impact of the purchase bonus is particularly analysed. For completeness, the subsequent section then shows results for the study's underlying (long electric-range) PHEV under the adapted set of policy measures (5.4.3). Finally, region-specific results are shown (5.4.4).

5.4.1 BEV-Hire results per scenario

The following set of graphs gives the number of identified BEV-qualifying households for the whole of France. They are shown as a % of the total French household population. Since the purchase bonus shows to have important impact on the results, each figure also depicts the bonus' assumed level for each modelled year. All other scenario-specific settings can be found in Section 5.3, or in the overview tables in the annex. Additionally, the graphs show the number of what we call "BEV-adapted" households. As introduced in Chapter 4, these are households that comply with all but the economic household selection criterion of the underlying constraints analysis. These households are motorised, and show BEV-adequate vehicle usage behaviour as well as BEV-adequate household infrastructure. The financial advantage of an EV purchase over a CV purchase is, however, not assured. Given the definition of each scenario and the varying application of household selection criteria per scenario, the number of BEV-adapted households changes over time. (See Section 5.3.3 on the evolving perceptions of EVs that define which household selection criteria is relaxed at what point in time and for which scenario.)

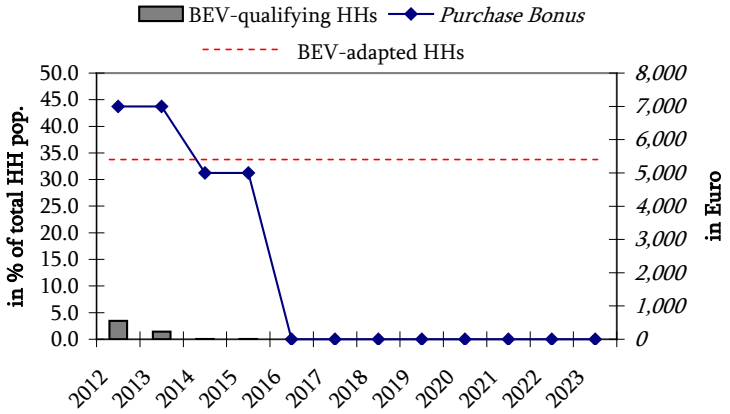
The first part of Figure 5.12 shows that the **CV+ scenario** results in hardly any potential for the underlying BEV models. Only in the first two years, when the high purchase bonus of EUR 7,000 supports the EV purchase, potential BEV households can be identified. Nevertheless, maintaining the EUR 7,000 purchase bonus up until 2013 shows to be insufficient for maintaining the 2012 share of BEV-qualifying households: the effect of all other framework conditions outweighs the effect of the continuous financial support on the TCO equation.

This results in a decreasing number of BEV-qualifying households. The decrease of the purchase bonus to EUR 5,000 in 2014 shows to have major impact on the BEVs' potential: the BEV's potential drops significantly. Only a negligible number of BEV-qualifying households can be identified. Since there are not any household selection criteria that are relaxed in the CV+ scenario, the share of BEV-adapted households remains constant until 2023.

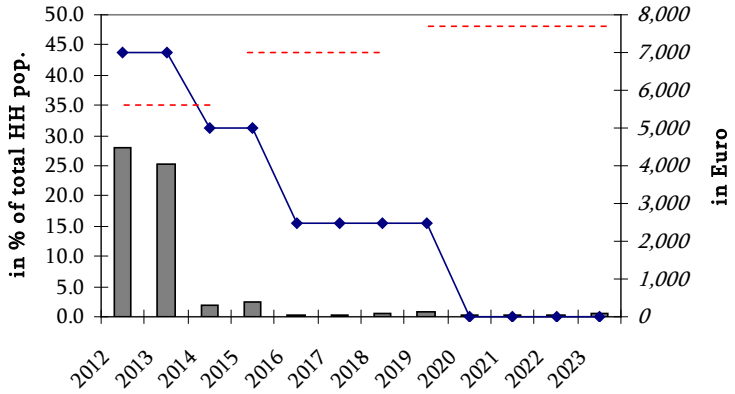
Taking a look at the simulation of the **baseline scenario**, similar effects as in the CV+ scenario can be observed. A drop of the purchase bonus from EUR 7,000 to EUR 5,000 entails a major decrease of identified potential EV households; the maintenance of the purchase bonus at a EUR 7,000 level does not compensate the financial effect of other framework conditions on the TCO equation: in 2013 less EV-qualifying households can be identified than in 2012. After 2013, constant purchase bonus levels come along with an increasing number of EV-qualifying households. A reason for this changing effect of constant purchase subsidies can be found in the forecasted CV price development: the carried out regression analysis on past CV prices resulted in a slight CV price decrease for the year 2013, after which the price continuously increases up until 2023. Only for the years 2012 and 2013, significant EV potential can be identified. BEV-qualifying households represent 28 % and 25 % of the total French household population in 2012 and, respectively, 2013. Given the scenario settings of the baseline scenario, the number of BEV-adapted households changes over time. The effect of the relaxation of certain household selection criteria (being an increasing number of BEV-adapted households) however, does not show a significant effect on the resulting number of BEV-qualifying households.

The picture that is obtained from the simulation of the **EV+ scenario** is a significantly different one. The EV+ scenario is the only scenario that shows promising results: the framework conditions are sufficiently EV-advantageous to allow for a stepwise decrease of the purchase subsidy without engendering any fall of the number of BEV-qualifying households below the 30 % mark. From 2022 onwards, a purchase bonus appears to lose its justification: EV-advantageous framework conditions contribute to an increasing number of EV-qualifying households, also without the financial aid of a purchase bonus.

CV+ Scenario



Baseline Scenario



EV+ Scenario

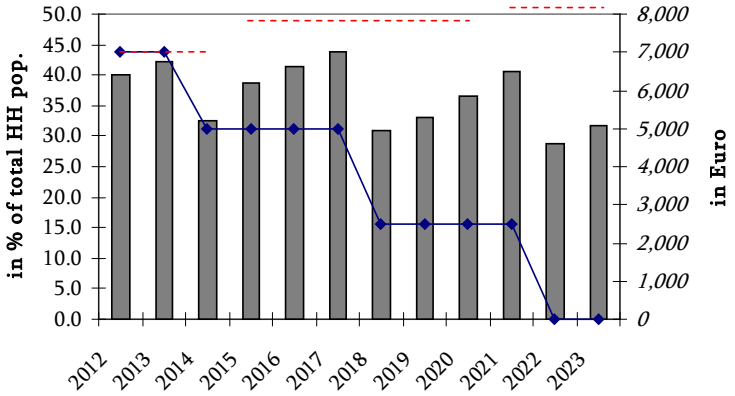


Figure 5.12: BEV-qualifying and -adapted households per scenario (considering a battery hire option)

All scenarios show that the assumed jumps in the level of the purchase bonus entail significant drops in the number of identified EV-households. A much smoother decrease of the purchase bonus over time therefore appears to be more reasonable.

The following section shows results of scenarios where the EV policy framework is adjusted. Its influence is analysed and reasonable levels of the purchase subsidy over time are identified.

5.4.2 Adapting the policy framework

The scenarios modelled so far are based on different underlying policy frameworks. Given that the above modelled CV+ and baseline scenarios have not allowed the identification of a promising number of potential EV households, we now take the policy measures as defined in the EV+ scenario as reference policy framework for all scenarios. This allows for the identification of the effect of the scenarios' framework conditions on the resulting number of BEV-qualifying households, independent of any differences in the underlying policy framework. As a recap, Table 5.12 gives an overview of the settings of the EV+ policy framework. The resulting numbers of EV-qualifying households per scenario are shown in Figure 5.13.

	Purchase bonus	Reg. tax exemption	Infra. install. costs	Fuel taxation	Electricity taxation	Parking policy	Infra. usage costs
	(Euro)	*(1 - yes, 2 - no)*	*(Euro)*	*(TICPE increase in %)*	*(annual increase in %)*	*(*)*	*(Euro/km)*
2012	7,000	1	0.00	0.00	0.01	2	0.00
2013	7,000	1	0.00	0.00	0.01	2	0.00
2014	5,000	1	0.00	1.00	0.01	2	0.00
2015	5,000	1	0.00	0.00	0.01	2	0.00
2016	5,000	1	0.00	0.00	0.01	2	0.00
2017	5,000	1	0.00	1.00	0.01	2	0.00
2018	2,500	1	0.00	0.00	0.01	2	0.00
2019	2,500	1	0.00	0.00	0.01	1	0.00
2020	2,500	1	0.00	1.00	0.01	1	0.00
2021	2,500	1	0.00	0.00	0.01	1	0.00
2022	0	2	0.00	0.00	0.01	1	0.00
2023	0	2	0.00	1.00	0.01	1	0.00
2024	*n.a.*	*n.a.*	*n.a.*	0.00	0.01	1	0.00
2025	*n.a.*	*n.a.*	*n.a.*	0.00	0.01	1	0.00
2026	*n.a.*	*n.a.*	*n.a.*	1.00	0.01	1	0.00
2027	*n.a.*	*n.a.*	*n.a.*	0.00	0.01	1	0.00
2028	*n.a.*	*n.a.*	*n.a.*	0.00	0.01	1	0.00
2029	*n.a.*	*n.a.*	*n.a.*	1.00	0.01	1	0.00
2030	*n.a.*	*n.a.*	*n.a.*	0.00	0.01	1	0.00

* 1 - no preferential EV policy, 2 - free public parking for EVs

Table 5.12: Overview of the EV+ policy framework

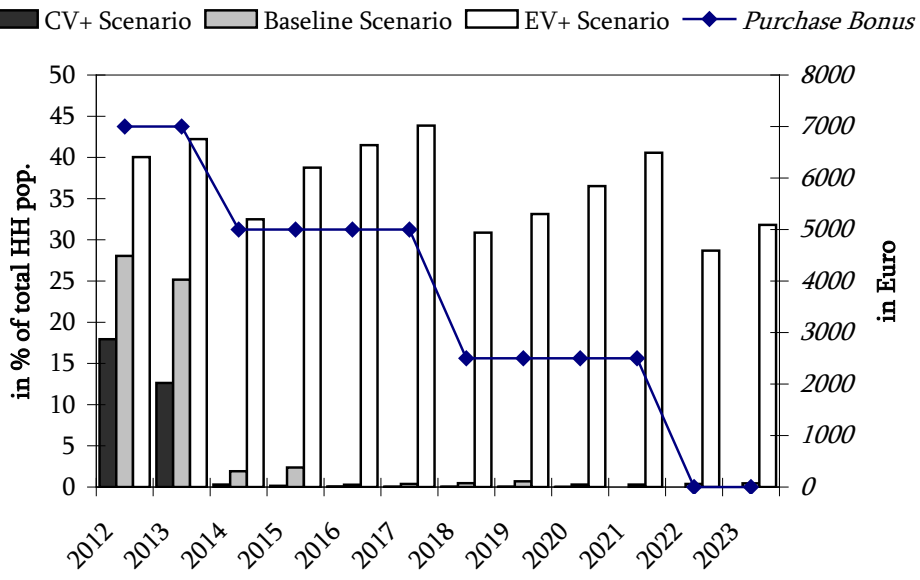


Figure 5.13: BEV-qualifying and -adapted households per scenario under the EV+ policy framework (considering a battery hire option)

Given that the EV+ policy framework is more EV-favourable than the baseline or the CV+ framework, the numbers of BEV-qualifying households for these latter two scenarios is now higher than the ones that were obtained when simulating the scenarios with their initial policy settings. However, all observed tendencies remain the same. Although the number of BEV-qualifying households increases significantly in some instances, it remains low for the baseline and the CV+ scenarios from 2014 onwards. The impact of the underlying policy framework on the results becomes apparent. However, the effect of all other framework conditions appears to be more crucial to the BEVs' potential.

All scenarios modelled so far are based on a purchase bonus development that shows sudden drops. These drops entail significant drops in the identified BEV potential. In the following, it is therefore explored how a progressive decrease of the proposed purchase bonus affects the number of BEV-qualifying households. We assume an annual decrease of the purchase subsidy by EUR 500 up until 2023, starting from the year 2012 level of EUR 7,000. In 2023, the purchase bonus is therefore assumed to still amount to EUR 1,500. Simulation results for the CV+, baseline, and EV+ scenarios are shown in Figure 5.14. The effect of the change in the purchase subsidy development becomes obvious for the EV+ scenario: the identified BEV potential now remains at the similar level of around 40 % during the whole forecasting period. Also the results for the baseline scenario are quite different to what has been observed before: now, a continuous decrease of BEV-qualifying households is observed. Given that the baseline scenario is assumed to be the most realistic one, the purchase subsidies defined here do not seem to be appropriate. We retain, however, the adapted EV+ policy framework as adequate policy framework for the EV+ scenario. Table 5.13 shows the framework's settings for the EV+ scenario (which are, with the exception of the purchase bonus development, the same as the initial EV+ scenario settings).

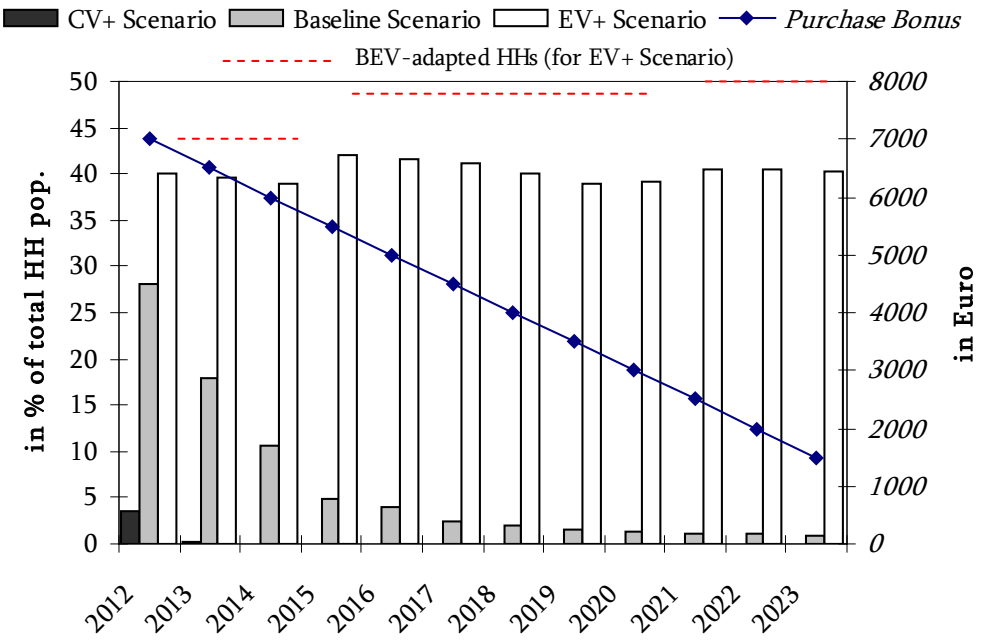


Figure 5.14: BEV-qualifying and -adapted households per scenario under the adapted EV+ policy framework (considering a battery hire option)

	Purchase bonus	Reg. tax exemption	Infra. install. costs	Fuel taxation	Electricity taxation	Parking policy	Infra. usage costs
	(Euro)	*(1 - yes, 2 - no)*	*(Euro)*	*(TICPE increase in %)*	*(annual increase in %)*	*(*)*	*(cEuro/km)*
2012	7,000	1	0	0.00	0.10	2	0.00
2013	6,500	1	0	0.00	0.10	2	0.00
2014	6,000	1	0	1.00	0.10	2	0.00
2015	5,500	1	0	0.00	0.10	2	0.00
2016	5,000	1	0	0.00	0.10	2	0.00
2017	4,500	1	0	1.00	0.10	2	0.00
2018	4,000	1	0	0.00	0.10	2	0.00
2019	3,500	1	0	0.00	0.10	1	0.00
2020	3,000	1	0	1.00	0.10	1	0.00
2021	2,500	1	0	0.00	0.10	1	0.00
2022	2,000	2	0	0.00	0.10	1	0.00
2023	1,500	2	0	1.00	0.10	1	0.00
2024	*n.a.*	*n.a.*	*n.a.*	0.00	0.10	1	0.00
2025	*n.a.*	*n.a.*	*n.a.*	0.00	0.10	1	0.00
2026	*n.a.*	*n.a.*	*n.a.*	1.00	0.10	1	0.00
2027	*n.a.*	*n.a.*	*n.a.*	0.00	0.10	1	0.00
2028	*n.a.*	*n.a.*	*n.a.*	0.00	0.10	1	0.00
2029	*n.a.*	*n.a.*	*n.a.*	1.00	0.10	1	0.00
2030	*n.a.*	*n.a.*	*n.a.*	0.00	0.10	1	0.00

* 1 - no preferential EV policy, 2 - free public parking for EVs

Table 5.13: Overview of the adapted EV+ policy framework

In the following, a purchase bonus is designed that allows for a constant BEV potential for the baseline scenario. Table 5.13 shows the settings of the whole policy framework for the baseline scenario that led to the results shown in Figure 5.15. The purchase bonus does not take any unrealistic value at any point in time and allows for a BEV potential that never drops underneath the 20 % mark. All other policy settings take the settings of the initial baseline policy framework – the, from our point of view, most realistic future settings, i.e. with regards to energy taxation.

	Purchase bonus	Reg. tax exemption	Infra. install. costs	Fuel taxation	Electricity taxation	Parking policy	Infra. usage costs
	(Euro)	*(1 - yes, 2 - no)*	*(Euro)*	*(TICPE increase in %)*	*(annual increase in %)*	*(*)*	*(cEuro/km)*
2012	7,000	1	590	0	0.03	2	0.26
2013	7,000	1	600	0	0.03	2	0.26
2014	7,000	1	611	0	0.03	2	0.26
2015	6,500	1	621	0	0.03	2	0.26
2016	6,500	1	632	0	0.03	2	0.26
2017	6,000	1	643	0	0.03	2	0.26
2018	5,500	1	654	0	0.03	2	0.26
2019	5,500	1	665	0	0.03	1	0.26
2020	5,000	1	677	0	0.03	1	0.26
2021	5,000	1	688	0	0.03	1	0.26
2022	4,500	1	700	0	0.03	1	0.26
2023	4,500	1	713	0	0.03	1	0.26
2024	*n.a.*	*n.a.*	*n.a.*	0	0.03	1	0.26
2025	*n.a.*	*n.a.*	*n.a.*	0	0.03	1	0.26
2026	*n.a.*	*n.a.*	*n.a.*	0	0.03	1	0.26
2027	*n.a.*	*n.a.*	*n.a.*	0	0.03	1	0.26
2028	*n.a.*	*n.a.*	*n.a.*	0	0.03	1	0.26
2029	*n.a.*	*n.a.*	*n.a.*	0	0.03	1	0.26
2030	*n.a.*	*n.a.*	*n.a.*	0	0.03	1	0.26

* 1 - no preferential EV policy, 2 - free public parking for Evs

Table 5.14: Overview of the adapted baseline policy framework

Figure 5.15 shows the results for the BEV with the battery hire option and for the BEV with the battery purchase option. As mentioned, the BEV potential of the latter business model is inferior to that of the battery hire business model. The number of BEV(-purchase)-qualifying households increases steadily, but stays at a significantly lower level than the number of BEV(-hire)-qualifying households.

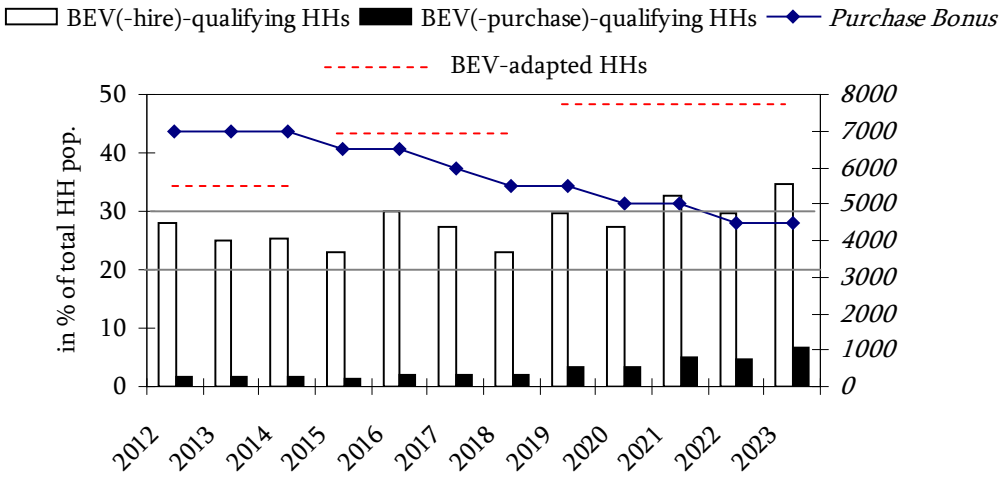


Figure 5.15: BEV(-hire and -purchase)-qualifying households for the baseline scenario under the adapted baseline policy framework

Given that hardly any BEV-qualifying households can be identified under the CV+ scenario, we waive this scenario for identifying a CV+ policy framework that shows satisfying results. We judge that such policy settings would lie outside of any realistic future policy scenario.

Instead of changing the purchase subsidy changes in other financial policy measures could also have yielded similar results. For example, EV-favourable parking policies could be maintained longer than until 2018. In Paris, this would yield an annual cost advantage for the EV of around EUR 900; in the Grande Couronne, and therefore also for the 'rest of France' area, this would yield an annual cost advantage of around EUR 220 in the underlying model (NB: stated values do not take the applied inflation into account).

All following results for the baseline and EV+ scenarios are based on the scenarios' initial settings and the adapted policy frameworks as derived in this section.

5.4.3 PHEV results under adapted policy settings

Previous results of Chapter 3 and 4 have already shown that the long-electric-range PHEV technology underlying this analysis is financially unviable in comparison to the study's other underlying technologies. This forecast analysis confirms these results. Figure 5.16 gives the share of French households that qualify for a long-electric-range PHEV until 2023 under the adapted policy packages as defined in Section 5.4.2. Both scenarios give extremely low numbers (NB: note that the scale of the y-axis has been changed in comparison to all previous figures). Even for the EV+ scenario, the share of households qualifying for a PHEV remains consistently well below 0.5 %. Again, the conclusion has to

be drawn that the possibly evolving demand for long-electric-range PHEVs will not evolve thanks to reasoned decision processes of well-informed customers, but rather thanks to EV enthusiasts that are willing to bear the financial disadvantage that comes with this technology.

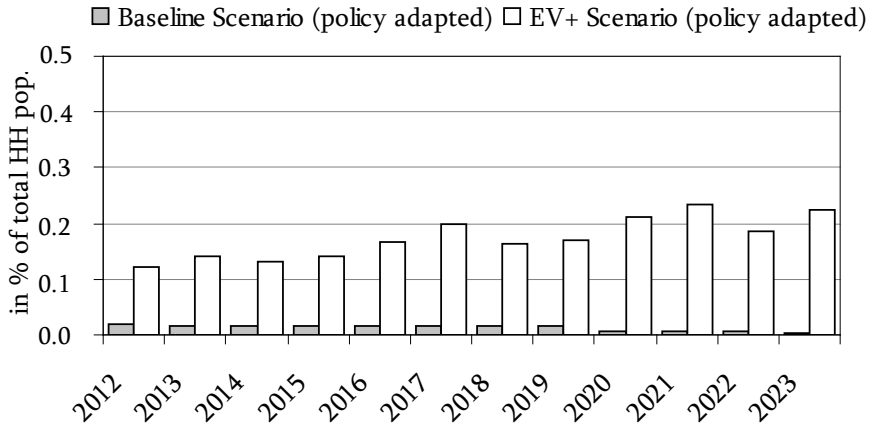


Figure 5.16: PHEV-qualifying households under the policy-adapted baseline and EV+ scenarios

5.4.4 BEV results per region under adapted policy settings

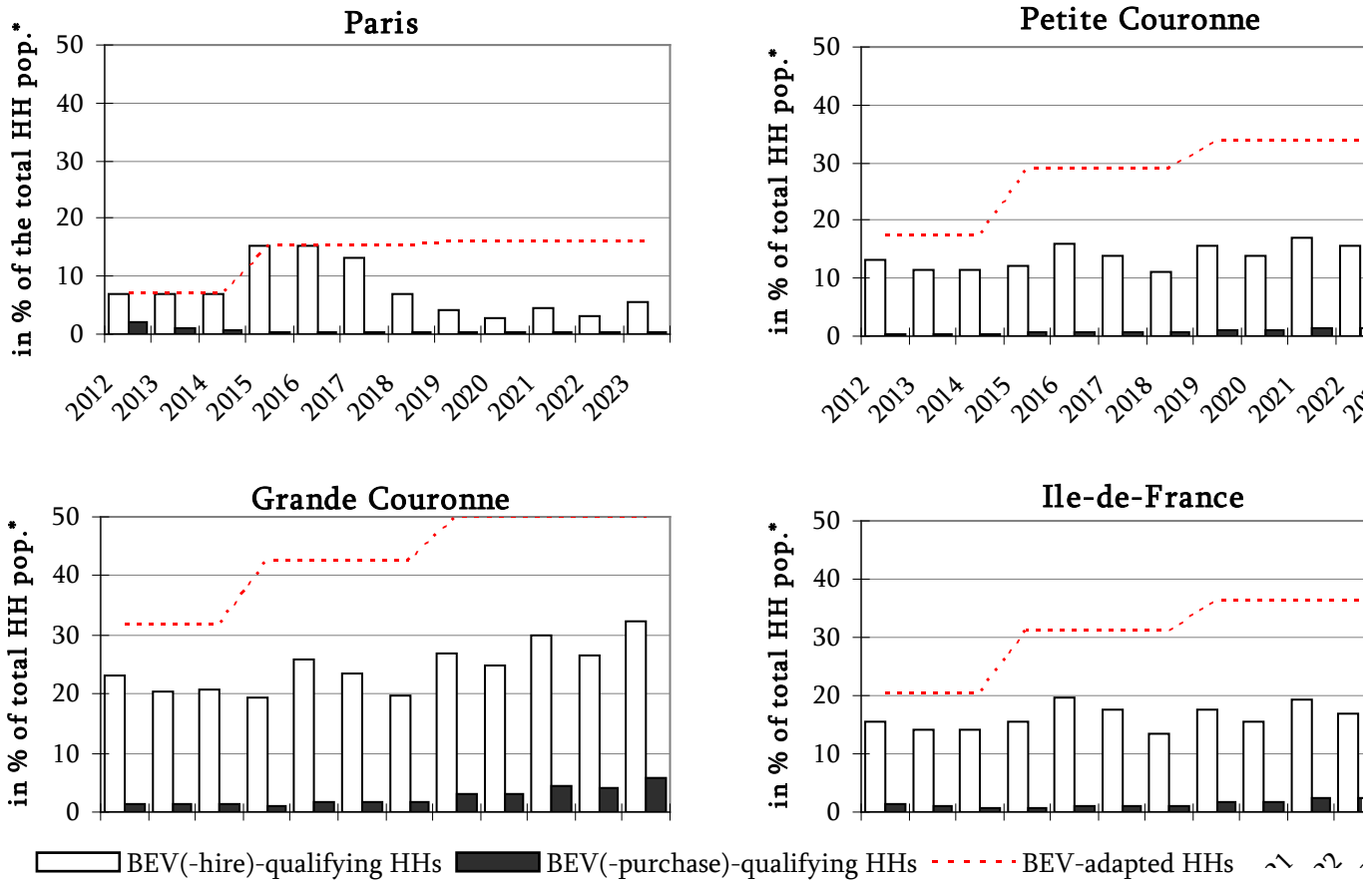
This section shows the results for the BEV battery hire and BEV battery purchase options per region. The simulated scenarios are the baseline and the EV+ scenarios under the adapted policy frameworks as shown in Tables 5.13 and 5.14 (Section 5.4.3). Figure 5.17 gives the results for the baseline scenario; Figure 5.18 gives the ones for the EV+ scenario (see Tables 5.13 and 5.14 for the scenario settings).

Simulations of the baseline scenario show that the highest BEV potential can be identified in the Grand Couronne area, where it remains above 20 % over the whole forecasting period (with a minor exception in the year 2015). In Paris and the Petite Couronne area, the potential is significantly lower. A main reason is directly identifiable from the graphs: the number of EV-adapted households is significantly less in those two areas – mainly due to infrastructure constraints (as shown in Chapter 4, Table 4.11). In Paris, the relaxation of the household selection criterion 4 in 2019 (which restrains BEV-qualifying households to those that have access to a parking place at a recurring destination for which their potential BEV is used) shows hardly any impact. This negligible effect could already be inferred from the results of Chapter 4 (Table 4.11): the number of potential BEV-households drops by only 0.1 % with the application of the household selection criterion in question. In the Petite Couronne, the impact of relaxing household selection criteria is more apparent than in Paris. However,

there the number of BEV-adapted households also never surpasses 35 %, whereas it attains 51 % in the Grande Couronne area from 2019 onwards.

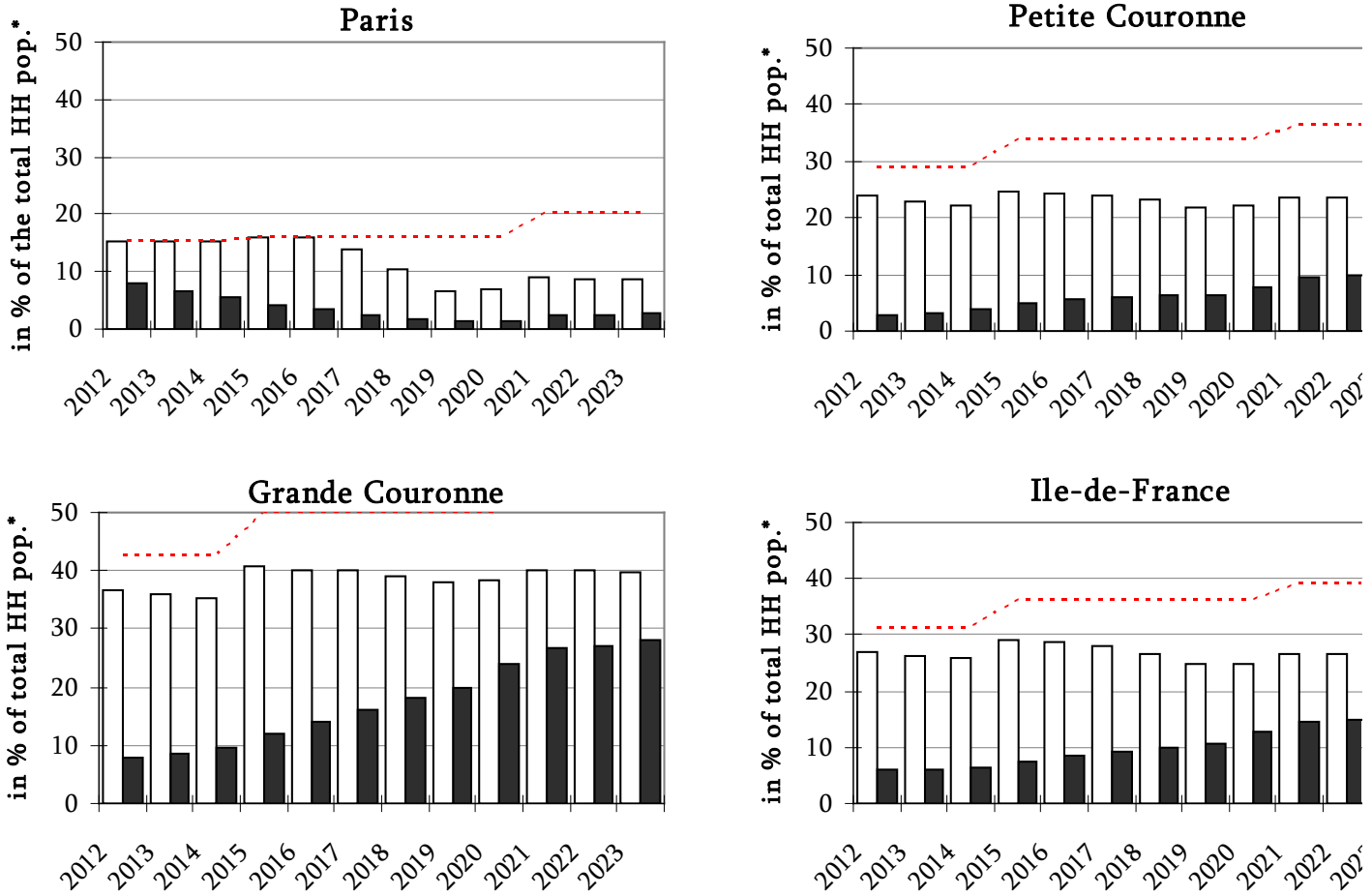
In Paris, the potential of BEV-adapted households can be fully exploited until 2016: all BEV-adapted households are also BEV-qualifying. From 2017 onwards, this potential starts decreasing and the financial impact of the scenario's underlying parking policies become apparent: Parisian vehicle owners that buy their vehicle in 2017 are subject to annual parking fees of around EUR 900 (real value) throughout 5 years of their assumed 7-year vehicle ownership period. Vehicle owners who buy their vehicle in 2018 are subject to these fees throughout 6 years, which has significant impact on the TCO equation. This way, the Parisian BEV potential continuously decreases until 2020. From then on, total parking costs remain constant; increasingly BEV-favourable framework conditions start showing their effect by an increasing number of BEV-qualifying households up to 2023. In the other sub-regions, this effect of parking policies is not identifiable. In the first years, the financial impact is not sufficient for the full potential of the BEV-adapted households to be exploited; in the later years, when the BEV-favourable parking policy ceases to be in place, no evident drop in the number of BEV-qualifying households can be observed.

Simulations of the EV+ scenario show that both the number of BEV-adapted but also of BEV-qualifying households is higher than in the baseline scenario. In the EV+ scenario, the potential of BEV-adapted households can be fully exploited by 2016 in Paris. All other results show the same tendencies as in the baseline scenario. As expected, the total identified BEV potential is significantly higher in all sub-regions. While it remained at 20-30 % of all households in the Grande Couronne area in the baseline scenario, it augments to around 40 % in the EV+ scenario – despite of the more moderate levels of the underlying EV purchase bonus in the EV+ scenario (see Tables 5.13 and 5.14).



* Paris: 1,163,041 HHs, Petite Couronne: 1,843,461 HHs, Grande Couronne: 1,964,507 HHs, IDF: 4,971,010 HHs

Figure 5.17: BEV(-hire and purchase)-qualifying households per region for the baseline scenario



* Paris: 1,163,041 HHs, Petite Couronne: 1,843,461 HHs, Grande Couronne: 1,964,507 HHs, IDF: 4,971,010 HHs

Figure 5.18: BEV(-hire and purchase)-qualifying households per region for the EV+ scenario

5.5 Deriving potential EV demand

Section 5.4 showed the number of EV-qualifying households for different scenarios. However, this number only gives an idea of how EVs could penetrate the private automobile market in the future. The fact that certain households qualify for an EV, does not yet make them actual EV purchasers. Whether and when an EV-qualifying household is in an actual vehicle purchase process remains to be explored. However, analysing this question in detail is out of the scope of this study. Such an analysis would, for example necessitate the estimation and application of vehicle replacement models that analyse households' vehicle purchase behaviour over time, its purchase attitudes and preferences, and the likelihood of a purchase event in a given year.

We therefore only make an attempt to derive a very approximate number of potential EV sales based on i) the findings in previous sections and ii) observation of households' vehicle purchase behaviour over the past years. In the following, we briefly describe the applied methodology by stating all underlying hypothesis and necessary sources. Next, we show results for the baseline and EV+ scenarios under their respective policy frameworks.

5.5.1 Methodology and underlying hypotheses

Information on the existing household vehicle stock is far from exhaustive in the ENTD 2007/08. Only in rare exceptions is information on the specifications and usage of more than one car of a household's fleet stated. This impedes retracing when and how often a household in question bought a new vehicle in the past. Assumptions based on such incomplete information are judged to be not reliable enough for the following analysis. We therefore decide to base this analysis on macroeconomic observations of French vehicle purchases and registrations. Observed tendencies are then applied to the results obtained from the disaggregate data set of the ENTD 2007/08, as presented in Section 5.4.

Macroeconomic data on French vehicle purchases and registrations reveal that i) from 2000 to 2011, on average 2.1 million new passenger vehicles have been registered per year (CGDD, 2012e), and ii) around 60 % of new passenger vehicle registrations are carried out by private households (61 % in 2011; SNLVLD, 2011). From these numbers it can be derived that approximately 1.26 million new passenger vehicles per year were sold to private households. Given the size of the French household population[85], we infer that around 4.6 % of French households buy a new passenger car per year – hereby assuming that the

[85] We take 27.5 million households as reference value – the French household population in 2009 according to INSEE (2012b).

number of households which buy two or more new cars in a single year is negligible.

In the following, this percentage is applied to the number of BEV-qualifying households as identified in Section 5.4. For this purpose, we formulate the following two hypotheses[86]:

1. *All underlying macro-level conditions, i.e. the number of annual passenger vehicle sales, the percentage share of passenger vehicle sales that go to private households, the motorisation rate of French households, and, finally, the French household population, remain constant until 2023.* However, all of these numbers might be subject to change in the upcoming decade: in 2012, passenger vehicle sales will drop underneath the 2 million threshold (NB: whereas sales in 2011 still reached 2.16 million, sales in 2012 were only 1.70 million by the end of November; CGDD, 2012c); the share of new passenger vehicles that go to company fleets is likely to increase (Boutueil and Leurent, 2013); household motorisation rates might increase in case they follow past trends or, alternatively, decrease in case mobility behaviour is subject to change[87]; and the French household population is expected to increase by, on average, around 4 % every 5 years until 2025 (INSEE, 2012b). For simplicity, we assume that the effects of these changes on the number of EV sales to EV-qualifying households even themselves out. However, a more detailed analysis of these observed tendencies would be needed in order to justify this assumption.
2. *The vehicle purchase behaviour of EV-qualifying households is similar to that of the total household population.* Chapter 4 (Section 4.4.5) revealed that characteristics of EV-qualifying households are, on average, slightly different to those of the total household population. Notably, they show to have higher monthly incomes, and, per definition, a higher motorisation rate. It could therefore be inferred that the share of new vehicle sales to EV-qualifying households is superior to the share of new vehicle sales to the total French household population. However, due to a lack of more detailed data sources on this issue, we refrain from adjusting the above found percentage value in favour of EV sales. We judge the value of 4.6 % therefore to be a conservative estimate of the possible "realisation potential" of EV purchases among EV-qualifying households.

[86] These, and all other hypotheses that were previously defined for the set-up of the TCO calculation model, the constraints analysis, and the above introduced forecast procedure have to be kept in mind when analysing the results.

[87] See section 2.2 of this chapter for a discussion on motorisation rates.

5.5.2 Results for the baseline and EV+ scenarios

In the previous section, we concluded that each year 4.6 % of EV-qualifying households might actually purchase a new passenger vehicle and be in the position of choosing an EV. Even if this percentage value is only an approximation, it gives an idea of potential EV sales in France: sales which are due to a rational vehicle choice based upon practical, technical, and economic features of the vehicle to be purchased.

The following graph gives the resulting cumulative BEV sales. They are based on the policy-adapted baseline and the EV+ scenarios presented in Figures 5.14 and 5.15 and on the BEV with the battery hire option. We take the year 2009 French household population of 27.5 million households as constant reference household population up until the year 2023. Although we estimated BEV-qualifying households for the year 2012, we do not take them into account for identifying the year 2012 sales potential. This is due to the following reasons:

- Given that Renault's ZOE Z.E. model, which underlies this analysis, has not been introduced on the market by the end of 2012, previously obtained results for the year 2012 can only be illustrative.
- The change of the French purchase bonus from EUR 5,000 to EUR 7,000 by mid 2012 has been ignored in all 2012 analyses.

Taking 2012 estimations into account would therefore only distort future estimations that should, from our point of view, be more coherent with actual French market conditions from 2013 onwards.

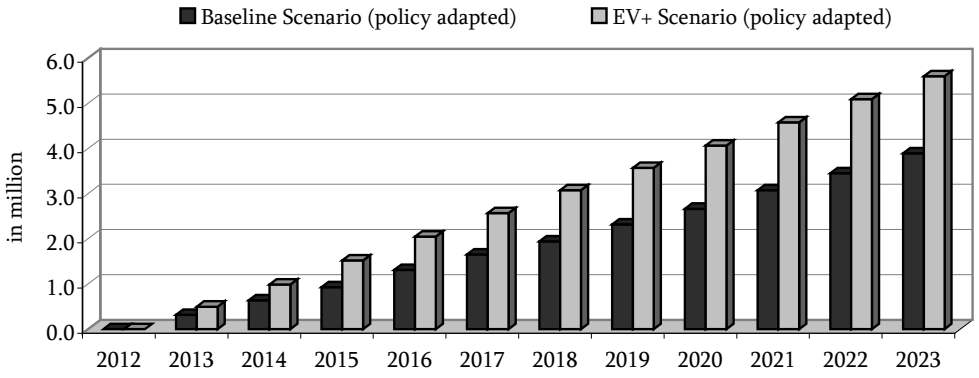


Figure 5.19: Projected cumulative BEV-hire sales potential in France under adapted policy settings

Figure 5.19 shows that the forecast of the BEV sales potential is promising assuming that the 'adapted policy frameworks' as described earlier are put in place: not only the EV+, but also the baseline scenario show significant sales potential until 2023. The following section discusses these findings in more detail.

5.5.3 Discussion of results

France's official target is to deploy 2 million EVs by 2020. So far in 2012, EV sales numbers have remained well beneath expectations. For this reason, the feasibility of achieving the set deployment objective is often questioned – as it was done in this study (see Chapter 2, Section 2.4).

Results of our forecast analysis show, however, that the number of 2 million vehicles can be attained and even surpassed in case the sales potential to private households can be exploited. This finding is even valid for the (from our point of view) most realistic scenario settings with regards to the vehicles' technological development, future market trends, and future mobility behaviour. However, a set of strong financial policy measures appears to remain a necessary condition.

Especially the following topics (that have already been mentioned throughout the build up of the whole analysis) should be kept in mind when interpreting these findings:

- Obtained cumulative potential EV sales numbers are based on policy settings that were specifically designed with the objective to maintain a certain number of BEV-qualifying households over time. Whether such policy measures will actually be maintained, and whether such policy measures are economically viable for the French budget, is a question that remains to be explored. The assumption of more rigid cuts in financial aids lead to significant drops in the number of BEV-qualifying households and therefore also in the number of BEV sales.
- The whole analysis explores the possible demand of assumingly well-informed decision makers. We assume rational decision makers that are not subject to any taste preferences, advices, or any other subjective decision behaviour that was not analysed in this study. We assume that decisions are based upon a criteria catalogue that resembles the set-up constraints analysis. All households that conform to the needs and limitations of an EV, and for which the TCO equation speaks for an EV, are potential EV buyers and do decide for an EV once they are in a new-vehicle purchase decision. In reality, this will not be the case: vehicle purchase decisions are based upon many other factors that are not captured in the underlying analysis. Factors such as taste preferences, habits, unawareness of certain products, etc. will withhold many potential customers (or what we call 'EV-qualifying households'), for whom an EV would actually make sense, from buying such a type of vehicle.
- As already mentioned at several instances, one main deficiency of the underlying methodology is that the whole analysis is based on the comparison of only several vehicle types. The French automobile market is obviously more complex than that. There are many more vehicle technologies, vehicle types and vehicle models to choose from. This

restrictive hypothetical choice set certainly leads to significant distortions in the results. Attention was put on comparing only similar vehicle types and models of different technologies with each other. However, it is far from given that a decision maker does not consider a vehicle choice for which an electric homologue is not yet available on the market. Consequently, a decision maker could compare a cheap and small CV to a bigger and therefore more expensive EV, simply due to the fact that an equitable comparison is not yet possible. NB: The previously stated deficiency of the analysis with regards to the negligence of the 2nd hand vehicle market is now compensated for. Potential EV sales numbers are based on estimations of *new* vehicle sales only.

For the reasons stated above, the results obtained here can not be taken as likely future sales numbers. They give the EV sales *potential*, that might be materialised in case i) the underlying set of policy measures was put in place, ii) decision makers reasoned in a rational and well-informed way, and iii) the EV market has evolved well enough to allow for a choice among several CV-competitive EV models.

Actual 2012 sales numbers show that financial policy measures are for the time being not sufficient for exploiting any sales potential identified here. Effort and money has to be put into awareness raising, education and the sensitization for EVs. Only well-informed customers that get adequate help and specific EV-oriented nudges in their decision process will become aware of the adequacy and even the advantages of an EV for their mobility needs.

5.6 Conclusion

The analysis presented in this chapter builds up on the work presented in previous chapters. After having developed a TCO (total cost of ownership) calculation model that compares the financial impact of the purchase and ownership of different EV (electric vehicle) models with CV (conventional vehicle) models in Chapter 3, Chapter 4 presented a constraints analysis that identified the number of EV-qualifying households on the basis of household selection criteria, that (among others) verified the financial profitability of different vehicle types. The analysis carried out in Chapter 4 explored the French situation as of 2012, assuming that certain EV models (i.e. Renault's ZOE Z.E.) was already on the market. An impression of the compatibility of French households to EVs was obtained.

This chapter now explored how the number of EV-qualifying households evolves over time.

5.6.1 Summary of methodology

Making forecasts on the number of EV-qualifying households comes with the need to formulate several hypotheses that allow making forecasts of the future. Largely, stable framework conditions with regards to travel behaviour, motorisation rates, households' vehicle and fuel type preferences as well as households' infrastructure availability and location were assumed. Each of these hypotheses were discussed and put into perspective with recent trends and observations. Whereas some assumptions were shown to lead to potential overestimations, others were likely to lead to underestimations.

In the following, three base scenarios were developed that mainly vary the diverse parameters that influence the TCO equation of the different vehicle types. Well-founded assumptions with regards to the development of energy prices, vehicle prices, battery prices, vehicles' energy consumption, and the general market trends were made. The baseline scenario is, from our point of view, the most realistic scenario. The EV+ and the CV+ vary all framework conditions to the favour of the EV or the CV technology respectively. Policy settings were set to be more or less EV-favourable, according to the scenario. After having estimated the number of EV-qualifying households with initial policy settings, policy measures were adapted in such a way that a certain household potential was never undercut until the year 2023. On the basis of these adapted policy scenarios, the number of EV-qualifying households per region in the Île-de-France area was estimated. All simulations are primarily carried out for the BEV (battery electric vehicle) with the battery hire option. Previous analyses showed the financial advantage of this EV technology and business model over the other ones that were also comprised in the underlying analysis. The forecast analysis confirms these findings.

5.6.2 Results of modelled scenarios

Results of the modelled scenarios show that financial policy measures have to be maintained until 2023 in order to assure a significant number of EV-qualifying households. In the baseline scenario, it was found that the purchase bonus should not drop underneath EUR 4,000 in order to maintain a 30 % share of EV-qualifying households until 2023. In the EV+ scenario, a progressive decrease of the EV purchase bonus to a level of EUR 1,500 in 2023 is sufficient to maintain a share of EV-qualifying households of even 40 %. The sensitivity of the results to the purchase bonus is, as already shown in the previous chapter, significant. Sudden drops in the purchase bonus lead to a significant loss in the number of EV-qualifying households. Also in the upcoming years, the impact of parking policies in the dense area of Paris appears to have major influence on the TCO equation and therefore on the number of EV-qualifying households in Paris. Whereas EV-favourable parking policies exploit the full potential of EV-adapted

households[88] in the first years, a suppression of such policies results in significant decreases of EV-qualifying households (the number of EV-adapted households cannot be fully exploited anymore). Naturally, this effect is less observed in less dense areas, where annual parking costs are less significant.

A baseline scenario forecasts a cumulative sales potential of over 2.5 million EVs to French households until 2020. For the EV+ scenario, this number amounts to almost 4 million. Both of these scenarios rely on a strong set of financial public policy measures until 2020. Further, it relies on well-informed and rational decision makers. "Soft" policy measures, such as educational and awareness campaigns will therefore be a necessary precondition for actually exploiting the estimated sales potential. The client-specific provision of TCO values could even become mandatory for vehicle dealers: common tools should be provided by the public authority for calculating and communicating TCO effectively to the customer. Only then the possible advantage (or disadvantage) of an EV will be comprehended. And only then, BEV-qualifying households will actually tend to make the most rational decision in line with their mobility needs and infrastructure availability.

5.6.3 Shortcomings and outlook

The set-up forecasting tool can be used for analysing the impact of different sets of policy measures on the potential demand for EVs up until 2023. How this potential demand will actually materialise over time will be very much dependent on the market availability of EV models, on the EV-awareness of vehicle purchasers, as well as on EV-specific nudges that vehicle purchasers are confronted with during the vehicle purchase process. For this reason, the findings presented give the potential numbers of EV sales under certain framework conditions and policy settings rather than actual sales numbers.

The issue of the viability of certain policy measures has not been touched upon in the underlying analysis. Naturally, high purchase bonuses that are maintained over the upcoming years will results in elevated sales. However, it is not clear if such purchase bonuses will be a viable solution for the public budget. The following chapter introduces a comprehensive modelling approach that allows incorporating social and financial effects of the introduction of EVs on the public budget. The profitability of the production and usage of EVs is explored. The introduced methodology and its application to the case of France allow for conclusions on whether public support of EVs appears to be justified from a national perspective.

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[88] "EV-adapted" households are households that conform to vehicle usage and households infrastructure selection criteria but not necessarily to the economic criterion based on the TCO calculations.

Chapter 6
EVs' impact on the public budget: an integrated evaluation model

6.1 Introduction

6.1.1 Context

So far, economic studies about electric vehicles have focused on costs for the user, to decide which target group to concentrate on and which demand-oriented policy measures to implement[89] – so too has the analysis presented in previous chapters of this work. As far as we know, there has been no analysis of the national economic costs and benefits, although life-cycle analyses have demonstrated a reduction in environmental impact provided that certain electricity production conditions are met. In order to shift from the economic impact on the user onto the nation, the economic impacts on all other parties concerned – in particular transport providers and the central government – need to be considered. A socio-economic assessment of the overall impact has been attempted for France (CGDD, 2011), but it did not take industrial effects or social transfers into account.

[89] Cf. BCG, 2009; CGDD, 2011; CE Delft, 2011; Deutsche Bank, 2009; Draper, 2009; Deutsche Bank, 2011; ESMT, 2011; Nemry, 2011.

6.1.2 Objective

The objective of the analysis presented in this chapter is to evaluate the financial effects of replacing a conventional vehicle (CV) with an electric vehicle (EV) on the public budget. These financial consequences are of different kinds: a specific policy to promote electric cars is only one of the obvious fiscal effects. The aim is to also show the hidden part, which includes industrial, fiscal and social factors. Industrial factors are taken here in their broadest sense, referring to the various activities involved in economic production, in particular manufacture and energy production, both in the construction of a vehicle and in the provision of products and services throughout its operating life.

The industrial factors have economic and social implications for employment, and therefore for salaries, for social contributions by employers and employees and for workers' incomes. We include these social accounts, along with unemployment benefits, in the accounts of the government that sustains them. Moreover, the value added by economic production is taxable and generates tax revenues, both on the consumption side (by the value added tax – VAT) and on the production side (by various taxes that are levered on the production). Finally, energy is subject to specific taxes.

Obviously, all these effects relate to a particular country, which shows its own system of production and economic, social and fiscal arrangements at any given time. This analysis provides generally applicable principles and a methodology of financial valuation, which are then applied to the specific case of the private car in France, taking (for the reason of data availability) the year 2007 as the base year of analysis.

6.1.3 Method: vertical economic valuation

We evaluate the replacement of a CV by an EV over the vehicle's whole life-cycle: the manufacture, the use of the vehicle and the associated consumption are considered. The vehicle use and its related consumption are quantified by vehicle type and annual mileage, which determine the attractiveness of the EV to buyers (as earlier shown in Chapter 3). We evaluate the industrial factors for each type of vehicle using an input-output model for economic production in the country. This model describes production, external trade and consumption for each type of activity. For consumption, we make a distinction between i) final demand by households and public bodies, ii) final demand by companies for capital goods (capital and depreciation) and iii) intermediate consumption arising from production, specified for each production activity. We adapt the input-output model to the composition and specific consumption requirements of an EV. We also use the production accounts and employment statistics for each type of activity, in order to evaluate the fiscal and social effects.

Our evaluation is therefore situated within the general framework of economic and social activity, incorporating direct and indirect economic effects. This way, the analysis goes beyond the conventional context of transport economics (e.g. Quinet, 1998), which focuses exclusively on transport service, by including industrial and social factors.

6.1.4 Outline of the chapter

The chapter is structured into three main parts and a conclusion. First, we describe the evaluation method, setting out the principles and specifying an accounting model for the different effects (Section 6.2). Section 6.3 gives a description of underlying data sources and necessary assumptions, for each type of vehicle. In Section 6.4, different scenarios for different locations of vehicle manufacture and use are developed and evaluated. A sensitivity analysis for most important input parameters is carried out. In the conclusion (Section 6.5), we describe the scope and limitations of our method, and suggest further research.

6.2 Methodology: principles and valuation model

Step-by-step, we describe i) the calculation by vehicle and life-cycle, ii) the input-output model of economic production, iii) the taxation model for the activity, for trading and for energy, and iv) the social model, before introducing v) the valuation formulae.

6.2.1 Calculation by vehicle and by life-cycle

In order to evaluate the economic effects of a type of vehicle – EV or CV – we calculate the unit costs and revenues for the manufacture and then the use of a car. This means that the calculation neither depends on the size of the vehicle stock, nor on the annual volume of vehicle sales.

We distinguish two essential phases in the life cycle of a car: first, the manufacture phase, and second, the use of the vehicle by the consumer during its operational lifetime.[90] We use an annual basis for both manufacture and use over the whole life-cycle and choose to work with the vehicle sales flow, counting all the costs associated with manufacture in a single year and allocating all the running costs over the lifespan of the vehicle to that year.

[90] We ignore the disassembly phase of a vehicle. This phase cannot be ignored in absolute terms, but we think that with regard to the differential between EV and ICV, its impact is minimal.

We postulate that the total cost of ownership (TCO) for the vehicle user is sufficiently alike between EVs and CVs for the difference to have no more than a negligible impact on the decision to buy, on the annual mileage covered by the user and on the length of ownership and therefore the economic lifespan of the vehicle. In formal terms, $\delta\mathbf{Y}_J^t = [\delta Y_j^t : j \in J]$ is the annual consumption vector associated with vehicle type $t \in \{\mathrm{C}, \mathrm{E}\}$, for the set J of production activities j.

6.2.2 Input-output model of economic production

The main activities associated with production include car construction, the manufacture of electrical equipment, metal products, textiles, the supply of car-related services and consumables, etc. We will identify the relevant items in the next section: for methodological purposes, we simply need to specify a set of activity types, J.

By activity type j, let X_j be the value produced annually within the study area. I_j is the value of imports, E_j the value of exports, $K_{j\bullet}$ the intermediate product consumption required by the various activities, and Y_j the final demand of households and public institutions (and firms in the case of capital goods). The result for the activity over a financial year within the geographical area is as follows:

$$I_j + X_j = K_{j\bullet} + Y_j + E_j . \tag{1}$$

Intermediate consumption arises from the volumes X_i of the various activities. We assume a linear dependence, giving the following breakdown:

$$K_{j\bullet} = \sum_{i \in J} K_{ji} \text{ and } K_{ji} = a_{ji} X_i . \tag{2}$$

We call the technical coefficients matrix $\mathbf{A} = [a_{ji} : j, i \in J]$. In matrix form, therefore, the total for all the activities is expressed as follows:

$$\mathbf{I}_J + \mathbf{X}_J = \mathbf{A}.\mathbf{X}_J + \mathbf{Y}_J + \mathbf{E}_J . \tag{3}$$

Assuming that final demand and foreign trade are known, domestic production is deduced from it as follows, where $\mathbf{U}$ is the identity matrix:

$$\mathbf{X}_J = (\mathbf{U} - \mathbf{A})^{-1}.(\mathbf{Y}_J + \mathbf{E}_J - \mathbf{I}_J) . \tag{4}$$

Replacing a CV with an EV entails a change from $\mathbf{Y}_J$ to $\mathbf{Y}'_J = \mathbf{Y}_J + \delta\mathbf{Y}_J^{\mathrm{E}} - \delta\mathbf{Y}_J^{\mathrm{C}}$. From here, we can use the accounting model to draw the consequences regarding $\mathbf{X}_J$, which becomes $\mathbf{X}'_J = \mathbf{X}_J + \delta\mathbf{X}_J$. By linearity,

$$\delta\mathbf{X}_J = (\mathbf{U} - \mathbf{A})^{-1}.\delta\mathbf{Y}_J \text{, where } \delta\mathbf{Y}_J = \delta\mathbf{Y}_J^{\mathrm{E}} - \delta\mathbf{Y}_J^{\mathrm{C}} . \tag{5}$$

So far, this is a standard national accounting procedure. However, it is not enough to take account of a change in production and the associated technologies. Making EVs is a different industrial activity to making CVs, because both the distribution and use of the inputs are different. To reflect this specificity, we model an additional type of activity, with its own notation j^* and specific technical coefficients both for output from the different sectors (a_{ij^*} for each $i \in J$) and for input (a_{j^*i} for each $i \in J$).

In formal terms, J should, strictly speaking, be adjusted to $J^* = J \cup \{j^*\}$, the vectors $\mathbf{V}_J$ to $\mathbf{V}^*_{J^*}$ etc. We will content ourselves by mentioning the conversion of matrix $\mathbf{A}$ into $\mathbf{A}^*$, to use formulas (3), (4) and (5).

6.2.3 Fiscal model of activity, exchanges and energies

A country's government is able to find as many taxation sources as there are types of activity and economic processes. For our problem, we differentiate between general taxes on consumption (VAT) $\mathbf{T}^Y$, taxes on production $\mathbf{T}^X$, import taxes $\mathbf{T}^I$ and export taxes $\mathbf{T}^E$.

We assume that each tax is proportional to the nature of the activity, with a specific coefficient. Remaining with the French case, tax on production corresponds to various specific levies, including the *Cotisation Economique Territoriale* (national economic contribution) and corporation tax. We assume that it is proportional to the Gross Operating Surplus (GOS, value added minus labour costs), if this is a positive figure. In addition, we first consider GOS proportionally to added value, and therefore ultimately to final demand. One proportionality leading to another, for each activity we take final domestic demand Y_j as the tax base for tax T^X_j.

In addition, we consider specific taxes on energy sources, expressed $\mathbf{T}^C$ with index C for Carbon, because in France this notably includes TICPE (domestic tax on petroleum products). We link them proportionally and specifically to each activity, to final demand, including consumption and specific energy sources.

In all, exogenous variations $(\delta\mathbf{Y}_J, \delta\mathbf{I}_J, \delta\mathbf{E}_J)$ and endogenous variations $\delta\mathbf{X}_J$ cause tax revenues to vary by

$$\delta R = (\mathbf{T}^Y + \mathbf{T}^X + \mathbf{T}^C).\delta\mathbf{Y}_J + \mathbf{T}^I.\delta\mathbf{I}_J + \mathbf{T}^E.\delta\mathbf{E}_J . \qquad (6)$$

Finally, the tax element needs to incorporate specific policies relating to car ownership and use, let us say a value of σ depending on which base year is chosen: in particular a subsidy for the purchase of an electric vehicle, or local exemptions from car parking fees, or the free supply of electricity on the public highway. Then

$$\delta F = \delta R - \sigma . \quad (7)$$

6.2.4 Social model

The social factors include return on investment, labour remuneration (including salaries and social contributions), together with unemployment benefits. We incorporate social revenues and expenditure into the national accounts, whilst retaining the possibility of isolating them if necessary.

Let us begin by expressing the value added per activity, V_j, as a function of production X_j and of the intermediate consumption that constitute an input into that production, K_{ij}:

$$V_j = X_j - K_{\bullet j}, \text{ where } K_{\bullet j} = \sum_{i \in J} K_{ij} = (\sum_{i \in J} a_{ij}) X_j . \quad (8)$$

In matrix form, if the unit row vector by type of activity is expressed $\mathbf{u}_J = [1 : j \in J]$, the product $\mathbf{u}_J.\mathbf{A}^*$ is a row vector $[\sum_{i \in J} a_{ij} : j \in J]$. These elements are used as diagonal terms in the square matrix $\text{diag}[\mathbf{u}_J.\mathbf{A}^*]$ whose non-diagonal terms are zero. Let us posit $\mathbf{B} = \mathbf{U} - \text{diag}[\mathbf{u}_J.\mathbf{A}^*]$ to summarise the linear relationship between the added value vector and the production vector. Formally,

$$\mathbf{K}_{\bullet J} = (\mathbf{U} - \mathbf{B}).\mathbf{X}_J \text{ and } \mathbf{V}_J = \mathbf{B}.\mathbf{X}_J . \quad (9)$$

Then, still by activity type, we assume that the number of people employed η_j is proportional to the value added, with an inverse factor of "individual productivity" ρ_j (i.e., the average individual salary charged):

$$\eta_j = V_j / \rho_j . \quad (10)$$

We then express the average wage per employee as $w_j = w_j^{(i)} + w_j^{(s)}$, where $w_j^{(i)}$ is the net wage and $w_j^{(s)}$ the employee's and employer's social contributions. For each activity, the social contributions are $w_j^{(s)} \eta_j = V_j w_j^{(s)} / \rho_j$.

The row vector of sectoral coefficients $[w_j^{(s)} / \rho_j : j \in J]$, multiplied on the right by matrix $\mathbf{B}$, gives us the vector of sectoral coefficients for social contributions:

$$\mathbf{W}_J = [w_j^{(s)} / \rho_j : j \in J].\mathbf{B} . \quad (11)$$

From this, we can deduce the variation in social contributions associated with a variation in production $\delta \mathbf{X}_J$:

$$\delta S^{+} = \mathbf{W}_J . \delta \mathbf{X}_J . \qquad (12)$$

If the government pays unemployment benefit at a net rate of z_j per unemployed worker in activity j (neutralising the social security contributions paid for the unemployed person), then the variation in social transfers associated with the variation in employment arising from a variation in production is the sum of social security contributions plus unemployment benefit,[91] i.e.

$$\delta S = \mathbf{W}_J^{+} . \delta \mathbf{X}_J \text{, where } \mathbf{W}_J^{+} = [(w_j^{(s)} + z_j)/\rho_j : j \in J] . \mathbf{B} . \qquad (13)$$

6.2.5 Provisional result

For the government, the balance of revenues net of expenditure for an exogenous variation $(\delta \mathbf{Y}_J, \delta \mathbf{I}_J, \delta \mathbf{E}_J)$ in final domestic demand and in foreign trade is

$$\delta B = \delta F + \delta S = \delta R - \sigma + \delta S . \qquad (14)$$

To put values on the terms, we need to first establish the different proportionality coefficients that characterise the territory's production system and socio-economic circuit, then deduce the variation in production that arises from exogenous variations.

Formula (14) summarises the model. This is linear by nature, so that it can be applied to any number of private vehicles that may be affected by the conventional being replaced by the electric motor within a given territory.

We have limited the sequence of impacts by ignoring the effects on household demand of a variation in income (from capital or from work), and the effects of the spatial distribution of households (if the residential zone is outside the employment zone, then the rebound effects of consumption occur outside). We also ignore the income tax levied on individuals, apart from social contributions based on salary. In principle, the effects on driver consumption should be very small, since our comparison is based on two products that are assumed to be nearly equivalent in terms of total cost of ownership. The effects on worker revenues are less clear, especially if there is a shift in employment between the main activities concerned (cars, electrical equipment, energy).

[91] Because the direction of transfer for the government needs to be taken into account: the government earns social contributions from a worker in employment, and also saves unemployment benefit, and therefore receives the sum of the two.

6.3 Data and assumptions

As of the end of 2011, we have annual statistics up to 2010 for the production accounts for each industrial sector in France, as well as for the number of people employed, salaries and social contributions (INSEE, 2011d). We also have an economic and social chart for 38 activity groups in base year 2009, in which car manufacture is part of the transport equipment manufacture, along with the rail and aerospace industries. A more detailed chart that distinguishes the French industry into 118 activity groups is available for the year 2007. It identifies the activity 'car manufacture' separately; it is our main source for the input-output model. We aggregate all activity groups other than car manufacture to 23 sectors for easing calculations and the demonstration of results.

6.3.1 Composition of a car

The French new car market continues to be primarily supplied by carmakers of French origin, but vehicles imported by those carmakers and their foreign competitors account for more than 40 % of the market (CCFA, 2011c). In the 2007 national accounts, French production in "car manufacture" was EUR 67 billion, imports EUR 38 billion and exports EUR 47 billion, all exclusive of tax. The breakdown of domestic demand was 60 % from households and public institutions, and 40 % from businesses. Final household demand reflects the number of private cars sold and the average unit price recorded in recent years (approximately 2.3 million cars per year and EUR 16,000 per car excluding VAT).

By relating intermediate consumption in the activity of "car manufacture" to its production value, we obtained the technical coefficients for this activity, which reflect the typical value composition of a CV. These items are shown in the first two columns of Table 6.1. The breakdown relates to intermediate consumption $[a_{ij} : i \in J]$ in activity j – "car manufacture" – and to its added value. The total purchase value of the assumed underlying vehicle is EUR 14,000 before taxes. This value is in line with the purchase price of the diesel-driven Renault Clio as introduced in the total cost of ownership (TCO) model of Chapter 3 (being EUR 17,450 after adding the VAT of 19,6 %).

On the output side of this activity, intermediate consumption K_{ji} is low compared with production X_i in activities i, because a car is a finished product that companies acquire as capital goods, not for their own production processes.

Let us move onto the modelling of the value composition for an EV. We treat the vehicle body and the battery as separate entities. Our assumptions about vehicle composition are set out in Table 6.1: we have assigned hypothetical values per car, deduced from those of the CV for most fittings, but reduced the value for the self-provision of the activity "car manufacture" by

EUR 1,000 excluding tax (assuming that the electric motor is easier to build than the conventional motor). For the battery, we have counted EUR 9,300 excluding tax under "Electrical and electronic equipment".[92] This value is in accordance with the price of a 10-year battery hire as per Renault's offers (see Chapter 3, Section 3.2.4). This is the assumed value of the battery (not taking into account any possible resale value of the battery after the assumed vehicle and battery lifetime of 10 years – see the next section).[93] Finally, having assumed the same added value for an EV as for a CV, we obtain a total production cost per EV (before tax), to which we apply the cost of each material supplied in order to obtain the technical coefficient of that material for column j^* of activity "car manufacture (EV)", in technical coefficient matrix $\mathbf{A}^*$. In addition, this activity row in the matrix was specified as zero apart from the diagonal self-provision term (engines, chassis).

Table 6.1 shows that the largest value contribution to a car comes from the car manufacture itself. It contributes almost 30 % to the total value of a car in the case of a CV. The second and third largest value contributions come from "metals and metalworking" (12 %) and "automotive equipment" (9 %). The given assumptions for the EV result in a different value breakdown: the value contribution of the "car manufacture" is only 14 %; the biggest value contributor is "electrical and electronic equipment" with a 43 %-share.

[92] Our decision to allocate the manufacture of the battery to this activity, rather than to vehicle construction, is a deliberate one intended to take better account of probable intermediate consumption. A sensitivity test suggests that the impact of this decision on the scenario evaluation is minimal.

[93] In the TCO model of chapter 2, the EV with a battery hire causes *continuous* battery costs that incur over the ownership period of the vehicle. In the input-output model, we consider the time of value creation of products and services. For this reason, the value of the battery is counted in the production factors of the vehicle rather then the use factors of the vehicle (as introduced in the next section).

Activity	CV		EV	
	EUR (before tax)	%	EUR (before tax)	%
Car manufacture (EV)	**0**	**0.0%**	**3,172**	**14.2%**
Farming, Agri-food Industry	9	0.1%	9	0.0%
Consumer goods	415	3.0%	415	1.9%
Car manufacture (CV)	**4,172**	**29.8%**	**0**	**0.0%**
Automotive equipment	1,286	9.2%	1,286	5.8%
Ship, aircraft, rail construction	8	0.1%	8	0.0%
Machinery	739	5.3%	739	3.3%
Electrical and electronic equipment	308	2.2%	9,608	43.1%
Mineral products	163	1.2%	163	0.7%
Textiles	167	1.2%	167	0.7%
Wood, paper, pulp	40	0.3%	40	0.2%
Chemicals, rubber, plastics	1,040	7.4%	1,040	4.7%
Metals and metalworking	1,671	11.9%	1,671	7.5%
Electrical and electronic components	260	1.9%	260	1.2%
Fuels	80	0.6%	80	0.4%
Water, gas, electricity	83	0.6%	83	0.4%
Construction	17	0.1%	17	0.1%
Car dealing and repair	9	0.1%	9	0.0%
Wholesale and intermediate trade	95	0.7%	95	0.4%
Transport	48	0.3%	48	0.2%
Financial, real estate, rental act.	1,060	7.6%	1,060	4.8%
Services to companies	789	5.6%	789	3.5%
Services to individuals	33	0.2%	33	0.1%
Education, health, social care	88	0.6%	88	0.4%
Administration	2	0.0%	2	0.0%
ADDED VALUE	*1,420*	*10.1%*	*1,420*	*6.4%*
TOTAL	**14,000**	**100.0%**	**22,300**	**100.0%**

Table 6.1: Value distribution of car manufacture

6.3.2 Car use

The standard running of a car entails the consumption of goods and services: in principle, this consumption can be tackled in an input-output model on a final demand basis. We specify this for an electric or conventional vehicle, for a technical and economic lifespan of 10 years with annual mileage of 12,000 km. It should be recalled that the average age of a passenger vehicle in France's automobile stock has increased from 7.3 years in 2000 to 8.1 years in 2011

(INSEE, 2011b), and annual mileage, which rose in the 1990s, fell from 14,000 km in 2000 to 13,000 km in 2009 (CCFA, 2011c)[94]. 12,000 km conforms to the median mileage of the 'first' vehicle of households that were identified to qualify for a battery electric vehicle (BEV) with a battery hire option (in 2012 – see Chapter 4, Section 4.4.5). We take this parameter value for calculating vehicle use costs. It reflects a vehicle mileage where buying a BEV with a battery hire option rather than a CV, is more financially advantageous, given all assumptions and 2012 policy settings that underlie the TCO model of Chapter 3.

Let us reiterate our accounting convention that was laid out in the methodology section: we count each year in terms of vehicles sold, so for this year we need to count the use of the vehicle over its entire life cycle. In all, use costs are fairly equal to acquisition costs for a CV (excluding any possible road toll or parking costs).

The vehicle use-related consumption costs consist primarily of fuel or electricity, plus service, maintenance and insurance costs (see Chapter 3).

Table 6.2 gives economic consumption, excluding tax, per vehicle type for a total mileage of 120,000 km over the assumed life-span of 10 years. Our standard CV is a compact diesel car, with above average annual mileage: the model is inspired by the Renault Clio (as in the TCO model introduced in Chapter 3), with average fuel consumption of 4 litres of diesel per 100 km. The main inspiration for the EV model is the Renault Zoe Z.E. (the electric counterpart to Renault's Clio), assuming consumption of 16 kWh per 100 km. Energy consumption is valued exclusive of tax at EUR 0.73 per litre of diesel and EUR 0.10 per kWh for electricity[95]. We valued maintenance at EUR 435 per year for the CV and EUR 410 per year for the EV, exclusive of tax. Insurance is rated at EUR 420 per year for the CV and EUR 325 per year for the EV, again exclusive of VAT.[96]

[94] For petrol vehicles it has fallen from 11,000 km in 2000 to 9,000 km in 2009; for diesel vehicles it has fallen from 19,000 km to 16,000 km in the same time period. (CCFA, 2011c)

[95] These are the average fuel and electricity prices of the year 2012 according to CGDD (2012f) and Eurostat (2012) respectively.

[96] All these values are again in line with the assumptions made and motivated in chapter 3, when the TCO model was introduced.

	CV	EV
Maintenance costs (EUR, before tax)	435	410
Insurance costs (EUR, before tax)	420	325
Annual driven distance (km)	12,000	12,000
Energy consumption per 100 km	4 l diesel	16 kWh
Costs per unit of energy (EUR)	0.73	0.10
Total energy costs (EUR, before tax)	350	189
Total usage costs (EUR, before tax)	1,205	924

Table 6.2: Use of a car: annual costs

Vehicle use-realted final consumption is shown in Table 6.4.

6.3.3 Fiscal and social effects

With regard to tax, for each activity we specify a VAT rate of 19.6 % and a tax on production based on the production ratio recorded for the activity in 2007. In addition, we included a TICPE[97] of EUR 0.45 per litre of diesel on car fuel, as well as specific taxes on electricity at a rate of 14 % on the amount before tax plus VAT (MEDDE, 2011; and according to the TCO model as introduced in Chapter 3).

Concerning the social factors, in each activity we considered the employer's and employee's social contributions proportional to salary, for a total of 45 % (cf. Urssaf, 2011): by concatenation we establish a proportional relation with production. In addition, we set unemployment benefit at a fixed amount of 50 % of the average net salary: this simplified method of valuation reflects quite accurately the amounts stipulated under industrial agreements (Urssaf, 2011).

Table 6.3 summarises the social effects of principal interest, for the main production activity groups. The inequalities between the groups' individual indicators arise from the fact that the link between jobs and activities is not very precise.

[97] Taxe Intérieure de Consommation des Produits Energétiques (domestic tax on the consumption of energy products): this term replaced TIPP in January 2011.

Activity	Car manuf.	Autom. equip.	Metals	Fuels	Water, gas, electr.	Car deal., repair	Services to individuals
Production Xj (M€, before tax)	67,310	27,662	97,453	58,477	78,675	46,248	179,886
Added value Vj (M€, before tax)	6,828	5,933	29,315	6,068	27,350	27,675	95,147
Full-time jobs (1,000)	179	65	464	38	133	461	2,325
Productivity Rj (1,000 €)	29.0	70.1	39.6	42.0	77.5	34.1	26.9
Social contr. wj_s (1,000 €)	13.1	31.5	17.8	18.9	34.9	15.3	12.1
Unempl. benefits zj (1,000 €)	8.0	19.3	10.9	11.6	21.3	9.4	7.4

Table 6.3: Taxes and social transfers based on production

6.4 Scenarios and results

In the two previous sections, we described the valuation model and the assumptions applied to the French domestic situation. We can now deduce the results, beginning with the factors of the scenario relating respectively to the manufacture of a vehicle for each type of vehicle – CV or EV – and to the use of a vehicle. Then we will examine different scenarios in which manufacture and use take place inside or outside the country.

6.4.1 Evaluation of the scenario elements

A scenario is a combination of manufacture elements (M) and use elements (U), per vehicle type. Four elements are of fundamental importance: the domestic manufacture of a CV (CM, C for Conventional and M for manufacture) and its use (CU), the domestic manufacture of an EV (EM) and its use (EU).

Table 6.4 gives the consumption for each element. The table reveals upon which sector the final demand resulting from a vehicle acquisition and the vehicle use is levered: the vehicle price is levered upon the respective car manufacture sectors; energy, maintenance, and assurance costs are levered upon the "Fuel" (or, respectively, on the "Water, gas, and electricity"), the "car dealing and repair", and the "Financial, real estate, rental" sectors. For the EV, additional EUR 500 and EUR 300 are levered upon the "Electrical and electronic equipment" and the "Services to individuals" sectors in the manufacture phase. These values reflect approximate costs for the installation of EV recharge infrastructure. In the TCO model (Chapter 3) the lump sum of EUR 590 reflected the home infrastructure installation costs (the equipment and installation costs of a 'wall-box'). The EUR 800 assumed here, represent these home infrastructure installation costs and (approximate) costs of public infrastructure installation incurred by a single vehicle.[98]

[98] These values are very approximate and will depend on the actual conditions of (home) infrastructure installation. The pro-rate public infrastructure installation costs further

	CV		EV	
Activity	**Manufacture**	**Use**	**Manufacture**	**Use**
(in EUR, before tax)	**CM**	**CU**	**EM**	**EU**
Car manufacture (EV)	0	0	22,300	0
Farming, Agri-food Industry	0	0	0	0
Consumer goods	0	0	0	0
Car manufacture (CV)	14,000	0	0	0
Automotive equipment	0	0	0	0
Ship, aircraft, rail construction	0	0	0	0
Machinery	0	0	0	0
Electrical and electronic equipment	0	0	500	0
Mineral products	0	0	0	0
Textiles	0	0	0	0
Wood, paper, pulp	0	0	0	0
Chemicals, rubber, plastics	0	0	0	0
Metals and metalworking	0	0	0	0
Electrical and electronic components	0	0	0	0
Fuels	0	3,504	0	0
Water, gas, electricity	0	0	0	1,893
Construction	0	0	0	0
Car dealing and repair	0	4,350	0	4,100
Wholesale and intermediate trade	0	0	0	0
Transport	0	0	0	0
Financial, real estate, rental act.	0	4,200	0	3,250
Services to companies	0	0	0	0
Services to individuals	0	0	300	0
Education, health, social care	0	0	0	0
Administration	0	0	0	0
TOTAL	**14,000**	**12,054**	**23,100**	**9,243**

Table 6.4: Final demand per car (for the whole 10-year life-cycle)

Table 6.5 specifies the production effects associated with the final demand caused by the manufacture and use of either a CV or an EV.

depend on the actual number of EVs in circulation. The integration of such forecasts into the input-output model is not object of this study. We therefore content ourselves with these approximations.

	CV		EV	
Activity	**Manufacture**	**Use**	**Manufacture**	**Use**
(in EUR, before tax)	**CM**	**CU**	**EM**	**EU**
Car manufacture (EV)	0	0	25,997	0
Farming, Agri-food Industry	466	240	764	165
Consumer goods	1,144	310	1,471	217
Car manufacture (CV)	20,018	418	100	385
Automotive equipment	2,162	259	1,809	227
Ship, aircraft, rail construction	149	39	208	24
Machinery	1,993	421	2,558	249
Electrical and electronic equipment	970	198	14,490	128
Mineral products	937	213	1,325	145
Textiles	481	50	541	35
Wood, paper, pulp	551	210	867	137
Chemicals, rubber, plastics	3,831	1,215	4,716	512
Metals and metalworking	6,331	905	8,445	558
Electrical and electronic components	910	228	2,064	160
Fuels	3,123	13,596	4,198	2,435
Water, gas, electricity	842	419	1,180	2,724
Construction	299	360	441	269
Car dealing and repair	37	4,393	45	4,133
Wholesale and intermediate trade	427	196	657	109
Transport	610	628	994	345
Financial, real estate, rental act.	6,626	9,416	10,209	6,868
Services to companies	1,641	184	2,379	106
Services to individuals	309	233	823	158
Education, health, social care	270	121	389	83
Administration	36	82	59	47
TOTAL	**54,163**	**34,335**	**86,729**	**20,221**

Table 6.5: Domestic production per car manufacture and use

Table 6.5 reveals that the domestic production caused by vehicle manufacture and use is significant: the demand associated with the car manufacture entails a domestic production of almost 4 times the value of the demand (of 3.9 times this value for the CV, and 3.8 times this value for the EV); the total demand associated to the car use entails a domestic production of 2.8 and 2.2 times of the value of this latter demand (for the use of the CV and EV respectively).

The financial proceeds for the government that result from the totality of the domestic production are given in Table 6.6. They are substantial: over the life cycle of a vehicle, the financial proceeds amount to EUR 28,000 for a CV and EUR 33,000 for an EV, excluding the EV purchase bonus. The proceeds from

manufacture are almost equivalent to the vehicle's selling price before tax. The proceeds from use are in the EV's case also almost equal to the final cost excluding tax; in the CV's case they are 20 % higher than the final expenditure.

Replacing a CV by an EV appears to benefit the public purse, provided that it is manufactured and used within the country. A purchase bonus of EUR 7,000 reduces the financial revenue from an EV by 21 %, taking them markedly below those from a CV. It results in a loss of EUR 2,400 for the government.

Within the financial proceeds, social effects are very substantial and paramount: 67 % for the CV and 73 % for the EV, let's say 70 % for the sake of clarity. This provides retrospective justification for evaluating them. Their distribution between manufacture and use varies according to vehicle type: 54-46 % for a CV compared with 72-28 % for an EV. Broken down by item, unemployment benefit represents around 38 % of net social contributions: we incorporated it into the accounts to reflect labour market conditions, which are currently difficult in France.[99]

VAT plays an important role, representing 19-20 % of proceeds. Additional energy taxes produce 8 % of the proceeds for a CV, but only 1 % for an EV. Finally, production taxes represent a significant, though proportionally small amount, i.e. 6 % for both vehicle types.

On the tax side, the proceeds from one CV would be EUR 9,400 compared with EUR 8,700 for an EV before bonus, and EUR 1,700 after bonus. These figures flesh out the results of CAS, 2011, by including tax on production on both the manufacture and use sides.

	CV				EV			
(in EUR per car)	**Man.**	**Use**	**SUM**	**%**	**Man.**	**Use**	**SUM**	**%**
Final expenditure	*14,000*	*12,054*	*26,054*		*23*	*9*	*32*	
Value added tax (VAT)	2,744	2,786	5,530	20%	4,528	1,812	6,339	19%
Energy taxes		2,160	2,160	8%		3	317	1%
Production tax	961	712	1,672	6%	1,560	522,000	2,082	6%
Net social contributions	10,159	8,754	18,912	67%	17,500	6,661	24,161	73%
Gross social contributions	6,305	5,433	11,739	42%	10,862	4,134	14,996	46%
Saved unemployment benefit	3,853	3,320	7,174	25%	6,638	2,527	9,164	28%
Total without EV bonus	13,863	14,411	2,827	100%	23,587	9,312	32,899	100%
Total with EV bonus	*13,863*	*14,411*	*28,274*		*16,587*	*9,312*	*25,899*	

Table 6.6: Financial proceeds

[99] This inclusion is particularly important for a job retained "on the margin" of production, directly linked with business volumes. Since our model is linear, applying an assumption to the margin means that it applies to the entire volume of activity. As each of our scenarios is differential, this should not generate distortions.

6.4.2 Definition and analysis of scenarios

In the baseline scenario, the manufacture and use of the vehicle take place within the territory under consideration.

We establish the following alternative scenarios:

1) **Import**: for a vehicle manufactured outside the territory but used inside the territory.
2) **Export**: the vehicle is manufactured within the territory but is used elsewhere.
3) **Competitive import**: a domestically produced CV is replaced with an imported EV.

In the Import scenario, the tax treatment of consumption is the same as in the base scenario. However, the tax on production in the manufacture phase is lost to the territory, as are the social effects in manufacture. In this case, the EV loses its main revenue-generating elements. The financial loss to the domestic government is in excess of EUR 3,000 per vehicle before applying the purchase bonus, and EUR 10,000 after the bonus.

However, the worst scenario is the "Competitive import", in other words replacing a domestically produced CV with an imported EV, where a foreign-based carmaker offers a domestic consumer an attractive vehicle that persuades them to switch type. Indeed, excluding bonus and for the manufacture phase, an imported EV would attract financial revenues of EUR 4,500 (the VAT), whereas a domestically produced CV brings in EUR 13,900, making a loss of EUR 9,400. Including use, the loss would rise to EUR 14,400 without bonus, and EUR 21,400 with bonus!

The Export scenario contributes neither VAT (on manufacture or use), nor social effects and energy surcharges during the vehicle use (ignoring the supply of spare parts). Its effects are restricted to the manufacture phase, and in this respect, an EV is almost twice as productive as a CV, provided that no bonus is applied at export, i.e. that the bonus is only allocated for domestic use of the vehicle.

Out of all the scenarios, substitution for export is the most beneficial to the public purse, whereas replacing a domestically manufactured CV with an imported EV is the most damaging. In the intermediate position, the baseline scenario with manufacture and use occurring domestically is positive without bonus, but negative with. It is markedly favourable than the Competitive import scenario.

	Scenarios			
(in EUR per car)	**Base**	**Import**	**Export**	**Comp. import**
Final net expenditure	*6,289*	*-1,027*	*9,100*	*-12,283*
Value added tax (VAT)	809	809	0	809
Energy taxes	-1,843	-1,843	0	-1,843
Production tax	409	-189	599	-1,150
Net social contributions	5,249	-2,093	7,341	-12,251
Gross social contributions	3,258	-1,299	4,557	-7,604
Saved unemployment benefit	1,991	-794	2,785	-4,647
Total without EV bonus	4,624	-3,316	7,940	-14,435
Total with EV bonus	-2,376	-10,316	940	-21,435

Table 6.7: Evaluation by scenario

6.4.3 Sensitivity analysis

As stated in the preface of this work, this chapter is largely based on Leurent and Windisch (2013). While the whole methodology and large parts of this chapter are equal to what is presented in Leurent and Windisch (2013), the analysis presented here deviates with regards to several underlying data and assumptions. The reason for that is that we put these assumptions and data in line with what has been presented in previous chapters of this work. Resulting observed magnitudes and tendencies of results largely stay the same as in Leurent and Windisch (2013). Nevertheless, the assumptions taken in this study lead to more EV-advantageous results than in the latter reference. In the following table, we state all parameter settings that changed between the two studies. Table 6.9 compares then the results for the base scenario of the two studies in question.

The differences in parameter settings of all cost or price items do not appear to be crucial. The most crucial parameter change is certainly the annual driven distance: we assume it to be 3,000 km inferior to the one in Leurent and Windisch (2013). Further, we also assume maintenance costs, next to energy costs, to be dependent on the annual driven distance. This suggests that the main reason for the differing results of the two underlying studies stems from the different assumptions on the annual driven distance.

Table 6.9 shows that the effect of all changes put together is important: while the replacement of a CV with an EV results in an almost neutral outcome for the public budget in Leurent and Windisch (2013), the same replacement results in a EUR 4,600 surplus in this study (both neglecting the impact of the purchase bonus). The biggest difference in the financial proceeds comes from the social contributions. The origins of this difference are explored in the following sensitivity analysis.

Parameters		Assumed settings: *Leurent and Windisch (2013)*	Assumed settings: *This study*
Annual driven distance (in km)		15,000	12,000
Purchase price battery		10,000	9,300
Purchase price CV		14,600	14,000
Annual maintenance costs			
	CV	800	435*
	EV	500	410*
Annual insurance costs			
	CV	440	420
	EV	330	325
Energy consumption			
CV (in l diesel/100 km)		5	4
EV (in kWh/100 km)		18	16
Diesel price (per liter)		0.70	0.73
Electricity price (per kWh)		0.0930	0.0986

all cost/price items in EUR, before taxes

** dependent on the annual driven distance*

Table 6.8: Comparison of parameter settings

(in EUR per car)	*Leurent and Windisch (2013)*	*This study*
Final net expenditure	*2,964*	*6,289*
Value added tax (VAT)	-81	809
Energy taxes	-2,955	-1,843
Production tax	234	409
Net social contributions	2,872	5,249
Gross social contributions	1,782	3,258
Saved unemployment benefit	1,089	1,991
Total without EV bonus	**70**	**4,624**

Table 6.9: Results of the two studies for the base scenario

First, we explore the sensitivity of results to parameters that describe the vehicle's use and energy consumption. Figure 6.1 shows the results' sensitivities to the annual driven distance and the time of vehicle use (a parameter that has not changed in the two studies in question). Figure 6.2 gives the sensitivities to the petrol and, respectively, electricity consumption.

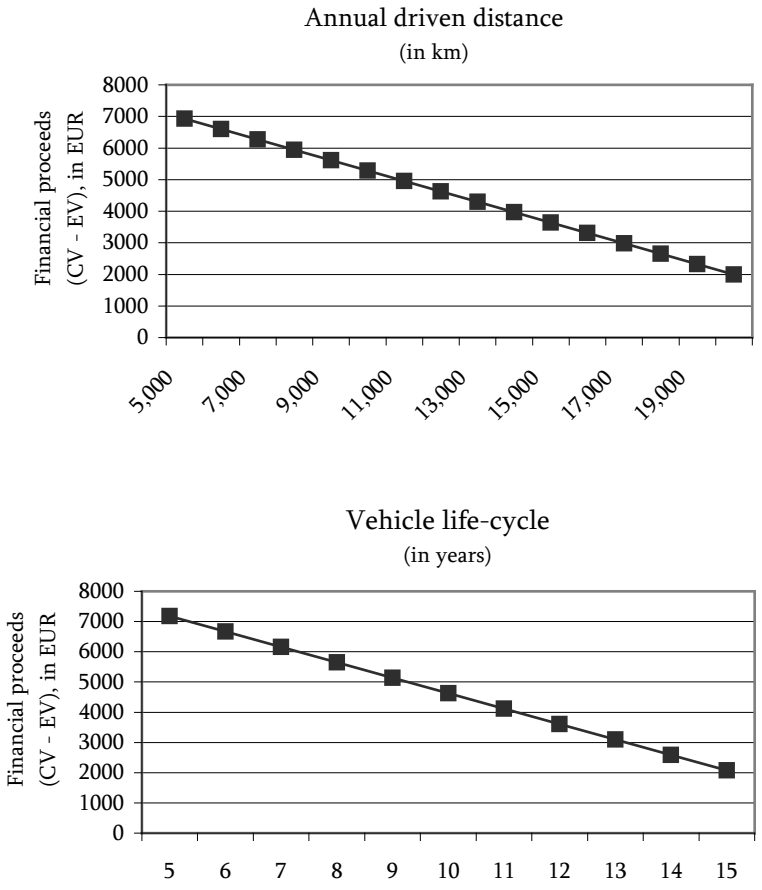

Figure 6.1: Sensitivity to vehicle use parameters

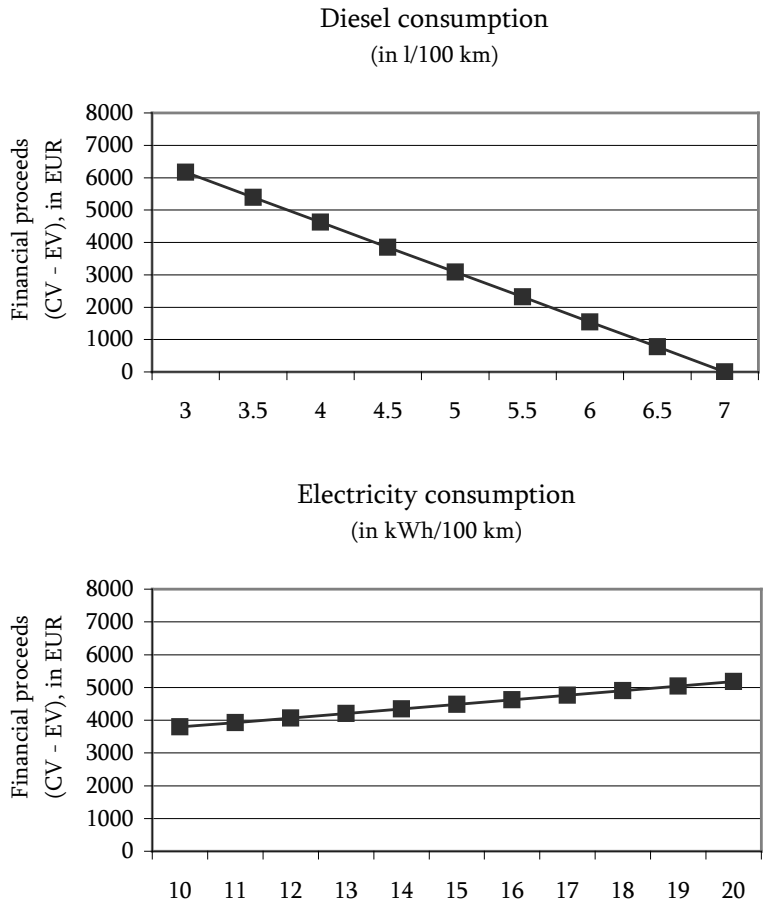

Figure 6.2: Sensitivity to the vehicles' energy consumption

In Figure 6.1 and 6.2, the linear dependence of results on the parameter values becomes apparent. It stems from the underlying linearity assumptions as introduced in Section 6.2.2.

Both parts of Figure 6.1 show that the more the vehicle[100] is used, a lower public finance benefit is observed. Missing fuel taxes or missed industrial activity due to the replacement of a CV that is more frequently (or longer) used is not balanced by the increased electricity tax income or increased industrial activity from the replacing EV that is, in the same way, more frequently (or longer) used.

[100] NB: According to our assumptions, the vehicle use does not change with the event of the vehicle replacement. The assumed use of the replaced CV is therefore equal to the assumed use of the replacing EV.

The left part of Figure 6.2 shows that the higher the fuel consumption of the conventional vehicle is assumed, the less EV-advantageous the financial proceeds of the vehicle replacement are. Since we do not assume any related parameter change concerning the EV, the increased fuel consumption entails increased activity in the petroleum sector (and its interrelated sectors) that is missed in the case of a CV-EV replacement – without any compensation of any increased activity thanks to the EV. The same argument holds for increased electricity consumption of the EV: the more the EV consumes, the more industrial activity is enhanced, and the more production and consumption taxes are received. Replacing a CV with a less energy efficient EV is therefore found to be more advantageous for the public budget than the replacement with a more energy efficient EV.

Figures 6.3 and 6.4 now explore the sensitivity of model parameters that are neither vehicle use nor consumption related. Examined parameters refer to vehicles' and battery's values as well as energy prices. These analyses show how the set-up model is sensitive to the assumptions that should be as closely in line with the study's underlying input-output matrix as possible, since the latter is derived from value flows that are aligned to product and service values of the year in question. Not having detailed information about the values of single products and services, we are obliged to use approximate values.

The left part of Figure 6.3 shows that assuming a different purchase price for the CV in question has no impact on the outcome of the study. This is due to the fact that we assume i) EV prices (without the battery) to be perfectly related to CV prices, and ii) the value flows behind EV manufacture to be the same as CV manufacture (except for the EV's battery). The impact of changes in the purchase price of the EV's battery is, however, significant (see the right part of Figure 3). Assuming an increased battery purchase value, equals the assumption that more activity in the according industry sector (electrical and electronic equipment) is taking place and, consequently, that also all other sectors related to the electric equipment sector are subject to increased activity. Replacing a CV with an EV in such an increased activity scenario, leads to increasingly EV-advantageous proceeds for the public budget.

Figure 6.4 shows the expected effects of changes in energy prices. In cases where diesel prices are assumed to have been higher than what we initially assumed, the replacement of a CV by an EV becomes less favourable. Increased industrial activity would be missed for an unchanged level of activity that is due to the EV. The inverse effect of a CV-EV replacement is observed in case we assume higher electricity prices (and therefore higher industrial activity in the electricity and all related sectors).

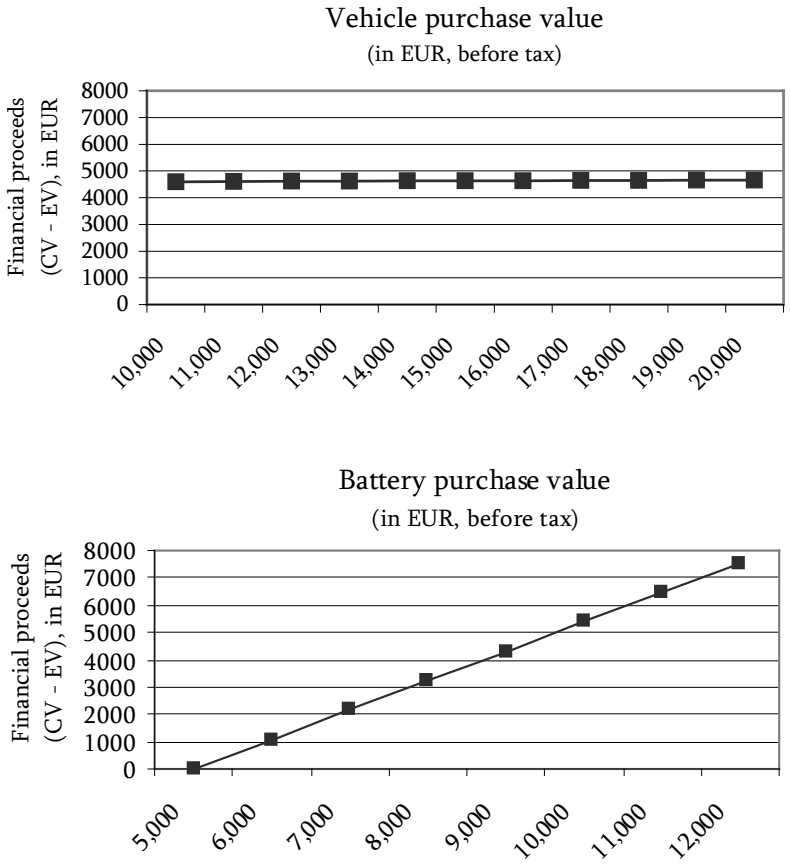

Figure 6.3: Sensitivity to purchase values

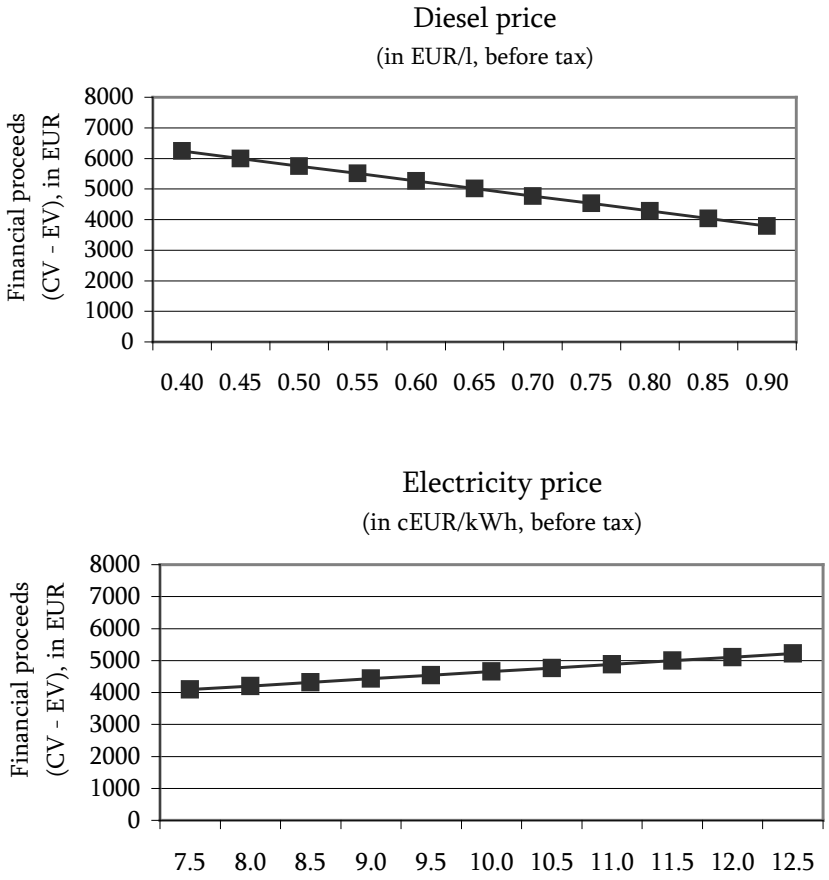

Figure 6.4: Sensitivity to energy prices

Sensitivity analyses presented in Figures 6.3 and 6.4 underline the importance of the accordance between product and service values and the underlying input-output matrix, which is based on the actual values of these products and services in the year in question. Assuming values that are not in accordance with the underlying matrix entail severe distortions in the results. This is due to the fact that wrong value assumptions lead to mistaken assumptions for industrial activity of all product (or service) related industry sectors in the applied methodology.

6.4.4 Discussion

The financial outcome is very sensitive to the place where the vehicle is manufactured and used. The domestic authority needs to subtly adjust its policy, to reflect inherent national conditions.

The outcome of the baseline scenario is favourable to EVs: the loss on fuel surcharges would be more than offset by the gains in social contributions. To bring in these gains, the industrial operators need to keep industrial employment within the country and increase it in proportion with activity. This kind of cooperation with the general interest is less easy for governments to control than taxes on energy: herein lies a significant risk in the implementation of a policy in favour of electric vehicles.

Other specific tax arrangements can distort the results. Notably, in France fuel used by taxis is tax-exempt (up to an annual quota for specific taxes), which would improve the financial outcome of the baseline scenario before bonus, and would similarly improve the outcome of the import scenario.

The results of the different scenarios cover a very wide scope, from the highly negative to the broadly positive: in other words, the development of electric vehicles is a risky undertaking for the public finances of a country, depending on its industrial competitiveness.

The bonus for purchasing an EV constitutes a government incentive, which reverses the outcome of the baseline scenario from positive to negative. It is difficult to justify on the grounds of the long-term goal of protecting the climate by reducing greenhouse gas emissions, because the advantage of the EV over the CV in the use phase, under our assumptions regarding mileage and unit consumption, only represents the equivalent of 13 tonnes of CO_2 for the energy mix of electricity production in France[101]. The cost to the government of saving one tonne of CO_2 by replacing an CV with an EV, in the baseline scenario, would be almost EUR 200 after bonus; in the Import scenario, EUR 250 before bonus and EUR 800 after; in the worst-case scenario, EUR 1,100 before bonus and EUR 1,600 after. All these costs are much higher than the costs of reduction in other sectors, in the short and medium term (e.g. Vogt-Schilb and Hallegatte, 2011; McKinsey, 2009b).

It is therefore worth asking whether a nationwide tax bonus is an appropriate economic instrument. The climate benefit is insufficient, at least in the short and medium term. The same is true for energy factors, which are also part of the carbon economy. Local environmental priorities – improving air quality and reducing noise – should rather be tackled by local methods, obviously including a local bonus for using vehicles in town centres. Concerning encouraging local manufacture, this produces no benefit from a bonus on purchases, which applies to any vehicle wherever it is made. By the same account, this is also true of the social aim of maintaining domestic employment.

[101] If, for the use phase, we count 3.1 tonnes CO_2 emitted per cubic metre of diesel consumed, and 0.085 tonnes CO_2 emitted per MWh produced in France, a lifetime driven distance of 120,000 km causes 13 tonnes more CO_2 in the case of a CV than in the case of an EV.

Therefore, all that remains for governments are strategic questions of energy independence, which are relevant both to foreign trade and to very long-term risk management: the bonus is certainly a high price to pay. Ultimately, the bonus would seem primarily to be a coordination instrument, providing an incentive for consumers and reducing risks for carmakers. It is important that it should be applied only to vehicles that are used and manufactured domestically.

In summary, this discussion is about fairness between the taxpayer represented by government and the car user exposed to specific policies. It is also about geographical fairness between places where the use of EVs develops, and places that fund the public subsidies for this development through taxation. And it is also about fairness between the industrial operators in different sectors, as potential beneficiaries of public subsidies.

6.4.5 Comments on the methodology

The quantitative treatment provides retrospective evidence of the need for a sufficiently sensitive valuation model. Both vehicle manufacture and use need to be taken into account, from a life-cycle analysis perspective; otherwise there is a risk of twofold or even three or fourfold errors on certain items. Location, within or outside the country must also be covered, to avoid comprehensive errors both of sign and order of magnitude. Rebound effects need to be included: different production activities, in particular automobile construction, are highly interdependent, and the values propagate within a complex system of production: here again, there is a risk of large-scale errors. And finally, the social accounts need to be taken into account, and not only the taxation factors, again at the risk of substantial errors.

One limitation of our model is its linear approach. The social factors are based on a number of jobs per activity, assuming proportionality, in other words a constant level of efficiency. However, a significant priority for any company is to look for economies of scale, and therefore increase efficiency of all resources, including human resources. The linearity of the model entails the risk that an application may overestimate the effects. Nonetheless, we believe that this risk is moderate for an emerging industrial activity such as EV manufacture, where economies of scale will only develop at a later point in time.

Here, we reach another limitation inherent to input-output models: a transformation in the system of production is difficult to fit into the model in its rapid development phase. We postulated a new industrial activity, with its consumption in normal running mode, but without its specific investments. Their omission undoubtedly leads us to underestimate the short-term economic and financial impacts, which would counterbalance the risk of overestimation caused by linearity.

Our analysis of international trade is only a first approach. The consequences on imports and exports have only been drawn in the definition of

the scenarios but not at the level of the input-output model. Thus, for instance, the oil dependency of France on foreign suppliers has been omitted. Furthermore, the impact on public funds is only one element in the broad picture of international trade; it does not indicate the surplus that the country derives from the international markets. Lastly, the environmental impacts on local and national level are not (sufficiently) evaluated.

6.5 Conclusion

From a factual perspective, we have shown that the manufacture and use of an automobile has a significant impact on government revenue. The French case has several salient features: an industrial infrastructure that allows local manufacture, a surcharge on end-consumption of fuel, high rates of social contributions and benefits. In these circumstances, the return per vehicle for the public finances is favourable to the EV compared with the CV, before the EV purchase bonus, which would reverse the comparative outcome. As part of an export strategy, the EV is more profitable to the public purse than the CV. The worst scenario is the import of a foreign manufactured EV for domestic use, in preference to a locally manufactured CV.

From a methodological perspective, the valuation model has strengths and weaknesses. A first strength is that it deals with monetary values, whereas the traditional socio-economic evaluation in transport economics is very largely based on user well-being. Secondly, in "vertical" terms, it takes account of economic production activities, their relation through intermediate consumption between customer and supplier, and therefore the rebound effects. Thirdly, that in "horizontal" terms, it includes the economic and social effects of the different tax sources, and the social transfers based on working activity. Finally, it sets spatial limits on the public authority, by distinguishing between domestic and foreign territory. All these strengths greatly enrich the traditional framework of transport economics.

The weaknesses relate to the input-output model on which the valuation is based. Firstly, we only know the intermediate consumption between economic activities for trade within the country, not foreign trade. Secondly, our model of an industrial infrastructure for the manufacture of the EV is of our own creation, and needs to be compared with reality in order to be improved. Thirdly, sensitivity analysis showed the important effect of underlying assumptions on the outcomes. Assumed value flows should be in line with the values flows underlying the available input-output matrix. This has not been the case in this study where we largely apply assumptions valid for 2012 on the 2007 input-output matrix.

Conclusion

The EV as one element of future mobility

The introduction and launch of electric vehicles is to be understood as one piece in the complex puzzle of adapting our current mobility system to its future challenges. Mobility is to become increasingly resource efficient in order to meet the worldwide increasing demand for passenger and goods transport in a sustainable way.

Passenger transport is hereby to mainly rely on intermodal public transport systems. Where such systems do not offer a viable alternative, falling back on individual transport means, such as the passenger car – the object of this study -, will remain necessary. Undoubtedly, the passenger car will continue to be an integral part of the mobility system, even though the modes of walking, cycling and the use of energy-efficient motorised 2- and 3-wheelers are to be privileged. Irrespective of whether such passenger cars are more or less efficiently used – as e.g. in a shared car fleet or, in its 'traditional' way, in a household's private fleet – the energy efficiency of the cars will be a primordial factor for the sustainability of this mode. And this is where the electric car (the EV – electric vehicle) comes in.

If the right policy framework is put in place, the energy-efficient "zero tailpipe emission" vehicles are a means to contribute to emission reductions in road transport, while not transferring the avoided emissions to the energy sector. Simultaneously, the country's oil reliance can be reduced hereby alleviating the nation's trade deficit in the energy sector. Further, given the electricity storage capacity of the vehicles' batteries, electricity providers and grid operators can benefit from EVs for optimising the electricity net's stability. An increasing integration of intermittent renewable energy sources into the country's energy mix might become feasible (Chapter 1).

A system development with the backing of public policy

Since the EV demands supportive information and infrastructure for optimised battery recharging at private and public grounds, the introduction of EVs signifies more than offering a new product on the market. Many stakeholders

will be involved in order to build up a whole new electromobility *system* that assures the convenient use of the EV to the customer. This will bring about new business opportunities for existing mobility stakeholders that are willing to adapt their strategies and forms of cooperation. Also opportunities for new stakeholders to enter into the market will open up.

The whole system will be supported by information and communication technologies. Their increasing acceptance and usage as observed in the past decade allow anticipating that the uptake of EVs will not be constrained by any unfamiliarity with regards to such technologies. Nevertheless, gaining market share will not be an easy task: even though the EV carries many potential opportunities for the public well-being, the advantage to the single user is not yet evident. The EV will be in fierce competition with the conventional internal combustion engine vehicle – a vehicle technology which has been enjoying a predominant market position in the automobile sector throughout the last decades, which is supported by influential industry stakeholders, and which benefits from large customer acceptance. The EVs' remaining challenges will be an additional burden to its uptake: recharge infrastructure that is still in its infancy, the battery electric vehicle's range that lies well beneath the one of a CVs, and the high up-front purchase costs mainly caused by the vehicle's battery are all factors that are likely to hamper EV uptake in the upcoming years.

Public policies will therefore play a primordial role in the support of EV technology. They are to ensure the electromobility system's sustainable development on the one hand, and to increase the EV customer acceptance on the other hand. Only this way, the manifold potential opportunities that EVs bring about can be seized. (Chapter 1, Chapter 2)

Uncovering the effect of public policies – the contribution of this work

EV-supportive public policies are, however, contested. First, it is to be questioned whether EVs do actually carry all the potential opportunities that they are frequently cited for. Second, it is unclear which sets of policy measures, in which form and in which time and geographic scope will be most suitable and moreover sustainable for the effective support of EVs. Third, the question arises whether EVs are actually a cost-effective policy option to tackle current public concerns with regards to the transport system, its environmental impact and its related industries.

Within this context, this work is mainly concerned with the second issue, the question of when, how and how much EVs are to be publicly supported. More specifically, the attempt is made to create understanding of i) whether demand-side policy measures are an effective means to support the uptake of EVs, and ii) whether such measures can be financially justified from the public

authority's perspective. While the possible impact of non-financial demand-side measures is only anticipated, a focus is put on investigating the effect of financial measures that are to make EVs a palatable alternative to CVs among private households in France.

For this purpose, Chapters 3-5 developed a methodology that allows tracing the impact of (mainly fiscal) policy measures on the EVs' potential in the private household market. Chapter 6 then introduced a methodology that allows estimating the effect on the public budget of replacing a conventional vehicle with an electric vehicle: activity changes in the industrial sectors concerned with the manufacture and use of a vehicle as well as fiscal policy measures are accounted for.

The methodologies developed and their applications allow obtaining various results, of which the most interesting are recapitulated in the following.

Selected results

EVs can be financially interesting to the private customer – under certain conditions. Under French current market and policy conditions and realistic assumptions about their future development, battery electric vehicles (BEVs) can offer a financially interesting alternative to the private user. The BEV with a battery lease option appears to be able to compete with its conventional counterpart from the day of vehicle purchase. In case the battery is purchased up-front, a long enough vehicle ownership period combined with a sustained significant vehicle usage will be necessary to achieve a total cost ownership (TCO) equality of the two vehicle technologies. The long-electric-range plug-in hybrid electric vehicle (PHEV) does not appear to be a financially viable alternative under any realistic vehicle usage assumptions. All TCO comparisons necessarily rely on assumptions with regards to future fuel and electricity prices. These will significantly impact the outcome of such analyses. Also the residual value of vehicles and their batteries will play a role. This study takes, however, overly simplistic assumptions for investigating the impact of future resale values any further (Chapter 3).

French households are well-adapted to accommodate an EV in their household fleet. With the help of the National Transport Survey 2007-2008 we find that around 35 % of French households are adapted to the needs and limitations of a BEV, i.e. these households are motorised, have access to parking infrastructure where recharge infrastructure could be installed, and show vehicle usage behaviour that would not be constrained by the uptake of a limited-range electric vehicle (a BEV). 51 % of French households are found to be compatible with a PHEV: they are motorised and have access to parking infrastructure that can be equipped with a battery recharge infrastructure. In general, the need for

private parking infrastructure is a more limiting factor to potential EV uptake than incompatible vehicle usage behaviour (Chapter 4).

The financial viability of an EV is strongly conditioned to the French purchase bonus. If verifying the EV's TCO advantage over its conventional counterpart, in addition to the "practical compatibility" of French households with an EV stated above, we find that only 3.5 % of French households "qualify" for an EV under a EUR 5,000 purchase bonus scheme (hereby considering the most financially advantageous vehicle type and purchase option: the BEV with a battery hire option). This percentage rises to around 28.2 % under a EUR 7,000 purchase bonus scheme as in place since July 2012. These results are valid for 2012 market and policy conditions and realistic assumptions about their future development (Chapter 4, Chapter 5).

Regional differences: while predominantly rural areas are most compatible with the EV's needs and limitations, the main EV sales potential is found in dense urban centres. Households in predominantly rural areas show to be particularly adapted to the uptake of a limited-range EV: they have access to adequate parking infrastructure at their residence and are frequently multi-motorised, i.e. they can fall back on the household's conventional vehicle in case trips out of the range of a BEV are to be carried out. However, due to less constrained public parking infrastructure, financial policy measures offering preferential parking rights and tariffs for EVs show to have less impact in predominantly rural areas. A TCO advantage for the EV is harder to achieve here. Numbers that we find for the Île-de-France region support these findings: in Paris, 6.9 % of households show "practical compatibility" with BEVs (under the condition that all those who have access to co-owned parking facilities are able and willing to install recharge infrastructure at their parking place). In the (Petite) Grande Couronne area this percentage rises to (17.3 %) 31.4 %. Limiting these households to those for which the BEV (with a battery hire option) provides a TCO advantage to a comparable CV, we find 6.9 % of households in Paris, and (1.4 %) 3.0 % of households in the (Petite) Grande Couronne area that comply to all criteria. It is mainly thanks to the assumed preferential parking tariffs for EVs that all Parisian households which are found to be BEV-compatible, also "qualify" for a BEV purchase from a financial perspective (Chapter 4).

Under most realistic scenario settings, the EV purchase bonus will remain necessary to guarantee "financially-reasoned" EV potential up until 2023. According to our baseline scenario forecasts, a purchase bonus will remain a necessary condition to financially-reasoned BEV potential up until the end of the forecasting period (2023). To maintain an annual level of 20-30 % of households which qualify for a BEV purchase from a practical *and* financial

perspective, the purchase bonus should not drop beneath EUR 4,000 (5,000) until 2023 (2020). We estimate that annually 4.5 % of these potential BEV purchasers will actually be in a vehicle purchase process. In case all of these identified potential BEV households decide for a BEV when being in a purchase process, we estimate a cumulative BEV demand of 3.9 (2.7) million vehicles until 2023 (2020). These results are based on manifold assumptions and do not take any other than "practical and financial" purchase decision criteria into account. BEV demand that might evolve due to non-monetary values associated with the BEV is not considered; neither is the demand that will not materialise due to any vehicle purchase preferences, attitudes or motivations that are not in line with the specifications of an EV (Chapter 5).

The return per vehicle for public finances is favourable for the EV compared with the CV before applying the EV purchase bonus. Accounting for tax revenues stemming from manufacture and use of a vehicle as well as for all social contributions and benefits related to level of activity of the related industry sectors, replacing a CV with an EV turns out to be advantageous for the public purse in France. The purchase bonus reverses the outcome. As part of an export strategy, the EV is more profitable to the public purse than the CV. The worst scenario is the import of a foreign manufactured EV for domestic use, in preference to a locally manufactured CV. These results are based on a comprehensive valuation model, its underlying assumptions and data on the French economy as of 2007. (Chapter 6)

Results obtained in this study allow the derivation of several suggestions for EV manufacturers and policy makers concerned with the introduction and uptake of EVs. These are presented in the following. In line with this entire work, these suggestions also refer to demand-side stakeholders of the electromobility system, notably to the private customer for whom the EV is to be made palatable in order to guarantee its successful development.

Suggestions to EV manufacturers

This study showed that the EV can be a viable alternative from a technical and practical perspective for many French households. Neither the range limitations, nor the requirements for recharge infrastructure necessarily pose any vehicle usage constraints. This is especially the case for multi-motorised households that keep a conventional vehicle as a fall-back option in case long distance trips are to be carried out (Chapter 4). Nevertheless, it is especially range limitations and recharge requirements that will make many users refrain from this vehicle technology (Chapter 1). We suggest the following initiatives to EV manufacturers that will contribute in adjusting wrongly perceived vehicle requirements to actual needs of private (or corporate) customers. These

measures will increase awareness and help overcome important market barriers to the introduction of EVs:

Be present and create awareness in a client's vehicle purchase process
The vehicle purchase itself is typically only the last instant in a much longer vehicle choice process. This latter can range from a couple of days to several months. Within this choice process the vehicle purchaser has time to reflect upon his preferences and purchase decisions, to learn about new vehicle technologies, and to understand his actual mobility requirements and needs (Chapter 1). Vehicle manufacturers and their retailers are to make sure that this process is optimally accompanied: information material on EVs is to be disseminated, TCO calculations are to be provided in order to evaluate the financial implications of a specific client's vehicle usage behaviour, actual range requirements are to be discussed, and awareness of mobility offers that come with the EV – such as CV hire schemes for weekend or holiday trips – is to be created. It is to be assured that customers are optimally informed before making their final purchase decision.

Assure accompanied vehicle purchase processes in niche markets
The first niche markets of electric vehicles are expected to be corporate and public fleets (Chapter 1). Although fleet managers are in a good position to evaluate the potential cost advantages of incorporating EVs in their fleet, they are often unaware or unable to do so (Boutueil and Leurent, 2013). Consequently, fleet managers in particular are to be accompanied in their purchase processes to ensure that EVs develop in their predestined niche markets. Fleet vehicles for which EVs are especially suitable are to be identified, and CV hire schemes for weekend and holiday trips are to be offered if required. The visibility of certain vehicle fleets (such as taxis, pick up and delivery services, or the French post) can be an important leverage for raising awareness among the public and can consequently, be a motivating factor for private EV uptake.

Offer all-in solutions
Clients' concerns with regards to infrastructure installations could be alleviated by offering "all-in" solutions that provide the EV in combination with the installation of home recharge infrastructure. Such offers could be differentiated according to the specific context of the vehicle purchase: for example, they could be made available only to households that have access to their privately owned parking infrastructure.

Suggestions to policy makers

Our forecasts of the baseline scenario suggest that the purchase bonus will remain an important EV incitation measure up until 2023. The provision of the

bonus will be necessary to maintain a significant level of "financially-reasoned" EV potential among private households (Chapter 5). According to our estimates, such purchase bonus payments will, however, result in net losses for the public purse in most scenarios (Chapter 6). An efficient deployment of the purchase bonus is therefore of utmost importance. Focus is also to be put on non-fiscal policy measures. These have the potential to initiate private EV uptake even among those households for which TCO calculations do not turn out to be EV-advantageous. We suggest the following initiatives in this context:

Make TCO comparisons obligatory

Vehicle vendors could be obliged to deliver detailed TCO calculations for various vehicle technologies to the customers. A standardised method is to be offered that allows accounting for customer-specific input parameters (such as the expected ownership period, or the annual vehicle kilometres travelled). This way, customers are incited to make TCO one of their vehicle purchase criteria. The advantage of EVs being, among others, comparatively low vehicle usage costs, will become more evident to customers.

Facilitate the installation of residential battery recharging facilities in urban centres

Parking privileges for EVs can render this vehicle technology especially interesting for vehicle users in urban areas. They allow the EV user to benefit from practical (time) and financial gains. However, urban areas are not the best adapted for EV uptake: the lack of space and private parking infrastructure is likely to prevent potentially interested EV customers from actually investing in an EV. It is therefore of utmost importance to ensure that *at least* those vehicle users who do already have access to private parking infrastructure are in the position to cost-effectively install recharge infrastructure at their parking spaces. In urban areas, this will frequently signify infrastructure installations in co-owned residences. Administrative and practical hurdles in the process of installing recharge infrastructure in such circumstances are to be alleviated; even financial support for such infrastructure installation could be envisaged. The French "*droit à la prise*" is a first step towards facilitating recharge infrastructure installation at co-owned premises. However, especially with regards to already existing residences, the sole "right" to install recharge infrastructure will only seldom be sufficient for motivating a potential EV buyer to actually carry out and pay for all necessary works and installations.

Configure the purchase bonus according to the customers' needs

Rural areas show to be better adapted to EVs than urban areas in terms of infrastructure needs. In turn, in urban areas, parking policy measures are a more convenient means to foster a TCO advantage for the EV than is the case in rural areas. These territorial dissimilarities suggest that public policy measures should be adapted to local characteristics. An important role comes here to local

authorities that are to identify local needs and most adequate policy measures. The nationally deployed purchase bonus appears to contradict such an approach. We suggest reflecting upon methodologies that render the purchase bonus more cost-effective by making it to an area-dependent subsidy. Whereas in rural areas, an EV purchaser could be subsidised for the purchase of the vehicle, an EV purchaser in a dense urban area could benefit from similar amounts for the installation of recharge infrastructure at his (co-owned) premises.

Keep focus on niche markets first
As vehicle manufacturers, also public authorities should focus on the niche markets of EVs first. Public and private fleets will be an important means to bring down costs and create awareness among the public. As already suggested for vehicle manufacturers, public authorities should also make sure that fleet managers are assisted in the process of choosing their fleet vehicles. Furthermore, the support of shared EV services will be an effective measure specifically for creating awareness for EVs, and for assuring first customer experiences with them.. The support of shared vehicle services will in addition be in line with the ultimate goal of creating a more sustainable mobility system for the future.

France as role model

France proves to combine various EV-advantageous framework conditions which could enable the country to become a lead market in electromobility: the French electricity mix allows for an EV-favourable carbon-footprint; French public authorities appear to be highly EV-supportive and have already early started with the deployment of EV-favourable public policy measures; the French car manufacturers were (are) among the first ones to launch electric-drive fleets of the "new generation" on the market. Certainly, France is not the only nation that appears to be specifically EV-supportive: other European countries such as Norway, Denmark, Portugal, and Ireland, all of which show a high reliance on wind or hydro power, benefit from the relative geographic isolation of their territory (as also Israel does). Norway and Denmark further benefit from high home ownership rates, which are expected to drive the acceptance of limited-range vehicles that come with recharge infrastructure needs. Extensive EV-supportive public policy measures have been put in place in all of these countries (Chapter 2). Nevertheless, none of these countries appears to be as backed by a national automobile industry enlaced in electromobility as France. This comparative advantage of France gives reason to hope that the country can excel in developing a domestic market for EVs, in becoming next to prospectively South Korea, Japan, and China an internationally important player in electromobility, and in hereby benefiting from all the opportunities electromobility brings about.

Suggestions for further research

Different aspects of this study can be investigated in more depth. We briefly discuss some of the research directions that appear to be of main interest to us:

1. **Improve the methodology underlying this work.** Throughout this report we identified certain deficiencies of the applied methodology. In order to allow for more significant results, some of these should be addressed in more depth in future studies. These issues mainly pertain to:
   a. *Vehicle and battery resale values* (Chapter 3): The TCO model that underlies most parts of this work is based on the assumption that all explored vehicle technologies and even the different purchase options of the battery electric vehicle entail the same residual values for the vehicle owner at the end of the ownership period. This strong simplification is seen to be a severe deficiency of the applied model, which is to be addressed in subsequent studies in more detail.
   b. *Infrastructure installation costs* (Chapter 3): The TCO model is further based on the assumption that infrastructure installation costs do not vary among private households. In fact, these costs will strongly depend on the exact configuration of a household's parking space in question. Especially in Paris, where the parking space will frequently be situated in co-owned properties, the installation of recharge infrastructure is likely to entail much more costly works than simply the installation of a "wall-box", as this might be the case in e.g. a private garage. Data and methods that allow estimating infrastructure installation costs per parking type (and/or per type of residence) remain to be developed.
   c. *Regional differences* (Chapter 3): The underlying TCO model accounts for several regional differences in the Île-de-France region. Parameters that describe characteristics of the "rest of France" area are, however, assumed to be uniform. Accounting for regional differences also outside the Île-de-France region would add valuable precision to the results of this study.
   d. *Definition of constraints* (Chapter 4): The underlying constraints analysis that identifies households that are compatible with the needs and limitations of EVs is based on the data source of the National Transport Survey 2007/08. The set of defined constraints does not necessarily give reliable information whether identified "EV-compatible" households do not face any practical problems with the adoption of an EV. The data used does not allow us to identify unambiguously whether households are really capable or likely to install recharge infrastructure at their parking premises, or whether households are really unlikely to run into any range problems with a limited-range

vehicle. A refined definition of constraints and the exploration of travel diaries (where available) could add precision to the constraints analysis. Additional constraints with regards to likely characteristics of early adopters (as identified in other studies) could further allow the identification of where these early adopters are situated. This would allow public policy makers to focus on public infrastructure installations in the concerned areas.

e. *Future trends in household and travel behaviour characteristics* (Chapter 5): The forecasting tool developed is based on the assumptions that characteristics with regards to household specifications and travel behaviour remain the same over the next decade. However, various trends already now observable (as all discussed in chapter 5) suggest that e.g. motorisation rates, access to parking infrastructure, vehicle type and fuel type preferences of households, as well as distances driven annually might be subject to change in the upcoming years. Such trends should be integrated in subsequent forecasting tools. This will become increasingly important in case the time frame for forecasts is to be extended.

f. *Value flows behind EV manufacture* (Chapter 6): The valuation model developed that allows identifying the effect of EV manufacture and use on the public budget is based on simplistic assumptions with regards to inter-sectoral value-flows. Value-flows behind the manufacture of an EV are assumed to largely resemble those of a CV. More detailed analyses on the value components of an EV would improve the precision of the valuation model.

2. **Account for customers' vehicle purchase preferences:** The underlying study establishes a consistent methodology for defining the EVs' potential. This potential is constituted by those households that are, from a practical and technical perspective, most likely to be among the first adopters of EVs. Further research could be focused on exactly these households in order to uncover their specific vehicle purchase motivations and preferences (e.g. by means of stated preference surveys or the simulation of customers' choice experiences – see Chapter 1). This would help identify not only those households who *could* but also those who actually *will* buy an EV.

3. **Explore the firm market**: The underlying study analyses exclusively the potential EV *household* market. Potential EV sales to firms (and authorities) have not been explored, although sales to such entities are likely to constitute a significant EV market – particularly so in the first years after the EV market launch (see the discussion in section 1.6.3). Especially delivery services in urban areas appear to be well adapted for adapting limited-range EVs. Analysing the EV sales potential to firms (and public authorities) is therefore seen to be a necessary and logical complement to this study.

4. **Establish a comprehensive welfare analysis:** The methodologies developed could be extended in order to also evaluate the global and local environmental impacts of EV uptake. The expected number of the vehicle kilometres travelled replaced by an EV can be conveniently derived by extending the approach applied here. Evaluating the avoided emissions from the transport sector as well as the increased emissions from the energy sector would be a first step towards evaluating the full environmental impact of EVs. Conclusions on whether EV-supportive public policy measures are justified from a public welfare perspective could be derived.

5. **Establish a comprehensive mobility model:** The methodology and findings of this study could be integrated in a holistic mobility model that describes a household's (and firm's) need for mobility, its choice of transport means per specific trip purpose, and its resulting (or rather coupled) choice of motorisation. Such a mobility model could be the basis of a comprehensive welfare analysis that takes local specifications of, and impacts on, the given territory into account (as suggested in point 4 above). The model should go far beyond a financial analysis: generalised costs, that quantify time gains thanks to home recharging or preferential parking rights as well as environmental impacts on local and global scale are to be taken care of. This way, such a mobility model would constitute an appropriate means for analysing the impact of local policy measures.

6. **Observe and analyse EV sales**: In order to facilitate future studies on EV purchase behaviour as well as EV demand analyses, it is primordial to sufficiently observe first EV purchases. Information on EV purchase motivations and data on buyers' characteristics as well as on EV usage behaviour is to be collected in the most comprehensive way. This will allow the identification, in a more precise way, of how public policy measures influence vehicle purchase behaviour and which place EVs will finally take in the automobile market.

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Annex

Annex 2.1 – Overview of the milestones defined in the European Roadmap Electrification of Road Transport (Source: ERTRAC et al., 2012)

Technology fields	Milestone 1 Introduction - 2012	Milestone 2 Intermediate - 2016	Milestone 3 Mass Production - 2020	Milestone 4 Fully Revised EV Concept - 2025
Energy Storage Systems	Understanding of all relevant parameters for safety, performance, lifetime and their interplay. Concepts for their proper management.	Manufacturing of long life, safe and cheap energy storage systems with advanced energy and power density.	Batteries providing compared to 2009 Li-Ion technology status doubled energy density, tripled lifetime at 20-30 % of cost compared to 2009 status and matching V2G in mass production.	Move towards post Li-Ion batteries. Batteries providing 4-5 times higher energy density and tripled lifetime at 15 % cost compared to 2009 technology and cost status. Wide spread fast charging and bi-directional capabilities.
Drive Train Technologies	Concepts of drive train components optimized for efficient use and recovery of energy. First implementation in prototypes.	Manufacturing of range extenders and update of electric motors and power electronics for optimized use of materials and functionality.	Implementation of powertrain systems providing a range comparable to ICE at sharply reduced emissions in mass produced vehicles.	Drive train systems based on innovative concepts. Distinctly improved energy recovery. Use of novel materials. Functionality optimized for varying driving modes/conditions. Zero emission EV. Multi-fuel compatible range externders.
System Integration	Solutions for safe, robust and energy efficient interplay of power train and energy storage systems. First implementation in prototypes and product lines.	Optimized control of energy and thermal flows based on hard- and software for the electrical architecture.	Mass production of novel platform based in overall improved system integration.	Entirely revised EV modular platform including revised ICT-reference architecture/middleware.
Grid Integration	Charging adaptive to both user and grid needs.	Charging at enhanced speed. Standardization for (fast-) charging in place.	Standardized quick, contactless and smart charging with bidirectional capacilities.	Full integration into the grid with charging-while-driving functionality. Wide spread use of inductive charging. Enhanced bi-directional energy flow.
Transport System	Road infrastructures and communication tools encouraging the use of electric vehicles.	Extensive integration of electric vehicles with other modes of tranpsort.	Semi-automated driving based on active safety systems and car-to-x communication.	Enhanced usage of car-to-x communication for automated and cooperative driving for zero-accident road safety and highly convenient driving. Integration of EV in multi-modal transport system.
Safety	Electric vehicles (tested and inspected for) meeting (new) safety standards at same levels as conventional cars.	Implementation of solutions for all safety issues specific to mass use of the electric vehicle and road transport based on it.	Safety systems and functionalities following innovations in EV development. Enhanced exploitation of active safety measures for electric vehicles including safety of vulnerable road users.	Active and passive safety measures for Evs used in multi-modal transport.Updated safety systems to enhanced modular vehicle platform with multiple integrated functions.

Annex 2.2 – 2011 EV fleet and country indicators (I + II)

	Passenger Vehicles (PV)	Busses	LDV	Trucks	Total EV stock	Source	Included EV types
AUT	989	0	13	38	**1,040**	PV: Statistik Austria (2012), Other: AgentschapNL (2012)	BEVs only (most likely)
CHN*	5600		3400		**9,000**	The Australian (2012)	BEVs, PHEVs
DEU	4541	90	1457	0	**6,088**	PV: KBA (2012), Other: AgentschapNL (2012)	BEVs only (most likely)
DNK	749	11	96	10	**866**	AgentschapNL (2012)	unknown
ESP	753	6	-	25	**784**	AgentschapNL (2012)	unknown
FRA**	2814	91	164	-	**3,069**	PV: Automobile Propre (2012), Other: AgentschapNL (2012)	BEVs, PHEVs
KOR	50	2	-	-	**52**	AgentschapNL (2012)	unknown
NLD	1139	91	101	21	**1,352**	AgentschapNL (2012)	BEVs, PHEVs, REVs, FCEVs
NOR	5448	10	0	2	**5,460**	PV: Gronnbil (2012), Other: AgentschapNL (2012)	BEVs, PHEVs
PRT	250	22	434	0	**706**	AgentschapNL (2012)	unknown
UK**	1481	17		487	**1,985**	DfT (2012)	Ultra low carbon emission vehicles (PEVs)
USA	18076	5	3	-	**18,084**	AgentschapNL (2012)	BEVs, PHEVs, REVs

*2011 EV sales only **2010 + 2011 EV sales only - values unknown

	Vehicle Stock 2009*** *World Bank, 2012a/b*	Population 2011 *World Bank, 2012b*	EVs per 1000 inhabitants	EVs per 1000 vehicles***
AUT	4,759,841	8,419,000	0.124	0.218
CHN	62,574,860	1,344,130,000	0.007	0.144
DEU	46,192,901	81,726,000	0.074	0.132
DNK	2,640,039	5,574,000	0.155	0.328
ESP	27,361,522	46,235,000	0.017	0.029
FRA	38,702,699	65,436,552	0.047	0.079
KOR	17,459,610	49,779,000	0.001	0.003
NLD	8,584,600	16,696,000	0.081	0.157
NOR	2,791,004	4,952,000	1.103	1.956
PRT	5,387,431	10,637,000	0.066	0.131
UK**	32,327,167	62,641,000	0.032	0.061
USA	246,030,766	311,591,917	0.058	0.074

***4-wheel vehicle stock

****taking the 2009 stock as reference

Annex 2.3 – 2012 (electric) vehicle registrations per country

	Total Vehicle Registrations	EV Registrations	EV registrations per 1000 veh. registr.	EV registrations in % of 2011 EV stock*	Type of vehicles	Source
AUT Jan-Sep	266,890	309	1.16	31.24	PVs	Statistik Austria (2012)
CHN Jan-Jun	9,600,000	3,525	0.37	39.17	all	CRI (2012)
DEU Jan-Sep	2,358,798	2,023	0.86	44.55	PVs	KBA (2012)
FRA Jan-Sep	1,669,169	4,339	2.60	154.19	PVs	Total: CGDD (2012), EVs: Automobile Propre (2012)
NLD Jan-Sep	818,084	3,716	4.54	274.85	all	Total: CBS (2012), EVs: AgentschaapNL (2012)
NOR Jan-Sep	129,432	3,217	24.85	59.05	PVs	Total: TradingEconomics (2012), EVs: Gronnbil (2012)
UK Jan-Jun	1,183,052	1,306	1.10	65.79	all	DfT (2012)
USA Jan-Sep	10,863,076	31,377	2.89	173.58	unknown	Electricdrive (2012)

*using according values from Annex 2.2

Notes: Total vehicle registration numbers for Norway approximated on the graph (see source)

Annex 3.1 – Underlying data of reviewed studies – Overview (I-III)

Values for baseline scenarios unless stated differently

	Initial Costs					
	BEV Price	*CV Price*	*Battery Price*	*Wall Box*	*Batt. Capacity (kWh)*	*Residual Value*
Funk and Rabl (1999)	14,204 €	10,400 €	1,122 €/year	-	?	-
Delucchi, Lipman (2001)	16,135 $	17,705 $	416 $/kWh	0.22 $/mile	20	-
Carlsson and Johansson-Stenman (2002)	+ 6,406 $	0 (reference)	in BEV price	-	17	-
BCG (2009)	?	?	700 $/kWh (2020)	-	20	?
*Becker (2009)**	20,000 $	20,000 $	500 €/kWh	-	24	?
Biere et al. (2009)	- 731 €	0 (reference)	596 €/kWh (2010), 306 €/kWh (2020)	800 €	60	-
Deutsche Bank (2009)	?	?	488 $/kWh (2015)	-	25	-
EDF (2009)	12,640 € (2012) 11,850 € (2020)	11,850 € (2012) 11,850 € (2020)	800 €/kWh (2012), 350 €/kWh (2020)	-	25	-
*Figliozzi et al. (2010)***	33,720 $	13,320 $	in BEV price	-	24	?
Prud'homme (2011)	20,000 €	12,000 €	10,007 €	-	-	0
Deutsche Bank (2011)	34,000 € (incl. Battery)	11,000 €	in vehicle price	-	16	-
CAS 2011	16,000 €	16,000 €	20,000 €	-	20	1,718 € (BEV+CV) (20% loss/year)
CE Delft (2011)	€ 28 - 50,000 (2010) € 22,800 - 40,700 (2030)	9,000 - 19,000 € (2010) 10,900 - 23,100 € (2030)	in BEV price	-	*(range assumpt.: 175 km in 2010, 350 km in 2030)*	0 (as CV)
CGDD (2011)	-1,500 €	0 (reference)	800 €/kWh (2010) 300 €/kWh (2020)	500 €	25	0 (as CV)
ITF (2012)	20,700 €	16,000 €	79 €/month	1,200 € (incl. recharge cable)	22	-

" - " - parameter not taken into account *" ? " - value not stated* *BEV - battery electric vehicle* *CV - conventional gasoline vehicle*

Values for baseline scenarios unless stated differently

	Usage			Consumption		Energy Prices	
	Driven distance (km/year)	*Ownership (years)*	*Infra. Usage*	*CV (l/100km Petrol)*	*BEV (kWh/100km)*	*Petrol Price (per liter)*	*Electricity Price (per kWh)*
Funk and Rabl (1999)	9,125	10 (=lifetime)	-	7.0	25.0	0.96	0.07 $
Delucchi, Lipman (2001)	(variable)	lifetime (depending on mileage)	-	11.8	38.0	0.24 $ (w/o tax)	0.06 $
Carlsson and Johansson-Stenman (2002)	15,000	17 (=lifetime)	-	6.7	11.0	0.96 $	?
BCG (2009)	14,500	5	-	?	?	variable	?
Becker (2009)	24,000	5	1.0-2.0$ c$/mile	6.8	14.0	0.79 $	0.11 $
Biere et al. (2009)	12,000	12	-	4.0 - 7.7 (4 vehicle types)	19.0	1.24 € (2010) 1.46 € (2020)	0.14 €
Deutsche Bank (2009)	24,000	10	-	7.2	15.6	variable	0.1 $
EDF (2009)	8,540 - 15,860 (private) 11,480-21,320 (business)	8	1.5-3 c€/km (2020)	6.8 (2012) 5.0 (2020)	20.0	1.50 €	0.12 € (2012) 0.15 € (2020)
Figliozzi et al. (2010)	20,800	14	-	6.9	16.0	0.72 $	0.12 $
Prud'homme (2011)	10,000	15 (=lifetime)	-	5.0	20.0	1.15 € (2010-Diesel) oil price +6%/year	0.11 (constant)
Deutsche Bank (2011)	variable	-	-	5.5	10.0	1.60 €	0.22 €
CAS 2011	13,000	10	-	4.6	25.3 (losses/auxiliary use accounted for)	1.30 €	0.12 €
CE Delft (2011)	*depending on year and vehicle type*	14 (= lifetime)	-	8.0/9.6/12.0 (2010) 5.5/6.6/8.3 (2030) (small/med/large veh)	25.0/29.0/33.0 (2010) 20.4/23.6/26.9 (2030) (small/med/large veh)	1.35 € (2010) 2.05 € (2030)	0.16 € (2010) 0.24 € (2030)
CGDD (2011)	13,000	15 (=lifetime)	1.5 c€/km (2010) 0.7 c€/km (2020)	4.8 (2010) 3.7 (2020)	20.0	1.37 € (2010) 1.85 € (2020)	0.10 € (2010) 0.15 € (2020)
ITF (2012)	10,950	15	0	4.0 (Diesel)	11.0	as Prud'homme (2010)	0.12 € (+1%/year)

"-" - parameter not taken into account *"?" - value not stated* *BEV - battery electric vehicle* *CV - conventional gasoline vehicle*

Values for baseline scenarios unless stated differently

	Maintenance		Insurance			Results *
	BEV (per year)	*CV (per year)*	*BEV*	*CV*	*Taxes /Fees*	*(BEV with regards to a gasoline CV)*
Funk and Rabl (1999)	89 €	149 €	336 €/year	437 €/year	France (year 2000)	30-40% more expensive
Delucchi, Lipman (2001)	355 $	492$	6.75 c$/mile	7.91 c$/mile	US	Cost break-even at 0.59 $/l fuel retail price
Carlsson and Johansson-Stenman (2002)	-	-	-	-	Sweden	Cost break-even with $ 3840 subsidy (2010 forecast)
BCG (2009)	-	-	-	-	Germany	Cost break-even at 280 $/barrel oil price in 2020 (or at 120 $/barrel if battery costs 500 $/kWh)
Becker (2009)	- 25% compared to CV	?	?	?	US	Unsubsidized EV saves: *(high oil price)* 2012: -3c$ to 0c$ per mile *(up to 3c$)* 2017: 1c$ to 3c$ per mile *(up to 7c$)*
Biere et al. (2009)	0.018 € per km	0.028 € per km	-	-	DE	City BEVs break even in 2020 - dependent on vehicle usage
Deutsche Bank (2009)	?	?	?	?	US	Cost break-even at 1.05 $/l (or 4$/gallon) fuel retail price
EDF (2009)	-	-	-	-	France (2009)	2012: EV 16c/km more costly than CV, 2020: EV 6c/km more than CV
Figliozzi et al. (2010)	?	?	-	-	US	In a 14 year planning horizon the EV is not selected for vehicle fleets in base case
Prud'homme (2011)	same for BEV and CV		same for BEV and CV		F	TCO BEV 10-12,000 € higher than TCO CV
Deutsche Bank (2011)	same for BEV and CV		same for BEV and CV		-	Cost break-even after 330,000 kms
CAS 2011	400 €	800 €	same for BEV and CV		F	Even under favorable policy settings the BEV is not competitive to the CV
CE Delft (2011)	0.2/0.4/0.6 k€ (2010) 0.3/0.6/0.9 k€ (2030) small/med/large veh	0.5/0.9/1.4 k€ (2010) 0.7/1.4/2.1 k€ (2030) small/med/large veh	1.0/2.0/3.0 k€ (2010) 1.5/2.9/4.3 k€ (2030) small/med/large veh	0.6/1.2/2.0 k€ (2010) 0.9/1.8/2.9 k€ (2030) small/med/large veh	EU average	TCO of medium EV compared to CV: 2010: +60% ; 2030: +20%
CGDD (2011)	1,700 €	1,700 €	-	-	F	2010: TCO EV 12,000 € higher than TCO CV
ITF (2012)	same for BEV and CV		same for BEV and CV		F	TCO BEV 4-5,000 € higher than TCO CV

" - " - parameter not taken into account " ? " - value not stated BEV - battery electric vehicle CV - conventional gasoline vehicle

** Results without purchase subsidies unless stated differently*

Annex 3.2 – Break-even analysis for the sedan vehicle types

Sedane Diesel CV		Reference Scenario			Policy Scenarios						Market Scenarios					
					EV+			CV+			EV+			CV+		
(BE - Break-Even)	vs	*BEV*	*BEV Hire*	*PHEV*	*BEV*	*BEV Hire*	*PHEV*	*BEV*	*BEV Hire*	*PHEV*	*BEV*	*BEV Hire*	*PHEV*	*BEV*	*BEV Hire*	*PHEV*
BE Yearly driven distance	*(km)*	*51900*	*67200*	-	*46100*	*59600*	-	*1E+05*	*1E+05*	-	26900	27600	*1E+05*	*2E+05*	*2E+05*	-
BE diesel price 2020*	*(Euro/l)*	3.75	2.35	13.04	3.61	2.23	12.90	6.97	5.58	17.62	3.42	2.39	11.98	4.12	2.72	13.20
*(% increase to 2012 prices** by)*		*168*	*68*	*831*	*158*	*59*	*821*	*398*	*299*	*1159*	*144*	*71*	*756*	*194*	*94*	*843*
BE purchase price premium EV***	*(%)*	39	8	26	40	9	27	10	-21	-2	49	16	33	29	-2	19
BE ownership period	*(years)*	-	1-3	-	-	1-3	-	-	-	-	10+	1+	-	-	1-2	-

** after taxes, in nominal Euros* ***taking 1,43 Euro/l Diesel and 1,61 Euro/l Petrol as reference for 2012 after tax prices (ZAGAZ, 2012)*

**** compared to the CV price; BEV and PHEV: including battery; BEV-Hire: vehicle only*

Annex 5.1 – The French fee and rebate system (Bonus/Malus System) over time

Bonus / Malus		CO_2 Emissions				
		2008 / 2009	2010	2011	2012	
					Jan-Jul	Aug-Dec
Rebate/ Bonus	7 000 €					20 g/km or less
	5 000 €	60 g/km or less			50 g/km or less	from 21 to 50 g/km
	4 500 €					from 51 to 60 g/km
	4 000 €					hybrid vehicles emitting less than 110 g/km
	3 500 €				de 51 à 60 g/km	
	2 000 €	LPG vehicles, NGV or hybrid vehicles emitting:		hybrid vehicles emitting :		
		less than 140 g/km	less than 135 g/km	less than 110 g/km	less than 105 g/km	
	1 000 €	less than 100 g/km	less than 95 g/km			
	800 €			from 61 to 90 g/km		
	700 €	from 101 to 120 g/km				
	550 €					from 61 to 90 g/km
	400 €		from 96 to 115 g/km	from 91 to 110 g/km	from 61 to 90 g/km	
	200 €	from 121 to 130 g/km				from 91 to 105 g/km
	100 €		from 116 to 125 g/km		from 91 to 105 g/km	
Neutral	0 €	from 131 to 160 g/km	from 126 to 155 g/km	from 111 to 150 g/km	from 106 to 140 g/km	
Fee/ Malus	200 €	from 161 to 165 g/km	from 156 to 160 g/km	from 151 to 155 g/km	from 141 to 150 g/km	
	500 €				from 151 to 155 g/km	
	750 €	from 166 to 200 g/km	from 161 to 195 g/km	from 156 to 190 g/km	from 156 to 180 g/km	
	1 300 €				from 181 to 190 g/km	
	1 600 €	from 201 to 250 g/km	from 196 to 245 g/km	from 191 to 240 g/km		
	2 300 € + 160 €/year				from 191 to 230 g/km	
	2 600 €	more than 250 g/km	more than 245 g/km	more than 240 g/km		
	3 600 € + 160 €/year				more than 230 g/km	

Source: MEDDE (2012), CGDD (2012a)

Annex 5.2 – Forecasts of Vehicle/Technology Development

BATTERY PRICE

(in ratio to 2012 value)

	BEV			PHEV		
	EV+	Baseline	CV+	EV+	Baseline	CV+
2012	1.00	1.00	1.00	1.00	1.00	1.00
2013	0.95	1.00	1.00	0.96	1.00	1.00
2014	0.90	1.00	1.00	0.92	1.00	1.00
2015	0.86	1.00	1.00	0.88	1.00	1.00
2016	0.79	0.93	0.95	0.82	0.94	0.96
2017	0.73	0.86	0.90	0.77	0.88	0.92
2018	0.67	0.80	0.86	0.71	0.83	0.88
2019	0.61	0.75	0.81	0.66	0.78	0.85
2020	0.57	0.70	0.77	0.62	0.73	0.82
2021	0.53	0.65	0.74	0.58	0.70	0.78
2022	0.50	0.61	0.70	0.56	0.66	0.75
2023	0.47	0.58	0.66	0.53	0.63	0.72

VEHICLE PRICE

(in ratio to 2012 value)

	CV			BEV			PHEV		
	EV+	Baseline	CV+	EV+	Baseline	CV+	EV+	Baseline	CV+
2012	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2013	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2014	1.03	1.01	1.01	1.00	1.00	1.00	1.00	1.00	1.00
2015	1.04	1.02	1.01	1.00	1.01	1.01	1.00	1.00	1.01
2016	1.06	1.03	1.02	1.01	1.01	1.01	1.01	1.01	1.01
2017	1.07	1.04	1.02	1.01	1.01	1.01	1.01	1.01	1.01
2018	1.09	1.05	1.03	1.01	1.01	1.01	1.01	1.01	1.01
2019	1.10	1.06	1.03	1.01	1.01	1.01	1.01	1.01	1.01
2020	1.12	1.08	1.04	1.01	1.01	1.02	1.01	1.01	1.02
2021	1.13	1.09	1.04	1.01	1.02	1.02	1.01	1.01	1.02
2022	1.15	1.10	1.05	1.01	1.02	1.02	1.01	1.02	1.02
2023	1.17	1.11	1.05	1.02	1.02	1.02	1.01	1.02	1.02

ENERGY CONSUMPTION

(in ratio to 2012 value)

	CV - Petrol			CV - Diesel			BEV		
	EV+	Baseline	CV+	EV+	Baseline	CV+	EV+	Baseline	CV+
2012	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2013	0.99	0.99	0.98	0.99	0.99	0.98	0.97	0.99	1.00
2014	0.98	0.97	0.97	0.98	0.97	0.97	0.95	0.97	1.00
2015	0.97	0.96	0.95	0.97	0.96	0.95	0.92	0.96	1.00
2016	0.95	0.94	0.93	0.96	0.94	0.94	0.90	0.94	1.00
2017	0.94	0.93	0.92	0.94	0.93	0.92	0.88	0.93	1.00
2018	0.93	0.91	0.90	0.93	0.91	0.91	0.85	0.91	1.00
2019	0.92	0.90	0.89	0.92	0.90	0.89	0.83	0.90	1.00
2020	0.91	0.88	0.87	0.91	0.89	0.88	0.81	0.89	1.00
2021	0.90	0.87	0.86	0.90	0.87	0.86	0.79	0.87	1.00
2022	0.88	0.85	0.84	0.89	0.86	0.85	0.77	0.86	1.00
2023	0.87	0.84	0.83	0.88	0.84	0.84	0.75	0.85	1.00

Annex 5.3 – Forecasts of market trends

DIESEL PRICE

(in EUR/l - incl. TICPE of baseline scenario)

	EV+	Baseline	CV+
2012	1.63	1.26	1.00
2013	1.73	1.30	1.00
2014	1.81	1.35	1.01
2015	1.88	1.39	1.01
2016	1.98	1.43	1.00
2017	2.06	1.48	1.01
2018	2.14	1.53	1.02
2019	2.22	1.58	1.03
2020	2.30	1.64	1.04
2021	2.38	1.69	1.05
2022	2.46	1.73	1.07
2023	2.53	1.78	1.08
2024	2.60	1.83	1.09
2025	2.67	1.87	1.10
2026	2.75	1.92	1.11
2027	2.83	1.96	1.13
2028	2.90	2.01	1.14
2029	2.98	2.05	1.16
2030	3.04	2.09	1.17

PETROL PRICE

(in EUR/l - incl. TICPE of baseline scenario)

	EV+	Baseline	CV+
2012	1.60	1.38	1.22
2013	1.66	1.40	1.22
2014	1.71	1.42	1.22
2015	1.74	1.45	1.22
2016	1.80	1.47	1.22
2017	1.85	1.51	1.22
2018	1.90	1.54	1.23
2019	1.95	1.57	1.24
2020	2.00	1.60	1.24
2021	2.05	1.63	1.25
2022	2.09	1.66	1.25
2023	2.14	1.68	1.26
2024	2.17	1.71	1.27
2025	2.22	1.74	1.28
2026	2.27	1.77	1.28
2027	2.31	1.79	1.29
2028	2.36	1.82	1.30
2029	2.40	1.85	1.31
2030	2.44	1.87	1.32

ELECTRICITY PRICE

(in % increase/year - incl. baseline elec. taxation)

	EV+	Baseline	CV+
2012	14.31	14.45	14.87
2013	14.80	15.09	15.97
2014	15.30	15.75	17.15
2015	15.82	16.44	18.42
2016	16.36	17.17	19.79
2017	16.91	17.92	21.25
2018	17.48	18.71	22.83
2019	18.08	19.53	24.52
2020	18.69	20.39	26.33
2021	19.32	21.28	28.28
2022	19.98	22.22	30.37
2023	20.65	23.19	32.62
2024	21.35	24.21	35.04
2025	22.07	25.27	37.63
2026	22.82	26.38	40.41
2027	23.59	27.54	43.40
2028	24.39	28.74	46.61
2029	25.21	30.00	50.06
2030	26.07	31.32	53.76

INFLATION RATE

(in %)

	EV+	Baseline	CV+
2012	2.00	1.73	1.40

MARKET INTEREST RATE

(in %)

	EV+	Baseline	CV+
2012-30	5.50	6.50	6.50

BEV INSURANCE REDUCTION

(in %-share of CV costs, const. over veh. ownership)

	EV+	Baseline	CV+
2012	20.00	20.00	20.00
2013	18.78	18.00	16.00
2014	17.63	16.00	12.00
2015	16.56	14.00	8.00
2016	15.54	12.00	4.00
2017	14.59	10.00	0.00
2018	13.70	8.00	0.00
2019	12.87	6.00	0.00
2020	12.08	4.00	0.00
2021	11.34	2.00	0.00
2022	10.65	0.00	0.00
2023	10.00	0.00	0.00

EV MAINTENANCE

(in %-share of CV costs, const. over veh. ownership)

	EV+	Baseline	CV+
2012	80.00	80.00	80.00
2013	76.65	77.93	79.03
2014	73.45	75.92	78.08
2015	70.38	73.96	77.14
2016	67.43	72.05	76.21
2017	64.61	70.19	75.29
2018	61.91	68.38	74.38
2019	59.32	66.62	73.48
2020	56.84	64.90	72.60
2021	54.46	63.22	71.72
2022	52.18	61.59	70.85
2023	50.00	60.00	70.00

Annex 5.4 – Forecasts of policy measures (starting values)

PURCHASE SUBVENTION

(in Euro)

	EV+	Baseline	CV+
2012	7,000	7,000	7,000
2013	7,000	7,000	7,000
2014	5,000	5,000	5,000
2015	5,000	5,000	5,000
2016	5,000	2,500	0
2017	5,000	2,500	0
2018	2,500	2,500	0
2019	2,500	2,500	0
2020	2,500	0	0
2021	2,500	0	0
2022	0	0	0
2023	0	0	0

REGISTRATION TAX EXEMPTION

(1 - yes, 2 - no)

	EV+	Baseline	CV+
2012	1	1	1
2013	1	1	1
2014	1	1	1
2015	1	1	1
2016	1	1	2
2017	1	1	2
2018	1	1	2
2019	1	1	2
2020	1	2	2
2021	1	2	2
2022	2	2	2
2023	2	2	2

FUEL TAXATION

(TICPE increase in %)

	EV+	Baseline	CV+
2012	0.00	0.00	0.00
2013	0.00	0.00	0.00
2014	1.00	0.00	0.00
2015	0.00	0.00	0.00
2016	0.00	0.00	0.00
2017	1.00	0.00	0.00
2018	0.00	0.00	0.00
2019	0.00	0.00	0.00
2020	1.00	0.00	0.00
2021	0.00	0.00	0.00
2022	0.00	0.00	0.00
2023	1.00	0.00	0.00
2024	0.00	0.00	0.00
2025	0.00	0.00	0.00
2026	1.00	0.00	0.00
2027	0.00	0.00	0.00
2028	0.00	0.00	0.00
2029	1.00	0.00	0.00
2030	0.00	0.00	0.00

ELECTRICITY TAXATION

(annual increase in %)

	EV+	Baseline	CV+
2012-30	0.1	0.3	0.5

INFRA USAGE COSTS

(Euro/km - change with inflation rate)

	EV+	Baseline	CV+
2012-30	0.0000	0.0026	0.0100

INFRA INSTALLATION COSTS

(constant over time, apply inflation rate)

	EV+	Baseline	CV+
2012-30	0	590	590

Annex 5.5 – Evolving perceptions of BEVs

(reflected by adjustments of the applied household selection criteria in the constraints analysis)

(criteria that are relaxed - see chapter 4 for the definition of criteria)

	EV+	Baseline	CV+
2012	7	none	none
2013	7	none	none
2014	7	none	none
2015	4, 7	7	none
2016	4, 7	7	none
2017	4, 7	7	none
2018	4, 7	7	none
2019	4, 7	4, 7	none
2020	4, 7	4, 7	none
2021	4, 6, 7	4, 7	none
2022	4, 6, 7	4, 7	none
2023	4, 6, 7	4, 7	none