Integration of electric vehicles into the power system in France

MAY 2019

MAIN RESULTS

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INITIAL INFORMATION IN RTE'S 2017 LONG-TERM ADEQUACY REPORT ON INTEGRATING E-MOBILITY IN THE ELECTRICITY SYSTEM

1.1 The expansion of e-mobility is now a certainty and preparations must be made to integrate it in the electricity system

In France, the energy consumption of the transport sector accounts for almost 30% of the final energy consumption and almost 40% of greenhouse gas emissions, 95% of which is emitted by road transport. It is the only sector in which emissions have been increasing continuously since 1990. The state objectives for reducing greenhouse gas emissions – in particular reaching carbon neutrality by 2050 – in line with the Paris agreement objectives will require a major reduction in the emissions in this sector.

As well as greenhouse gas emissions, the transport sector has various local environmental impacts (noise pollution, air pollution, etc.) which affect the quality of life and the health of the population. The Government's priorities therefore also include the transition from ICE vehicles to other types of mobility.

Faced with these environmental and public health issues, European, national and local authorities are introducing public policies designed to stimulate and promote the emergence of cleaner types of mobility. These tools concern both transport supply and demand, and take the form of prescriptive measures or financial incentives: mandatory targets for manufacturers on the average emissions of new models put on the market, introduction of "low emission zones" (LEZ), car-scrapping subsidy, ecological bonus-penalty system, carbon tax, tax exemption for electric vehicle charging provided by companies for their employees, tax exemption on clean company vehicles, etc.

The environmental impacts of transport will be managed using various solutions: shift to public transport or soft mobility, development of carpooling and reducing the need to travel, and also the development of various technical solutions for clean mobility (all-electric vehicles, plug-in hybrid electric vehicles, fuel cell electric vehicles, natural gas vehicles, etc.).

Electric vehicles are currently the main solution proposed for reducing the greenhouse gas emissions of road transport, using low-carbon electricity generation facilities. While electric vehicles are not the only solution for decarbonising the transport sector, their development is significantly more advanced than that of the alternative clean technologies. Although the market share of electric vehicles is quite small at the moment, it is growing fast both in France and globally.

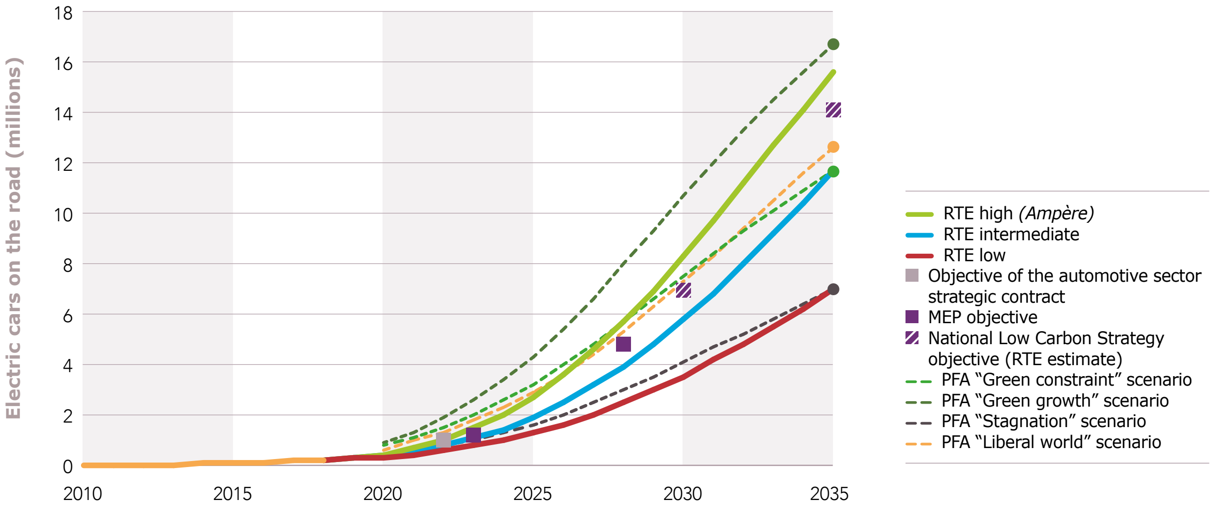
While there are a number of uncertainties regarding the specific process for the penetration of e-mobility in the medium term, there are clear indications that electric vehicles will expand massively in the next few years. The various projections of manufacturers (PFA (French automotive industry association) scenarios) and the authorities (objectives of the Multiannual Energy Plan (MEP) and the National

Low Carbon strategy) are based on there being over a million electric vehicles on the road in France by 2022-2023, 4.8 million in 2028 (end of the Multiannual Energy Plan), and possibly reaching 7 to 16 million units (private vehicles and light-duty commercial vehicles) in 2035 (i.e. between almost 20% and over 40% of the total number of vehicles). The development would initially concern mainly private vehicles and light-duty commercial vehicles, but would ultimately include HGVs (electric buses and trucks).

The massive development of electric vehicles is a challenge and a pivotal change for the energy and transport sectors; several conditions must be met for this development to be successful. Increasing the accessibility of charging points, accompanying the industrial change to the automotive sector, ensuring the security of the electricity supply, and managing the environmental impacts and costs for both the community and the user are all factors that can facilitate the integration of e-mobility.

However, these issues raise further questions. Some of them concern the capacity of the electricity system to supply the energy for millions of electric vehicles, or the advantage of implementing smart vehicle charging solutions. These issues must be studied in detail in order to anticipate the impacts of the development of e-mobility and to prepare the electricity system for the massive integration of this new use.

Figure 1. Projected changes in the numbers of light-duty electric vehicles (private vehicles and light-duty commercial vehicles) in France, including all technologies: 100% electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV)



1.2 The 2017 RTE Long-term adequacy report demonstrated the capacity of the electricity system to integrate a huge number of electric vehicles subject to minimum smart charging

In 2017, RTE provided initial information on the impacts of the development of e-mobility in the Long-term adequacy report, which is produced each year in accordance with the Energy Code.

The long-term scenarios that are devised in consultation with the stakeholders in the energy sector and published in the 2017 RTE Long-term adequacy report incorporate the various contrasting options for the development of e-mobility, reaching up to 15.6 million electric vehicles by 2035. The *Volt* and *Ampère* scenarios, used by the Government to devise the MEP scenario, predict sustained development of e-mobility.

The aim of the analyses carried out in the 2017 Long-term adequacy report was not to predict the penetration of electric vehicles, but to test the resilience of the electricity system to massive development of this technology. In particular, **the studies carried out on the "high" scenario for the development of e-mobility demonstrated, on initial consideration, the capacity of the system to take up to 15 million electric vehicles by 2035 without any major problems.**

These analyses lead to a two-fold conclusion:

- *Energy consumption:* the analyses in the RTE long-term adequacy report showed that there was no doubt as to the capacity of the electricity system to generate the amount of electricity needed for charging several million vehicles, in a context of falling consumption observed on other uses. Thus, the annual consumption of 15.6 million electric vehicles would represent approximately 35 to 40 TWh of electricity, i.e. less than 8% of France's total electricity production.
- *Power demand:* it was identified that vigilance will be needed regarding the management of peak demand periods in winter evenings, but the capacity to absorb a huge number of electric vehicles seems to be confirmed as soon as simple smart systems (for example, time-of-use smart charging based on the peak/off-peak period signal, similar to devices currently used for domestic hot water) are put in place for some electric vehicles.

These results are based on a simplified representation of the behaviour of people when it comes to travelling and commuting (hereafter referred to 'travel behaviour'). Most of the analysis focussed on the main characteristics of the transition scenarios (changes in the number of nuclear power stations, changes to renewable energy sources and thermal power plants, schemes to change consumption, energy policies of neighbouring countries, etc.).

1.3 Requests from stakeholders for greater detail, to clarify the discussions on the "energy" and "mobility" roadmaps

The information in the RTE long-term adequacy report has been widely used since November 2017 in the context of further foresight work on the electricity system, and preparing the draft MEP. This information has provided the technical foundations for considering scenarios for fast deployment of e-mobility.

In this context, RTE has received regular requests from stakeholders to continue the process started in 2017 and to carry out more in-depth cross-cutting analyses on the development of clean mobility and its impacts on the electricity system. These requests have focussed on a number of specific points: analysing specific events such as periods of mass holiday departures, specifying the economic value of smart charging and the cost for the consumer, detailing the challenges in terms of reducing CO_2 emissions by integrating the lifecycle analysis of the batteries, analysing the economics of second-life batteries, etc.

Numerous reports on e-mobility have been produced in recent months. The FNH (Nicolas Hulot Foundation for Nature and Mankind) study, published in April 2018, analysed the carbon footprint of electric vehicles, and called for further investigations. In autumn 2018, a report published by the CRE (Energy Regulatory Commission) considered the opportunities offered by flexibility of charging and how it is implemented, and noted the need for further investigations on the integration of e-mobility in the electricity system. In March 2019, OPECST (Parliamentary Office for Scientific and Technological Assessment) released a report on the technological scenarios for achieving the objective of stopping the sale of ICE vehicles in 2040.

To investigate these topics further and respond to demands from the authorities, RTE, together with AVERE-France (national association for the development of e-mobility) has set up a working group which brings together all interested parties: those involved in the electricity system (producers, suppliers, those managing distribution networks, demand-response aggregators, State institutions and representatives, regulator, etc.), those involved in the mobility sector in the broad sense (vehicle manufacturers, start-ups offering smart charging solutions, operators of charging points, planners, communities, etc.), NGOs, trade associations, consultants, universities and public institutions (representatives of the State, regulators, etc.).

The definition of the work, the assumptions used, and the preliminary and final results were presented, discussed, and refined in this working group. This consultation work took more than a year to complete. It required adaptation of RTE's modelling tools in order to deal with widely differing mobility scenarios.

The consultation process also took into account guidelines on energy policy (energy-climate law, Multiannual Energy Plan and National Low Carbon strategy) and transport (French mobility orientation law), currently being discussed in Parliament. In particular, the draft National Low Carbon strategy is based on major electrification of vehicles in the medium term (with objectives comparable to those of the *Ampère* scenario in RTE's 2017 long-term adequacy report), and the draft MEP published in January 2019 plans an ambitious deployment of electric vehicles (4.8 million units in 2028) and includes a specific section on a "clean mobility development strategy". One of the challenges of this strategy is enabling the parallel, coordinated development of "new carbon-free energies and alternative-fuel vehicles with associated logistic infrastructures".

The analyses carried out and detailed in this document clarify the public debate on the interactions between France's "energy" and "mobility" roadmaps.

THE MAIN CHALLENGE FOR THE IN-DEPTH STUDY – UNDERSTANDING THE DETERMINANTS AND KEY PARAMETERS OF THE ELECTRICITY SYSTEM

2.1 Travel behaviour – A detailed analysis based on National Travel Survey data

Being able to characterise all forms of mobility for electric vehicles is essential for modelling their impact on the electricity system in predictive and prospective approaches alike.

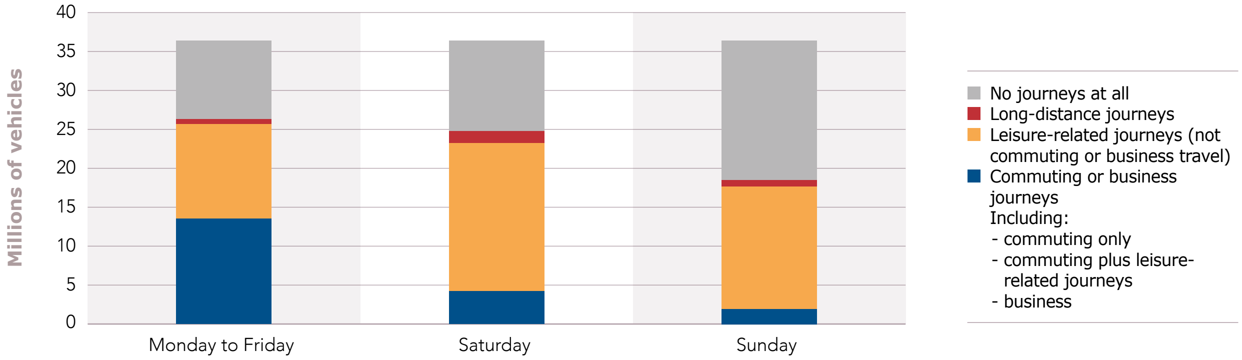
It involves not only a robust assessment of distances (and speeds) travelled – which will dictate energy consumptions – but also identifying the types of journey made and their departure and arrival times and locations (which will help determine when and how users are likely to charge their vehicles), and even characterising the flexibility services that these vehicles can offer the electricity system without restricting user mobility.

The way in which these mobility needs are presented and how they are likely to evolve is based on a detailed study of current and predicted transport behaviour, including:

i. A detailed analysis of current mobility patterns within different population categories, derived from travel behaviour surveys (the French National Transport and Travel Survey in particular)
ii. Various projections on how these mobility needs might evolve (taking factors like remote working and carpooling into account)
iii. Assumptions about future e-mobility distribution among the different user profiles

The National Transport and Travel Survey (ENTD)[1] conducted by the French Institute of Statistics and Economic Studies serves as the reference document on travel behaviour. It provides detailed data on the

Figure 2. Average mobility profile of light-duty vehicles in France according to the day of the week (calculations based on the 2007-2008 National Transport and Travel Survey)



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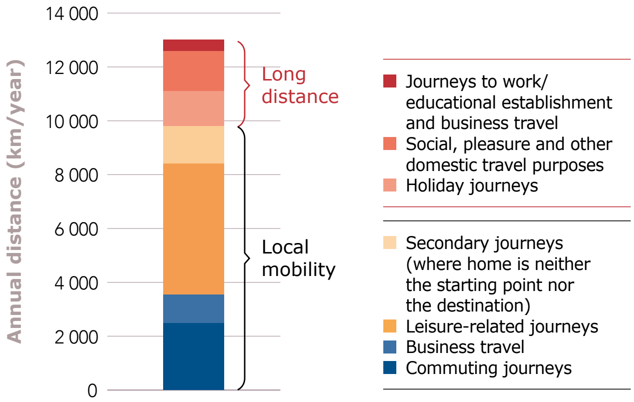
[1] The most recent survey was conducted in 2007/2008. Another survey is planned for 2020.

mobility of light-duty vehicles, the different kinds of journeys made (reasons, start and end points, distances travelled, departure and arrival times according to the day and category of user). A comprehensive analysis of this survey data has helped to build an accurate picture of mobility of households in France, which is potentially different from any implicit understanding that people may hold.

It reveals some striking features of mobility:

- **On working days, only 30% of vehicles are used for commuting to and from work, and just 7% of vehicles are used for business travel.** The remaining vehicles are used for other types of local (33%) or long distance[2] (2%) journeys, or are not actually used at all (28%).
- Among the vehicles used for commuting, **a significant number (15%) are driven home at lunchtime** (this finding is a typically French behaviour pattern).
- **Only 15% of distances travelled by car annually equate to journeys of more than 250 km,** a distance, which is likely to exceed the current typical range of an electric vehicle.
- **The average daily distance travelled in a vehicle used for local mobility is around 35 to 40 km,** which means that the current typical range of an electric vehicle would allow the equivalent of one week of average journeys.

Figure 3. Average annual distances travelled in France *(source: ENTD 2008)*



It is these "intrinsic" characteristics that will determine the load profiles on the electricity system and the potential margins for smart charging. Typically, the charging requirements for a vehicle being driven on long distance journeys will be highly restrictive – yet very few vehicles are used for this purpose on a daily basis. In contrast, the majority of vehicles making "local" journeys (70% of vehicles during the week, 48% of vehicles on Sundays) or not used at all (28% of vehicles during the week, 50% of vehicles on Sundays) will offer greater scope for smart charging.

These characteristics appear to be eminently favourable, not only to electric vehicle development, but also to charging at the user's convenience (rather than charging times being imposed upon users).

2.2 Electric vehicle development – Identifying the key parameters

Modelling the power demands of electric vehicles and the flexibility they are likely to afford hinges on several assumptions and "key parameters". The consultation process on these assumptions has highlighted a number of uncertainties and disparities between the expectations of the various stakeholders regarding these parameters.

Contrasting assumptions have been considered in an effort to assess the sensitivity of the technical, economic and environmental results with respect to the different parameters.

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[2] In the ENTD survey, long distance journeys are defined as travel to a main destination located at least 80 km from home as the crow flies.

Non-autonomous light-duty electric vehicles

(projected 2035 fleet)

Low trajectory:
7 million BEVs/PHEVs

Medium trajectory
with substitution by
autonomous vehicles:
8.2 million BEVs/PHEVs

Medium trajectory:
11.7 million BEVs/PHEVs

High trajectory:
15.6 million BEVs/PHEVs

Different electric vehicle evolution trajectories have been considered. The scenarios studied focus on the medium and high trajectories to assess the resilience of the electricity system in ambitious e-mobility development scenarios.

Autonomous light-duty electric vehicles

(projected 2035 fleet)

Zero or modest development
of autonomous electric vehicles

1 million shared autonomous
electric vehicles

The analysis incorporates the possibility of developing a new form of mobility, in which a proportion of users do not own a vehicle themselves, but are able to use mobility services based on shared autonomous electric vehicles in the form of "robo-taxis".

Modal share of the various forms of mobility

Government objectives
regarding future modal share

Significant increase in the share
of public transport

Better public transport and
support for soft mobility

Efforts to decarbonise transport may also serve to transform future mobility needs, with greater use of public transport and/or soft mobility options for instance.

Electric trucks and buses

(projected 2035 fleet)

20,000 electric trucks
5,000 electric buses and coaches

94,000 electric trucks
18,000 electric buses and coaches

129,000 electric trucks
27,000 electric buses and coaches

E-mobility development is expected to be less pronounced for heavy-duty vehicles, the majority of which have a substantial long-range requirement. Nevertheless, EV development offers potential in the specific case of heavy-duty vehicles which only make local journeys, such as buses and coaches in urban areas and urban and regional delivery vans.

Share of plug-in hybrid vehicles (PHEVs) and full battery electric vehicles (BEVs)

(projected 2035 fleet)


22% PHEVs/78% BEVs


40% PHEVs/60% BEVs


45% PHEVs/55% BEVs

Depending on the advances made in the different technologies, government funding policies or even user requirements in terms of vehicle range, the share of PHEVs in the overall EV fleet could settle at very different levels. A modest development in fuel cell electric vehicles (which use hydrogen generated by electrolysis) of between 16,000 and 35,000 units in 2035 is also considered.

Size of BEV batteries available

(in 2035)

56 kWh - 330 km

73 kWh - 440 km

89 kWh - 530 km

The current trend is to increase battery size to improve vehicle range performance and hence enhance EV acceptability. However, larger batteries also have a greater environmental impact and are not always justified for vehicles that are used primarily for short-distance journeys.

Battery manufacture and recycling

Manufactured
in France

Manufactured in Asia
(China, South Korea)

50% recycling

85% recycling

The place of manufacture and the level of recycling of batteries both have an impact on the environmental analysis.

Distribution

Electric vehicle distribution

Even distribution throughout the population

Greater uptake by affluent workers in urban or suburban areas

The growth of electric vehicles is likely to depend to a certain extent on the different population categories (workers/non-workers, high-mileage drivers, wealthier populations, etc.).

Mobility

Average mileage

km 11500
Average, excluding long distances

km 12500
Average, including long distances

km 14000
High, excluding long distances

km 15300
High

The use of electric vehicles and the annual distances travelled can differ according to the EV user category.

Charging points

Access to charging points

Limited access away from home

Moderate access away from home

Widespread access away from home

Access to charging points (at home, at work, on public roads, etc.) will determine not only the locations but also the periods during which EVs can be charged, as well as the flexibility in terms of shifting charging loads.

Charge point power rating

Low power
Average charging at home in 2035: 5.2 kW

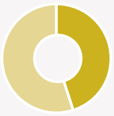
Medium power
Average charging at home in 2035: 6.2 kW

High power
Average charging at home in 2035: 6.7 kW

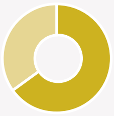
Charge point power ratings determine the battery charging speed (slow, fast or ultra-fast charging). These can vary considerably depending on where they are installed (home, workplace, public road, motorway service station, etc.). Domestic charging points will essentially be rated between 3.7 kW and 7.4 kW, whereas the power ratings for fast charging stations at motorway services could be as high as 350 kW.

Charging

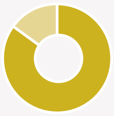
Plug-in frequency



45% routine plug-in



65% routine plug-in



85% routine plug-in

For EV users travelling short distances on a daily basis, their batteries will rarely be fully discharged by the end of the day. This presents the potential for different charging behaviours: users either routinely plug their car in whenever it is parked and they have access to a charging point, or they only plug it in when the battery falls below a certain level of charge (e.g. 50%). This parameter determines the charging frequency and the number of vehicles plugged in at any one time, and thus the flexibility potential available to the electricity system.

Controlled (smart) charging

Uncontrolled

Limited control
40% smart charging,
0% of which is V2G

Moderate control
60% smart charging,
3% of which is V2G

High degree of control
80% smart charging,
20% of which is V2G

The diffusion of EV smart charging in its various forms (time-of-use, dynamic, vehicle-to-grid (V2G), etc.) is one of the study's key parameters.

2.3 Smart charging – A systematic review of the potential variants

Electric vehicles as a "controllable" consumption according to system conditions

A private car is primarily a static object: it is stationary for the majority of time – parked either at home or at a workplace – and is typically used for just 4% of the time. In France, less than 10% of the nation's vehicle fleet is on the move at any one time, even during the busiest rush hours.

A proportion of these parked vehicles cannot routinely be plugged in to a charging point. For instance, 6 million households in France owning at least one car do not have access to private parking. Access to workplace charging also poses a challenge. Yet, even taking these factors into account, numerous cars are very often stationary in the immediate proximity of a charging point. **Once electric vehicles become more widely adopted and there is a sufficient number of charging points, a considerable number of electric vehicles could be plugged into the system more or less continuously: for all these vehicles, there is significant scope in terms of charging timing.**

What is more, analysis of data relating to mobility in France shows that cars typically stand idle while parked for long periods of time (especially overnight). These periods are sufficiently long to allow charging to take place at optimum times (for both the electricity system and the consumer). **Other than in specific conditions (such as charging en route on a long journey), electric vehicle charging can be controlled without impacting mobility.**

Smart charging therefore provides a useful source of flexibility for the electricity system. In principle, it offers a major benefit in a system where consumption and production depend primarily on external variables (weather temperatures, wind, sunlight, runoff).

Electric vehicles as a storage solution

Electricity systems have been designed and built according to a simple sizing and operating principle: electricity cannot be stored, and, with the exception of a limited number of pumped storage hydroelectricity (PSH) power plants, storage solutions are extremely costly.

Yet when electric vehicles become more widely adopted, a whole fleet of small batteries will be permanently plugged into the electricity system. This offers the potential for the large-scale sharing of this source of flexibility, whereby "distributed storage" could play an important role in optimising and balancing the system and reducing costs.

E-mobility development is thus causing a paradigm shift in the way we look at the electricity system, prompting us to consider this new use as a technical opportunity.

Considerable flexibility potential, controllable on a weekly basis

The technical analysis of these new sources of flexibility (either through simple control accessible via unidirectional charging, or use as a storage resource via reversible charging) demonstrates the substantial benefit that e-mobility represents for the electricity system from a technical perspective.

Smart charging can handle very high volumes of energy: flexible charging – i.e. charging that does not correspond to time-constrained needs – represents around 85% of annual EV energy consumption. In the intermediate scenario used in the analysis (11.7 million electric vehicles by 2035), controllable consumption equates to 25 TWh per year, which is equivalent to the energy consumed currently by hot water tanks, which are also controllable. With vehicle-to-grid systems, the flexibility offered by electric

FOCUS ON THE VARIOUS FORMS OF SMART CHARGING

Functionality – simple or reversible charging

Simple/unidirectional charging function:

Battery charging can be modulated over time but the electricity generated cannot be fed back into the grid.

Reversible/ bidirectional charging function:

The battery can draw power from the grid but can also feed electricity back into the domestic supply (V2H) and/or the public grid (V2G). This functionality requires an AC/DC converter in either the vehicle or the charging station.

Control pilot signals and sources of value

Simple time-of-use charging

Charging occurs within defined tariff bands (such as existing off-peak hours or other price signals). This can be achieved through time-of-use control (as is currently used for hot water tanks) and is thus transparent to the user.

Dynamic charging on electricity price signals

Charging start times (and potentially the times at which electricity is fed back into the grid) are controlled dynamically, as a function of the hourly wholesale electricity market prices and the user's future mobility needs.

Charging with real-time load balancing in the power grid

Battery charging (and potentially discharging) is modulated according to grid balancing requirements, via frequency response, for instance.

Combined with photovoltaic self-consumption

Charging (and potentially discharging) takes place in such a way as to make the best use of energy generated locally by photovoltaic (PV) panels.

Combined sources of value and other methods...

The various forms of smart charging

These different sources of value and functionalities can be combined in various ways to produce an array of smart charging formats of varying degrees of sophistication

1. Simple, unidirectional controlled time-of-use charging

2. Unidirectional charging with frequency balancing

3. Vehicle-to-home (V2H) charging: Using the bidirectional function to cover household consumption without feeding power back into the grid

4. Vehicle-to-grid (V2G) charging with contribution to the energy market

5. Vehicle-to-grid with frequency balancing

6. Charging management combined with self-consumption (with or without bidirectional functionality)

7. Etc.

vehicles is even greater. By 2035, the cumulative storage capacity of electric vehicles should represent between 6 and 11 times that of current PSH capacity: with only 20% of electric vehicles equipped for reversible charging, the flexibility that could be provided by vehicles at any one time is at least equal to that offered by PSH, both in terms of energy storage capacity and available power.

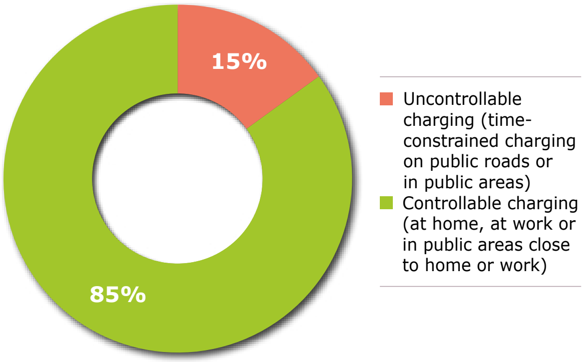
This flexibility allows variations to be managed on a weekly basis, not just throughout the day. In fact, even though battery capacity is considered to be a limiting factor by some potential EV users, this presently offers a range of around 250 km (for a 40 kWh battery), which is sufficient to cover an average week of journeys. This allows the majority of users to schedule their charging for the cheapest times of the week, typically the weekend. This degree of flexibility could be even greater by 2030-2035 considering the likely increase in battery capacity. In contrast, the flexibility provided by hot water tanks can only respond to daily variations.

Detailed analysis of charging methods

Numerous studies on electric vehicles tend to confuse functionality (unidirectional or bidirectional charging) with the method of control (which can be dynamic if required) and the sources of flexibility. In practice, identical functionalities can be associated with different sources of value: for example, reversible charging can be used to cover household consumption (in vehicle-to-home operation) or to feed power back into the public grid (in vehicle-to-grid operation). This results in a diverse range of possible models.

One of the aims of the new study conducted by RTE in collaboration with AVERE-France was to analyse these smart charging methods in detail and assess their impact on electricity system operation.

Figure 4. Share of flexible charging (in total annual energy)



The analysis covers the economic aspects too

Some reports on e-mobility which examine smart charging apply a "marginal" approach to their studies, i.e. they assess the value of smart-charging solutions by assuming the addition of a single vehicle, with all other things remaining equal. Since 2017 and the methodological improvements made to studies on smart grid development, RTE has systematically scaled up their results to verify that the sources of value identified are robust enough for mass deployment.

This new report follows the same approach, and therefore makes a distinction between potentially lucrative yet restricted sources of value (frequency balancing services) and more robust, scalable opportunities (such as widespread simple control).

2.4 The electricity system – Modelling the mix in line with scenarios outlined in the RTE long-term adequacy report and objectives laid down in the Multiannual Energy Plan

Evaluating the impacts of e-mobility development and the technical, economic and environmental issues associated with charging flexibility relies on modelling operation of the European electricity system. This modelling, also used for the analyses in the RTE long-term adequacy report, consists of simulating the balance between demand and supply on an hourly basis on a Europe-wide scale (allowing for the potential for exchanges at interconnections) for a very large number of unpredictable variables (consumption, wind, solar and hydro power production, availability of nuclear and fossil fuel power plants, etc.).

Electric vehicles have been modelled explicitly to represent their mobility needs, the times at which they are plugged in (and the corresponding power ratings) and the battery charge level. This modelling is used to simulate the utilisation of EV flexibility while taking into consideration mobility needs.

The assumptions used for analysing how the electricity mix will evolve are based on the objectives outlined in the draft Multiannual Energy Plan (MEP) published by the French government at the beginning of 2019. They include the following:

- Accelerated development of renewable energy sources (RES) between now and 2028 (2.5 times more onshore wind energy capacity by 2028 and 4 times higher photovoltaic capacity over the same period, plus development of offshore wind farms, etc.), assumed to be extended into the period 2029-2035
- Closure of coal-fired power stations in the medium term and no new fossil fuel power station infrastructure
- Decommissioning of 14 nuclear reactors by 2035 (including the two Fessenheim reactors) according to the time line announced by the French government in November 2018
- Stable final electricity consumption (with energy efficiency measures offsetting new uses like electric vehicles) and advances in hydrogen production by electrolysis
- Sustained development of grid interconnections

Figure 5. Modelling principles used in the analysis

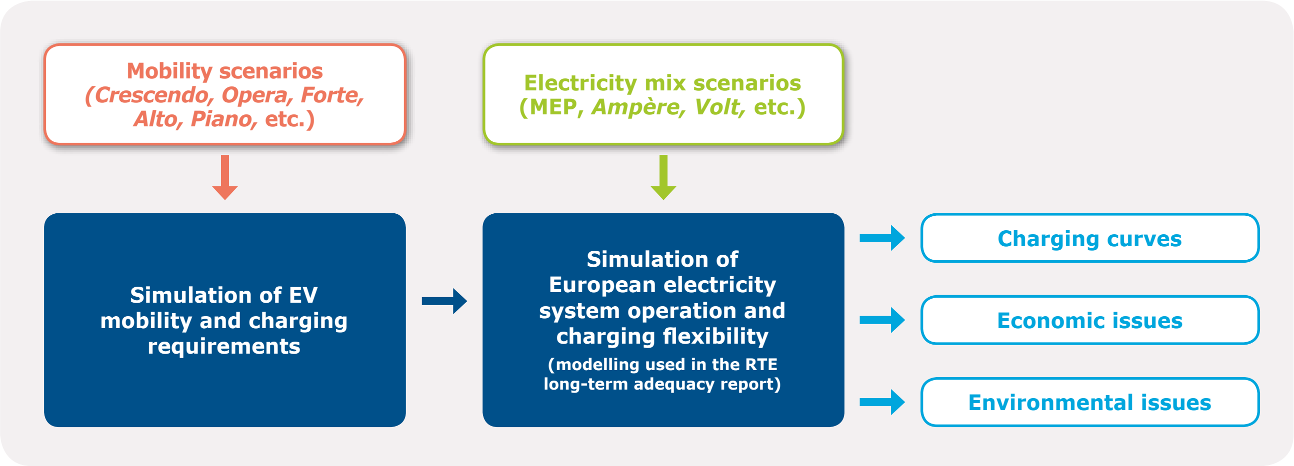
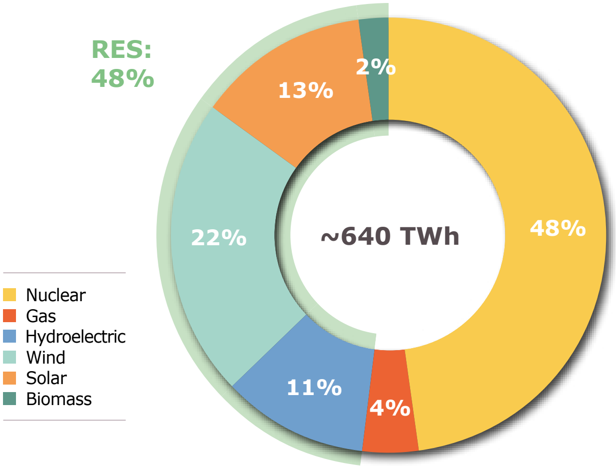


Figure 6. 2035 projected generation mix in the MEP scenario



This future electricity mix scenario shares several characteristics with the *Ampère* and *Volt* scenarios analysed in the 2017 RTE long-term adequacy report:

- One feature of the mix is a marked increase in the "low variable cost, low-carbon" fleet (renewable and nuclear energy sources). This means there is often a significant amount of low-cost power available and that this electricity is very competitive on the energy markets (and will therefore practically always find a buyer).
- Consequently, in a context where electricity consumption would be stable globally, the French electricity system would find itself exporting a considerable proportion of the electricity it generates, with annual export volumes potentially in excess of 100 TWh from 2030. This characteristic was analysed in greater detail following on from the 2017 RTE long-term adequacy report[3]. Further analysis confirmed the technical feasibility of a substantial export balance in this type of scenario but also highlighted the need for vigilance regarding the economic conditions of these exports (potential emergence of low prices in electricity markets).
- Lastly, this mix is deemed to have "moderate flexibility" for two reasons: firstly, *technical constraints* impose limitations on the modulation possibilities for both nuclear power (safety constraints in particular) and renewable energy sources; and secondly, from an economic perspective, it would be a shame to halt production methods with a low, if not zero variable cost. The example of Sunday 21 April 2019 illustrates this point perfectly: this particular day was marked by low consumption in France and more widely in Europe, and by high availability of wind and solar energy in Germany and nuclear energy in France. This led to a production surplus of low-cost energy and to negative prices at certain times of the day.

The benefit of the kind of mix outlined in the MEP is consequently considerably enhanced by controllable consumption, whereby consumption can be adapted to the availability of renewable energy production, and by new uses like electric vehicles, which can take advantage of the low variable cost low-carbon electricity generation in France and begin to compete with exports.

This underlines the benefit of an in-depth analysis of the coordination between the "energy" and "mobility" roadmaps. E-mobility development consistent with the MEP offers the opportunity to operate the electricity system in optimal conditions – where charging correlates with solar or wind energy production and curtailment of renewable energy production is reduced, and where flexible mechanisms, such as EV charging, rather than nuclear power, are relied upon for load adjustment purposes.

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[3] RTE, October 2018, *«Analyses complémentaires sur les échanges d'électricité aux interconnexions dans les scénarios du Bilan prévisionnel»*

CONTRASTING SCENARIOS FOR THE DEVELOPMENT OF E-MOBILITY

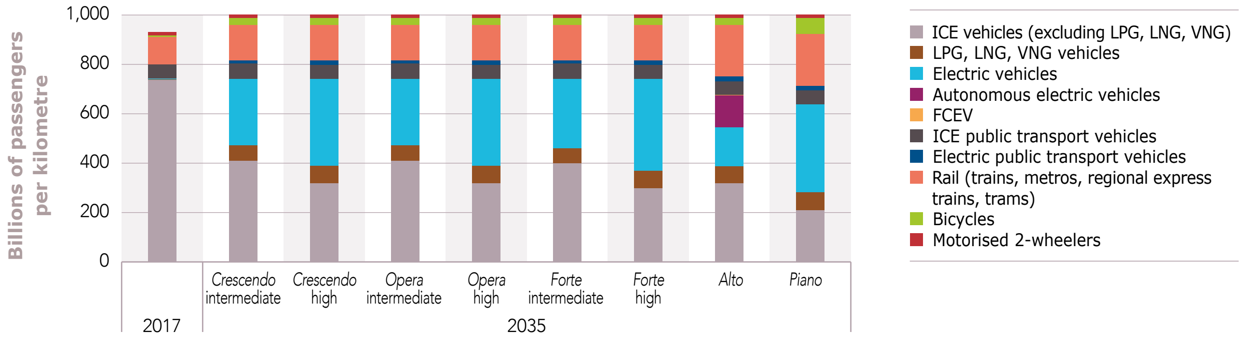
The key assumptions, established in consultation with the members of the working group, can be combined in many different ways. To help present their impact and provide relevant analyses, two guides for interpreting the results are proposed:

- Presentation based around five mobility scenarios, each describing one form of electrification of the transport sector. The aim of these scenarios is to examine deliberately contrasting situations for the electricity system: one scenario corresponding to the standard projections *(Crescendo),* one very favourable configuration *(Opera)* and another which is less favourable *(Forte),* are studied, to discuss the resilience of the electricity system. Another scenario is based on a change in mobility focussing on shared autonomous vehicles *(Alto),* and the last scenario is based on a larger share of soft mobility and choices that systematically reduce the carbon footprint of electric vehicles *(Piano).*
- A thematic analysis of the results, structured under four headings (technical, economic from a system perspective, economic from a consumer perspective, and environmental).

The *Crescendo, Opera* and *Forte* scenarios are presented according to an intermediate variant (based on the PFA's Green Constraint scenario) and a high variant *(Ampère* trajectory of the 2017 RTE long-term adequacy report). The *Alto* scenario leads to a similar electrification to the high variant of the other scenarios but is heavily based on the development of autonomous vehicles being used in the form of services ("robo-taxis"). The *Piano* scenario has the same number of electric vehicles as the first three scenarios, but fewer ICE vehicles due to the greater modal shifts to public transport and soft mobility.

CRESCENDO scenario	**Standard projections**
OPERA scenario	**Greater flexibility**
FORTE scenario	**Stress for the electricity system**
ALTO scenario	**Expansion of shared autonomous vehicles**
PIANO scenario	**Low-carbon mobility**

Figure 7. Passenger traffic for the various modes of land transport in the different scenarios



CRESCENDO SCENARIO – “STANDARD PROJECTIONS”

Principle and general framework

The *Crescendo* scenario simulates a major development of e-mobility, with a gradual change in mobility patterns.

Two variants of the e-mobility objectives are considered: an intermediate variant based on manufacturers’ projections (PFA Green Constraint scenario), and a high variant compatible with the public objectives of the MEP and the Low Carbon Strategy *(Ampère* scenario in the 2017 RTE long-term adequacy report).

Mobility is still organised around passenger cars, which are still by far the main mode of transport, but some of its characteristics change in line with current trends: development of carpooling (higher vehicle occupancy rate), working from home (reduction in mobility requirements per person), use of bicycles and public transport (modification of the modal shares). The distances covered by vehicles thus increase more slowly than the population.

From an industrial viewpoint, the characteristics of vehicles (size, performance and range) are in line with the current standard projections. The location in which the batteries are manufactured corresponds to the current industrial strategies, and is mainly in Asia.

In *Crescendo*, there is a more marked development of e-mobility with high-mileage drivers. Thus, it concerns first and foremost people driving their cars to their workplace, as well as those living in urban and suburban areas, where the use of ICE cars is most likely to be discouraged with the introduction of measures and incentives to limit local pollution.

Despite an increase in the capacity of vehicle batteries, vehicle range is still relatively restricting for long-distance journeys. All-electric vehicles are still used less than ICE vehicles for long journeys.

From the point of view of charging, the infrastructures are being developed on public roads and at workplaces, giving nearly 30% of users regular access to changing points other than at their homes. The charging points provide average power. Smart charging, in its simplest forms, is widely adopted, for example via time-of-use charging, similar to devices used for water heaters, which is easy to set up using smart meters. However, the services provided to the system by the user via reversible *(vehicle-to-grid)* charging are still marginal.

Numbers of vehicles

CRESCENDO SCENARIO – INTERMEDIATE – 2035	CRESCENDO SCENARIO – HIGH – 2035
11.7 million light-duty electric vehicles **+112,000 heavy-duty electric vehicles**	**15.6 million light-duty electric vehicles** **+ 156,000 heavy-duty electric vehicles**
40% of which are plug-in hybrid electric vehicles	**22% of which are plug-in hybrid electric vehicles**
26.6 million light-duty ICE vehicles 544,000 heavy-duty ICE vehicles	22.7 million light-duty ICE vehicles 500,000 heavy-duty ICE vehicles

Modes of use and behaviour

Medium capacity batteries
(average: 73 kWh/440 km)

An average of 14,000 km travelled each year for 100% electric light-duty vehicles

28% of vehicles have regular access to a charging point other than in the home

Medium power of charging points
(65% of 7.4 kW points in the home)

Mixed connection habits
(65% routine and 35% occasional)

60% of charging is smart,
including **3% V2G**

Environ. framework

Batteries manufactured in Asia (China and South Korea)

No strong choice in favour of recycling

Results

The *Crescendo* scenario captures an important part of the benefits (technical, economic and environmental) associated with e-mobility and described in the report. However, it does not follow the optimisation argument through to the end.

In this scenario, the annual electricity consumption associated with the development of e-mobility reaches around 29 TWh (intermediate scenario) to 40 TWh (high scenario), i.e. approximately 6% to 8% of France's total electricity consumption.

The widespread development of simple smart charging solutions limits power demand at peak periods. The contribution of electric vehicles to consumption peaks is between 2.2 GW and 3.6 GW, which is acceptable in the MEP scenario. In particular, there is no problem with regard to security of supply, including during busy holiday periods.

Smart charging enables the electricity generation facilities to be used efficiently on a European scale, and in particular better leveraging of low-carbon electricity (renewable energy sources and nuclear) in periods of surplus generation. Opportunities for optimisation are not fully utilised, but nevertheless limit the cost of generating electricity for charging vehicles.

The development of smart charging also enables consumers' energy bills to be controlled, with an average annual charging cost of less than 300 € (as against an annual petrol cost of around 1,200 € today).

In the *Crescendo* scenario, the development of e-mobility has a very positive effect on CO_2 emissions, with a reduction in the transport sector's carbon footprint of over 20 million tonnes a year. This is due to the fuel combustion emissions that are avoided as well as the globally optimised use of the electricity system by means of smart charging.

	CRESCENDO SCENARIO – INTERMEDIATE – 2035	CRESCENDO SCENARIO – HIGH – 2035
Electricity consumption	**29 TWh** consumption of electric vehicles **+2.2 GW** average variation in power demand during winter peak periods	**40 TWh** consumption of electric vehicles **+3.6 GW** average variation in power demand during winter peak periods
Effect on the electricity mix	**7.7 TWh** of low-carbon electricity production "recovered" for charging vehicles	**10.3 TWh** of low-carbon electricity production "recovered" for charging vehicles
Economic issues	**35 €/MWh** Average overall cost of producing electricity used for charging **290 €/year** Average annual charging cost for the consumer	**35 €/MWh** Average overall cost of producing electricity used for charging **290 €/year** Average annual charging cost for the consumer
CO_2 emissions	**-22 $MtCO_2$/year** carbon footprint avoided globally	**-26 $MtCO_2$/year** carbon footprint avoided globally

OPERA SCENARIO – “INCREASED FLEXIBILITY”

Principle and general framework

The *Opera* scenario examines the opportunities offered by widespread smart charging and advanced use of the flexibility of batteries. The design of this scenario makes it one of the most favourable configurations for the electricity system.

In this scenario, travelling by private vehicles is still predominant, within the same general framework as in *Crescendo* (continuation of the changes observed regarding the development of carpooling, working from home, public transport and soft mobility). Two main variants for the electrification of vehicles are studied – the intermediate variant is based on manufacturers’ projections (PFA *Green Constraint scenario),* and the high variant is based on the state objectives in the MEP and the National Low Carbon Strategy (RTE’s *Ampère* scenario).

The development of electric vehicles within the population is more marked with active high-mileage drivers living in urban and suburban areas who use their vehicles to go to work. In both cases, the existing industrial strategies (increase in battery range and battery production in Asia) are continued.

The specific features of the *Opera* scenario cover the various technical parameters, which make it easier to integrate e-mobility in the electricity system.

Firstly, access to charging points at the workplace and public charging points is widespread, thus smoothing the power demand during the day and timing power draw-off during peak solar generating periods.

Secondly, smart charging is expanded massively: 80% of charging is smart charging and a significant proportion of vehicles (20%) provide services to the electricity system using batteries to feed energy into the grid *(vehicle-to-grid).*

Lastly, users get into the habit of routinely connecting their vehicles to the grid, and the power of the charging points to which they connect is generally high, thus making it possible to provide considerable flexibility services to the electricity system.

Numbers of vehicles

OPERA SCENARIO – INTERMEDIATE – 2035	OPERA SCENARIO – HIGH – 2035
11.7 million light-duty electric vehicles **+ 112,000 heavy-duty electric vehicles**	**15.6 million light-duty electric vehicles** **+ 156,000 heavy-duty electric vehicles**
40% of which are plug-in hybrid electric vehicles	**22% of which are plug-in hybrid electric vehicles**
26.6 million light-duty ICE vehicles 544,000 heavy-duty ICE vehicles	22.7 million light-duty ICE vehicles 500,000 heavy-duty ICE vehicles

Modes of use and behaviour

Medium capacity batteries
(average: 73 kWh/440 km)

An average of 14,000 km travelled each year
for 100% electric light-duty vehicles

45% of vehicles have regular access to
a charging point other than in the home

High power of charging points
(80% of 7.4 kW points in the home)

Connection mainly regular
(85% regular and 15% occasional)

80% of charging is smart,
including **20% V2G**

Environ. framework

Batteries
manufactured in Asia
(China and South Korea)

No strong choice
in favour of recycling

Results

The considerable flexibility incorporated in the *Opera* scenario affects all the indicators studied.

It is easier to maintain high security of supply. Not only does the development of e-mobility not create any problems for dealing with consumption peaks, but electric vehicles also help to safeguard the security of the electricity supply due to the development of *vehicle-to-grid* technology, which provides an additional power reserve when there is stress on the electricity system. In total, e-mobility and *vehicle-to-grid* technology help to increase the margins of the system by around 5 GW in both of the variants considered.

What is more, the operation of the system is optimised. The strong development of flexibility and regular access to charging points (in particular in the workplace) make it possible to maximise the options for timing vehicle charging. In particular, this flexibility provides the opportunity to make optimum use of low-carbon electricity (renewable energy sources or nuclear) when there are production surpluses, thus leading to limitation of renewable generation curtailment or nuclear power modulation caused by an absence of outlets. It has a major effect, as in both variants an additional approximately 11 to 14 TWh variable low-cost low-carbon production is "recovered" using the batteries in electric vehicles.

These advantages are reflected in the assessment of the costs for the electricity system and users' energy bills, which are low. The average net annual charging cost for users (cost, including tax, of the electricity for charging, less any receipts for flexibility services) is less than 280 € a year. For the 20% of users who take advantage of the possibilities of reversible charging, this net annual cost is significantly lower.

From an environmental viewpoint, electrification of mobility reduces the carbon footprint of the transport sector by around 23 to 27 million tonnes of CO_2 a year. This broadly positive carbon balance is explained by the avoidance of emissions due to fuel combustion of ICE vehicles and by the development of smart charging and *vehicle-to-grid*, which optimises the operation of the European electricity system and reduces the use of fossil fuel electricity generation facilities.

	OPERA SCENARIO – INTERMEDIATE – 2035		OPERA SCENARIO – HIGH – 2035	
Electricity consumption	**28 TWh** consumption of electric vehicles	**-5.2 GW** average variation in power demand during winter peak periods (due to V2G)	**40 TWh** consumption of electric vehicles	**-5.2 GW** average variation in power demand during winter peak periods (due to V2G)
Effect on the electricity mix	**11.1 TWh** of low-carbon electricity production "recovered" for charging vehicles		**13.8 TWh** of low-carbon electricity production "recovered" for charging vehicles	
Economic issues	**23 €/MWh** Overall cost of the energy produced for charging vehicles	**275 €/year** Average annual charging cost for the consumer	**23 €/MWh** Overall cost of the energy produced for charging vehicles	**280 €/year** Average charging cost for the consumer
CO_2 emissions	**-23 $MtCO_2$/year** carbon footprint avoided globally		**-27 $MtCO_2$/year** carbon footprint avoided globally	

FORTE SCENARIO – "STRESS FOR THE ELECTRICITY SYSTEM"

Principle and general framework

The *Forte* scenario seeks to test a configuration that is deliberately unfavourable for the electricity system, marked by an absence of any strong choices made by the authorities, low deployment of smart charging strategies, and extensive use of electric vehicles for long-distance journeys. It thus responds to the wish to test the resilience of the system, in terms of security of supply, to a deliberately stressful scenario.

Mobility habits are assumed to be unchanged in relation to today's habits. Despite a very slight increase in the modal shares of other means of transport, the number of individual vehicles does not decrease. Users of electric vehicles essentially expect an electric vehicle to provide the same "service" as an ICE vehicle: their priority is range and therefore high capacity batteries, so that they can travel long distances.

The development of e-mobility is not accompanied by any choices designed to facilitate its integration in the electricity system and create value for flexible charging.

There is very little development of workplace charging or public charging stations. Therefore most vehicles used for travelling between home and work cannot be charged during periods of high solar generation. Moreover, only a minority of users have smart charging for their electric vehicles and no vehicles play an active role in the operation of the system via *vehicle-to-grid* technology. As a consequence, charging follows a largely natural pattern, mainly taking place when users return home in the evening, during periods when the electricity system has lower margins.

The charging points are high-powered and most users get into the habit of plugging in their vehicles as soon as they get the chance to do so: as charging is carried out routinely, it only covers the requirements of one day's travel and is done at relatively high power levels. Charging is not therefore spread out over time, is not very flexible and is relatively concentrated during the periods when users return home.

Numbers of vehicles

FORTE SCENARIO – INTERMEDIATE – 2035	FORTE SCENARIO – HIGH – 2035
11.7 millions light-duty electric vehicles **+ 112,000 heavy-duty electric vehicles**	**15.6 millions light-duty electric vehicles** **+ 156,000 heavy-duty electric vehicles**
40% of which are plug-in hybrid electric vehicles	**22% of which are plug-in hybrid electric vehicles**
26.6 million light-duty ICE vehicles 544,000 heavy-duty ICE vehicles	22.7 million light-duty ICE vehicles 500,000 heavy-duty ICE vehicles

Modes of use and behaviour

High capacity batteries
(average: 89 kWh/530 km)

An average of 15,300 km travelled each year
for 100% electric light-duty vehicles

16% of vehicles have regular access to
a charging point other than in the home

High power of charging points
(80% of 7.4 kW points in the home)

Connection mainly routine
(85% routine and 15% occasional)

40% of charging is smart
No V2G

Environ. framework

Batteries made in Asia
(China and South Korea)

No strong choice
in favour of recycling

Results

The design of the *Forte* scenario is the least favourable for the electricity system. E-mobility has a significant impact on the peak power demands, with an average contribution of between 5.7 GW (intermediate variant) and 8 GW (high variant).

In the high variant with 15.6 million vehicles, the rate of smart charging must be at least 55% to ensure the level of security of supply required by the authorities.

The consumption peaks are due to charging for "daily" mobility requirements. Despite the use of vehicles for long distance journeys, the episodes of stress on the security of supply are not associated with high travel periods (heavy traffic flows during summer holiday periods, etc.) which generally occur during periods when the system has some margin.

Requirements for vigilance on the security of supply are mainly a consequence of low development of smart charging, in particular in the home. Greater development (55% rather than 40%) than in the assumptions of the scenario would be enough to avoid any problem of security of supply.

From an economic perspective, the *Forte* scenario does not allow full advantage to be taken of the synergies with the low-carbon electricity production mix. The electricity used for charging remains very competitive, but is more expensive than in the other scenarios. In particular, during some periods, production surpluses from renewable energy and nuclear sources at variable low costs, or even at no cost, are not utilised, whereas they could be used for charging vehicles.

This can be seen in consumers' energy bills, for whom the average annual charging cost is higher than 350 €, while it could be reduced considerably. Electric vehicles remain broadly less expensive to use, but the full potential for cost reduction is not used.

From an environmental perspective, the carbon balance associated with the electrification of vehicles remains broadly positive (around 20 to 23 million tonnes of CO_2 avoided each year), although most of the parameters are unfavourable: the large size of the batteries, their manufacture in Asia and their low recycling rate result in a higher carbon balance for electric vehicles, and the poor optimisation of charging leads to higher emissions in the European electricity sector. Additional mechanisms for reducing CO_2 emissions or chemical pollution are still therefore available.

	FORTE SCENARIO – INTERMEDIATE – 2035	FORTE SCENARIO – HIGH – 2035
Electricity consumption	**32 TWh** consumption of electric vehicles **+5.7 GW** average variation in power demand during winter peak periods	**45 TWh** consumption of electric vehicles **+8 GW** average variation in power demand during winter peak periods
Effect on the electricity mix	**+6.6 TWh** of low-carbon electricity production "recovered" for charging vehicles	**+9.0 TWh** of low-carbon electricity production "recovered" for charging vehicles
Economic issues	**45 €/MWh** Average overall cost of producing electricity used for charging **360 €/year** Average charging cost for the consumer	**46 €/MWh** Average overall cost of producing electricity used for charging **365 €/year** Average charging cost for the consumer
CO_2 emissions	**-20 $MtCO_2$/year** carbon footprint avoided globally	**-23 $MtCO_2$/year** carbon footprint avoided globally

ALTO SCENARIO – “EXPANSION OF SHARED AUTONOMOUS ELECTRIC VEHICLES”

Principle and general framework

The *Alto* scenario is defined in the context of a profound change in modes of travel, initiated by a technological breakthrough – the autonomous vehicle (level 5) – and organised around the principle of shared mobility services – using “robo-taxis”.

The number of autonomous vehicles reaches a million units on the road by 2035. These vehicles are not owned by households, due to their high cost, but are used regularly and shared as “robo-taxis”: the fact that there is no driver makes these taxis much more accessible for users, and some of the population may then change over permanently to this type of mobility for daily journeys.

The spread of autonomous electric vehicles leads to many households no longer owning their own vehicles and using the mobility services provided by autonomous electric vehicles, together with increased use of public transport. The number of light-duty vehicles falls significantly, from the current 38 million units to less than 32 million in 2035. On average, one robo-taxi takes the place of seven private cars.

Autonomous electric vehicles are used on a massive scale, on average 50% of the time (as against less than 5% of the time for a conventional vehicle) and 100% of the time during “peak” mobility periods. A consequence of their shared mode of use is that autonomous vehicles often make journeys with no passengers.

Autonomous vehicles are charged during periods of lower mobility requirements (essentially at night but also during the day, outside peak mobility periods). During these periods, smart charging is controlled dynamically using the advanced functions of the vehicles.

The change to shared mobility is organised by the authorities in conjunction with an increased public transport offering. The autonomous vehicle thus makes access to public transport easier in areas where the transport networks are less dense.

Concurrently with the development of autonomous vehicles, other light-duty vehicles are electrified with 8.2 million units on the road in 2035. The remaining number of light-duty ICE vehicles falls to 22.7 million units, i.e. the same number as in the “high” variant in the other scenarios. In relation to the other scenarios, the substitution of autonomous vehicles for individual vehicles therefore only concerns electric vehicles.

ALTO SCENARIO – 2035

Numbers of vehicles

8.2 million “conventional” light-duty electric vehicles
+ 156,000 heavy-duty electric vehicles

1 million shared autonomous
electric vehicles

22% of which are plug-in hybrid electric vehicles

22.7 million light-duty ICE vehicles
500,000 heavy-duty ICE vehicles

Modal shift to public transport

Modes of use and behaviour

“Conventional” vehicles

Medium capacity batteries

An average of 14,000 km travelled each year for 100% electric vehicles

28% of vehicles have regular access to a charging point other than in the home

Medium power of charging points

60% of charging is smart, including 3% V2G

Mixed connection frequency

“Autonomous” vehicles

Very high capacity batteries (150 kWh)

125,000 km travelled each year

Access to dedicated charging points

50 kW charging points

100% of charging is smart, but with limited flexibility. No V2G

Routine connection

Environ. framework

Batteries manufactured in Asia (China and South Korea)

No strong choice in favour of recycling

Results

The *Alto* scenario has specific technical characteristics, resulting from the development of a new type of mobility with robo-taxis. The consumption of electric transport is higher in this scenario, due to several characteristics associated with autonomous vehicles (heavier due to high capacity batteries and on-board electronics) and the form of mobility being studied (the mobility services involve a considerable amount of journeys with no passengers, which account for close to 40% of the distances travelled).

The charging patterns also change. Due to the mobility constraints specific to robo-taxis, their high usage and the long distances they cover daily, there is less flexibility for charging these vehicles than for private vehicles. There is less opportunity for optimising the electricity system, and it is not possible to take full advantage of variable low-cost low-carbon production during certain periods.

The average cost of producing electricity for charging vehicles is still controlled, even without taking into account the positive externalities offered by this type of scenario (reduction of the total number of vehicles, increase in the services provided, accident reduction, etc.).

The *Alto* scenario leads to a significant reduction in greenhouse gas emissions. However, it highlights a contrasting carbon balance for the use of autonomous electric cars as robo-taxis. On the one hand, the use of autonomous vehicles reduces the total number of light-duty vehicles and therefore the environmental footprint associated with manufacturing these vehicles. On the other hand, the footprint of the high capacity batteries and the on-board electronics, together with the shorter service life, constitute worsening factors.

This analysis is not sufficient to reach a conclusion on the subject of shared mobility services, but does underline that there is no automatic correlation between increased range and environmental performance. The issue should be studied further: numerous deployment models can be considered for autonomous vehicles, with more or less close coordination with other types of mobility, and some of them are likely to improve the economic and environmental equation of the scenario. The life cycle emissions specific to autonomous vehicles are subject to a number of uncertainties and are still poorly documented.

ALTO SCENARIO – 2035

Electricity consumption

48 TWh
consumption of electric vehicles including 25 TWh for autonomous electric vehicles

+5 TWh
of additional consumption of public transport

+4.4 GW
average variation in power demand during winter peak periods

Effect on the electricity mix

+10.7 TWh
of low-carbon electricity production “recovered” for charging vehicles

Economic impacts

39 €/MWh
Average overall cost of producing electricity used for charging

310 €/year
Average charging cost for the consumer

CO$_2$ emissions

-18 MtCO$_2$/year
carbon footprint avoided globally

SCÉNARIO PIANO – “LOW-CARBON MOBILITY”

Principle and general framework

In the *Piano* scenario, public policies and societal changes combine to bring about a major change in travel behaviour.

In this scenario there are a great deal fewer journeys in private vehicles, in favour of soft mobility and public transport, for which the offering is increased. In urban areas, a large proportion of short journeys (less than 6 km) are travelled using soft mobility (bicycle, electric bicycle, on foot, scooter, etc.). The modal share of public transport increases significantly, representing nearly 20% of passenger kilometres in 2035.

This change in the modes of travel is not based on any technological breakthrough and is the result of proactive public policies: limitation of the use of vehicles (especially ICE vehicles) in towns and cities, development of infrastructures for soft mobility (cycle routes), increased public transport offering, easier intermodality between soft mobility and public transport (for example with the introduction of secure cycle parks for bicycles), etc.

For individual travel in light-duty vehicles, e-mobility develops strongly, according to the highest scenario (more than 15 million electric vehicles on the road by 2035).

To improve its environmental benefits, the development of e-mobility is systematically accompanied by technical choices to facilitate integration in the electricity system. This involves access to charging points in the workplace and widespread use of smart charging. These choices enable best use to be made of the low-carbon electricity generation facilities.

The concern to limit the environmental impact of e-mobility results in the use of small batteries and choosing battery manufacturers in France (which enables low-carbon electricity to be used in the energy-intensive manufacturing process) and increasing the recycling rate to levels above those in the current regulations.

PIANO SCENARIO – 2035

Numbers of vehicles

15.6 million “conventional” light-duty electric vehicles
+ 156,000 heavy-duty electric vehicles

22% of which are plug-in hybrid electric vehicles

22.7 million light-duty ICE vehicles
500,000 heavy-duty ICE vehicles

Modal shift to public transport and soft forms of mobility

Modes of use and behaviour

Low capacity batteries
(average: 56 kWh/330 km)

14,000 km travelled each year for
100% electric light-duty vehicles

45% of vehicles have regular access to
a charging point other than in the home

High power of charging points
(80% of 7.4 kW points in the home)

Connection mainly routine
(85% routine and 15% occasional)

80% of charging is smart,
including **20% in V2G**

Environ. framework

Batteries made in France

High battery recycling rate

Results

The design of the *Piano* scenario gives an improved environmental performance: overall use of individual vehicles decreases in relation to today, a great many of the light-duty vehicles on the road are electrified, and this electrification is accompanied by a reduction in the emissions of vehicles across their life cycles.

The electricity consumption of the transport sector is higher in this scenario. The electrification of light-duty vehicles and the modal shift of some ICE mobility to electric public transport contribute to this.

Widespread use of smart charging enables a high degree of security of supply to be achieved. It also provides various economic benefits: the cost of producing the electricity used for charging is controlled. This also results in lower energy bills for consumers, with an average net annual electricity cost (cost, including tax, of the electricity for charging, less any receipts for flexibility services) of just 280 € for users, which is considerably lower for users who take advantage of the possibilities of reversible charging.

From an environmental perspective, this scenario is the most beneficial: the reduction of the carbon footprint of the transport sector is particularly significant. The development of soft mobility for short journeys in urban areas and the shift to public transport lead to a reduction in both the numbers of ICE vehicles and the distances covered, and results in a saving of 7 million tonnes of CO_2 a year. The manufacture of batteries in France alone saves up to 3 million tonnes, and the additional requirements on the recycling rate contribute to close to 1 million tonnes. In total, the carbon footprint of mobility can be reduced by slightly less than 40 million tonnes a year.

PIANO SCENARIO – 2035

Electricity consumption

40 TWh
consumption of
electric vehicles

+5 TWh
of additional consumption
of public transport

-3.3 GW
average variation in power demand during
winter peak periods (due to V2G)

Effect on the electricity mix

14.4 TWh
of low-carbon electricity production “recovered” for charging vehicles

Economic issues

30 €/MWh
Average overall cost of producing
electricity used for charging

280 €/year
Average charging cost for the consumer

CO_2 emissions

-38 $MtCO_2$/year
carbon footprint avoided globally

AN ELECTRICITY SYSTEM CAPABLE OF ACCOMMODATING EV DEVELOPMENT

SUMMARY OF RESULTS FROM A TECHNICAL PERSPECTIVE

E-mobility development represents a new use for electricity. This new study bases its findings on a finely tuned mobility model to provide an accurate view of the potential impacts this technology may have on the electricity system.

According to the different scenarios, the transport sector is expected to reach a consumption level somewhere between 40 and 65 TWh by the year 2035. This includes not only light-duty electric vehicles – private cars and light commercial vehicles – (accounting for around 30 TWh in the intermediate and high scenarios), but also HGVs and buses (less than 5 TWh), autonomous vehicles (25 TWh in the *Alto* scenario) and rail transport (10 to 15 TWh).

The potential impact on peak demand varies widely depending on the extent of smart charging and the general characteristics of each scenario. The average variation in winter peak demand ranges from an increase of 8 GW and 3.6 GW in the *Forte* and *Crescendo* scenarios respectively, to even a reduction of 5.2 GW in the *Opera* scenario.

Several strong conclusions are highlighted:

1) Firstly, they confirm the conclusions drawn in the 2017 RTE long-term adequacy report: that total electricity consumption for private and public transport is estimated to represent less than 10% of total electricity consumption in France by 2035. Which is not a significant proportion by any means: in fact it is less than the total domestic heating consumption; indeed, it is less than the rise in electricity consumption in France between the years 2000 and 2010. The proposed electricity generation fleet defined in the MEP is more than adequate to cover this new use.

2) Collective perceptions tend to associate cars with long journeys – a belief which is reflected in the kinds of questions frequently asked of RTE regarding the electricity system's capacity to "absorb" the heavy holiday traffic periods of July and August in France, or the long public holiday weekends in May. However, this does not, in fact, pose a risk in terms of security of supply. Long-distance journeys account for a small proportion of the total distances travelled each year, and the most demanding episodes are likely to occur at times when the electricity system has a surplus of supply, such as in summer or at weekends. The only situation identified as a period where vigilance is required is the Christmas holidays in a particularly heavy cold snap.

3) Contrary to this popular misconception, it is actually daily mobility patterns which represent the main challenge for the electricity system. In a scenario where charging is uncontrolled (i.e. no smart charging), power demand would be concentrated mainly around the 7 pm to 9 pm mark. Other lower demand peaks are likely to occur at other times of the day, like in the morning on arrival at work or during lunch breaks, but these do not require any particular attention.

4) From a technical perspective, smart charging offers a clear benefit to smoothing these charging demands and avoiding peaks in the evenings. The benefit is even more evident in an electricity system such as that outlined in the MEP (where there are few controllable thermal power plants and a predominance of low-cost generation facilities, such as wind, solar and nuclear, which have no technical or economic basis for load following with significant power ramps). For instance, smart charging would allow consumption to be adapted to quite a considerable degree to variations in solar and wind energy production over both a daily and a weekly time scale.

5) The widespread development of smart charging does not necessarily constitute a *technical prerequisite* for e-mobility integration: with certain exceptions, power demands associated with e-mobility appear to be manageable. The electricity mix described in the MEP should generate significant margins, and only the high variant in the *Forte* scenario would cause a problem in terms of security of supply (if less than 55% of charging is controlled).

6) Smart charging is clearly a no-regret option for the system – certainly as far as ensuring the security of supply at the lowest cost is concerned (even the simplest smart charging solutions are very effective). It generates considerable additional margins (6 GW for simple smart charging and 13 GW for dynamic smart charging with V2G injection compared with "uncontrolled" charging), which not only helps to enhance the system's resilience to cope with random events, but also opens up further avenues for transforming the electricity mix or using it to decarbonise other sectors.

4.1 The French power plant fleet will be more than capable of generating the amount of energy consumed by electric vehicles in all scenarios

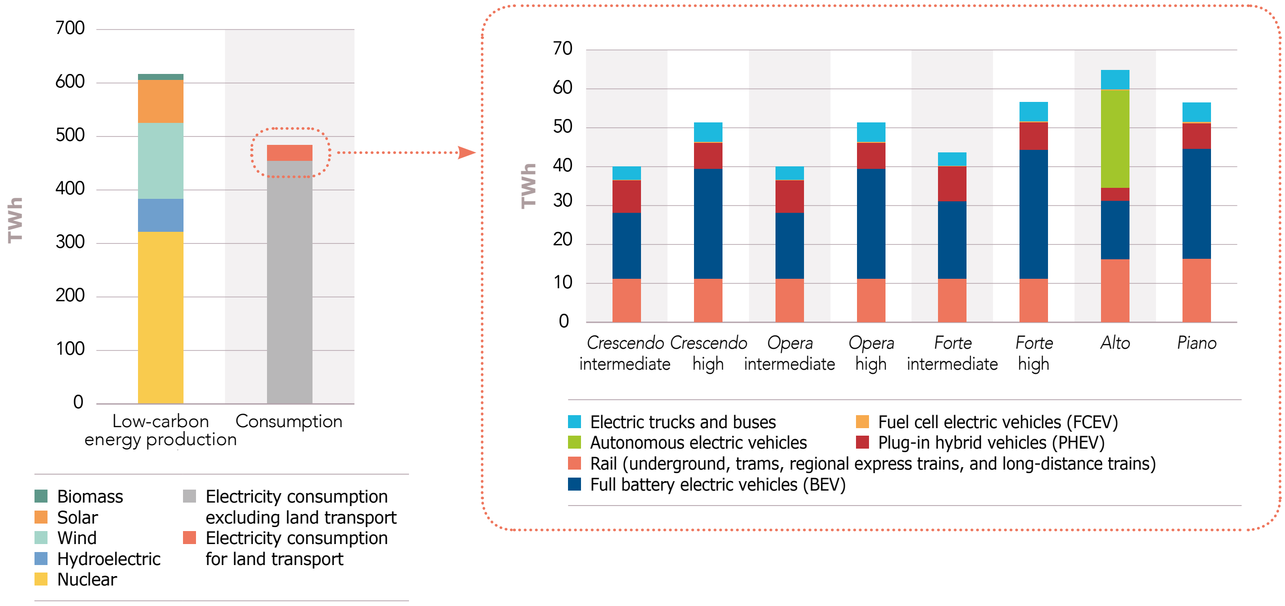
Taking account of all the different types of mobility modelled (light-duty vehicles, HGVs, public transport, etc.), electrification of the transport sector is expected to result in a level of electricity consumption somewhere between 40 and 65 TWh by 2035 (compared with 13 TWh today, the largest proportion of which is attributable to rail transport). Although this corresponds to a significant rise in consumption, it only represents 8% of total electricity consumption on average, and a maximum of 10% in scenarios like *Alto* (due to robo-taxis), *Piano* (due to the growth of the rail sector) and *Forte* (which features a large number of long distance journeys).

This amount is still less than the total consumption for heating in the residential sector (which currently stands at 44 TWh). This volume would be reached within 15 years, which is by no means an unprecedented rate of growth (electricity consumption increased by 55 TWh in France between 2000 and 2010) and should occur against a backdrop of decreasing energy consumption for other uses.

The policies outlined in the MEP should lead to a total possible low-carbon electricity generation (from nuclear and renewables) in France of around 615 TWh by the year 2035. In this case, even in a scenario with high e-mobility development, national electricity consumption would be more than covered by the French electricity production fleet. **The conclusion from the *Ampère* scenario in the 2017 RTE long-term adequacy report is therefore confirmed within the scope of the MEP scenario and a refined representation of mobility.**

Hence, the challenge in terms of e-mobility integration is not one of fleet capacity to meet the energy demands for EV charging, but rather one of matching the power drawn by electric vehicles with the power produced by the electricity fleet at any one moment in time.

Figure 8. Annual electricity consumption and total low-carbon electricity production capacity (nuclear and renewables) in France by 2035, according to government policy on the future of electricity generation



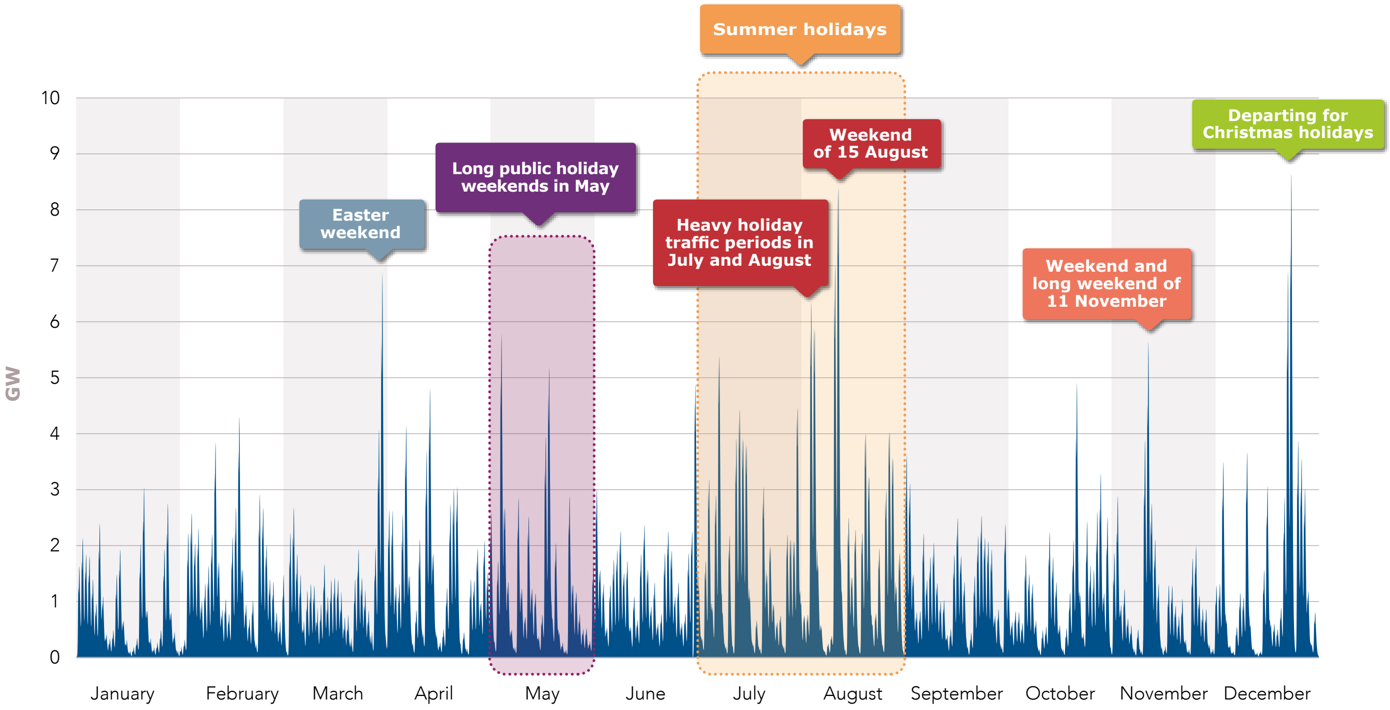
4.2 Power demands during busy holiday periods with excessive traffic present no cause for concern in terms of security of supply

Long-range[4] mobility needs currently account for around 25% of distances travelled. They occur in highly concentrated periods throughout the year, mostly at weekends and particularly over the long public holiday weekends (such as Easter and Pentecost), at the start of the school holidays, and in the main July-August holiday period.

The new analyses conducted by RTE show that, in the most challenging scenarios, power demands for long-range mobility needs may represent more than 8 GW during the busiest travel periods (typically the Saturday of the 15 August weekend and at the start of the Christmas holidays). Such high power demands only exist in scenarios where significant advances have been made in long-range e-mobility – which is not yet the case and should not be the priority for e-mobility, at least not in the next few years – and only assuming that adequate on-road charging infrastructure exists to cope with these mobility peaks (without any certainty on the economic viability of some charging stations that would seldom be used throughout the rest of the year).

Although these power demands are high, they do not present any cause for concern in terms of security of supply. In fact, they should essentially

Figure 9. Power drawn for long-range mobility needs in the *Forte* high scenario (sum total of power drawn en route and power drawn at destination)



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[4] Journeys over 80 km from home as the crow flies

be concentrated over periods when the electricity system already has considerable margins, such as in the summer months and at weekends.

The primary issue highlighted by the study is not actually the main summer holiday period, but rather the Friday the schools finish for Christmas, when all three regional holiday zones in France are "synchronised". The power demands for long-range mobility needs could exceed 8 GW and could raise concerns for the electricity system if they were to coincide with a cold snap.

However, in these very specific circumstances, remedial measures already exist to ensure the security of supply, by controlling electricity consumption for different uses during peak load times.

During peak travel periods, only 30 to 40% (depending on the assumed vehicle range) of energy used for long-range mobility would actually be drawn *en route* at on-road charging stations. The rest corresponds to charging that can take place either before departure or on arrival at the destination: this charging can be controlled and planned to take place at times when the electricity system has greater margins of supply (overnight the night before a journey, for example).

The geographical location of power demands for long-range mobility could, however, create a need for reinforcement of the transmission and distribution networks at a local level.

4.3 The challenge for the electricity system lies essentially in meeting daily mobility charging needs

The main challenge for the electricity system therefore is to satisfy the charging demand for local mobility needs. This equates to around 75% of distances travelled by existing vehicles and the transition to electric vehicles is likely to focus on this kind of mobility.

The power demand profiles will depend largely on the shape mobility takes in the future. **The situation facing the electricity system will depend firstly on the ability to charge vehicles during the day, and secondly on the distribution of e-mobility development within the different population categories (workers[5]/non-workers, urban/rural residents, income level, business users and company vehicle fleets, etc.).**

In contrast, battery capacity, charging frequency, proportion of hybrid vehicles, or even the power rating of charging stations, have less of an impact on the power demand profile.

In all the configurations studied, the power demands without smart charging (in "uncontrolled charging" variants) are mainly concentrated around the two-hour period from 7 to 9 pm. This corresponds to the time during which commuters return home from work. Two other, less pronounced peaks are also likely to occur: (i) in the morning, corresponding to charging on arrival at the workplace, and (ii) in the middle of the day, corresponding to the time when non-workers return home or commuters arrive home for lunch.

Without smart charging, these power demands are unfavourable for the electricity system. Firstly, they are concentrated at times of the day when the electricity system has the lowest capacity margins (peak electricity demand in the evening when there is no photovoltaic production). And secondly, they are temperature-sensitive, due to the energy required for vehicle heating systems. In a high e-mobility development scenario, EV consumption

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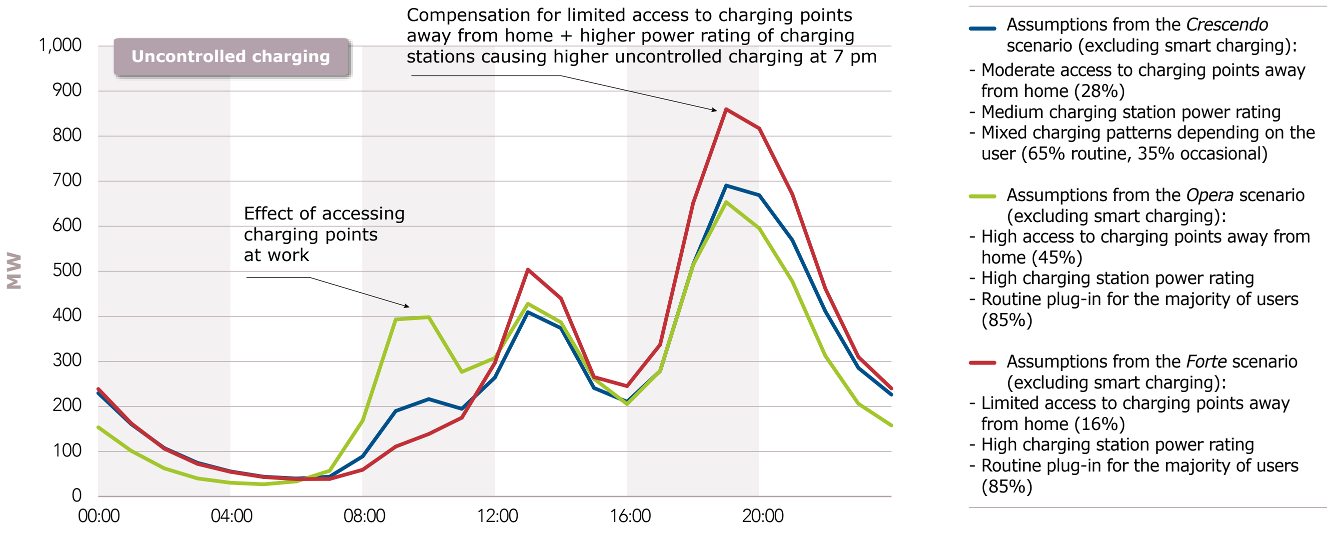
[5] The term "worker" used in this report designates those members of the population who are in paid employment or full time education.

Figure 10. Typical charging curve for an average weekday for one million electric vehicles in the different scenarios considered (in variants without smart charging)



Compensation for limited access to charging points away from home + higher power rating of charging stations causing higher uncontrolled charging at 7 pm

Effect of accessing charging points at work

at 7 pm would be 3 GW higher on a bitterly cold day (with temperatures comparable to those experienced on 8 February 2012 – France's highest electricity consumption on record), compared with an average winter day.

This illustrates how daily journeys clearly present the biggest challenge facing the electricity system in terms of e-mobility development. Smart charging therefore represents a very interesting opportunity.

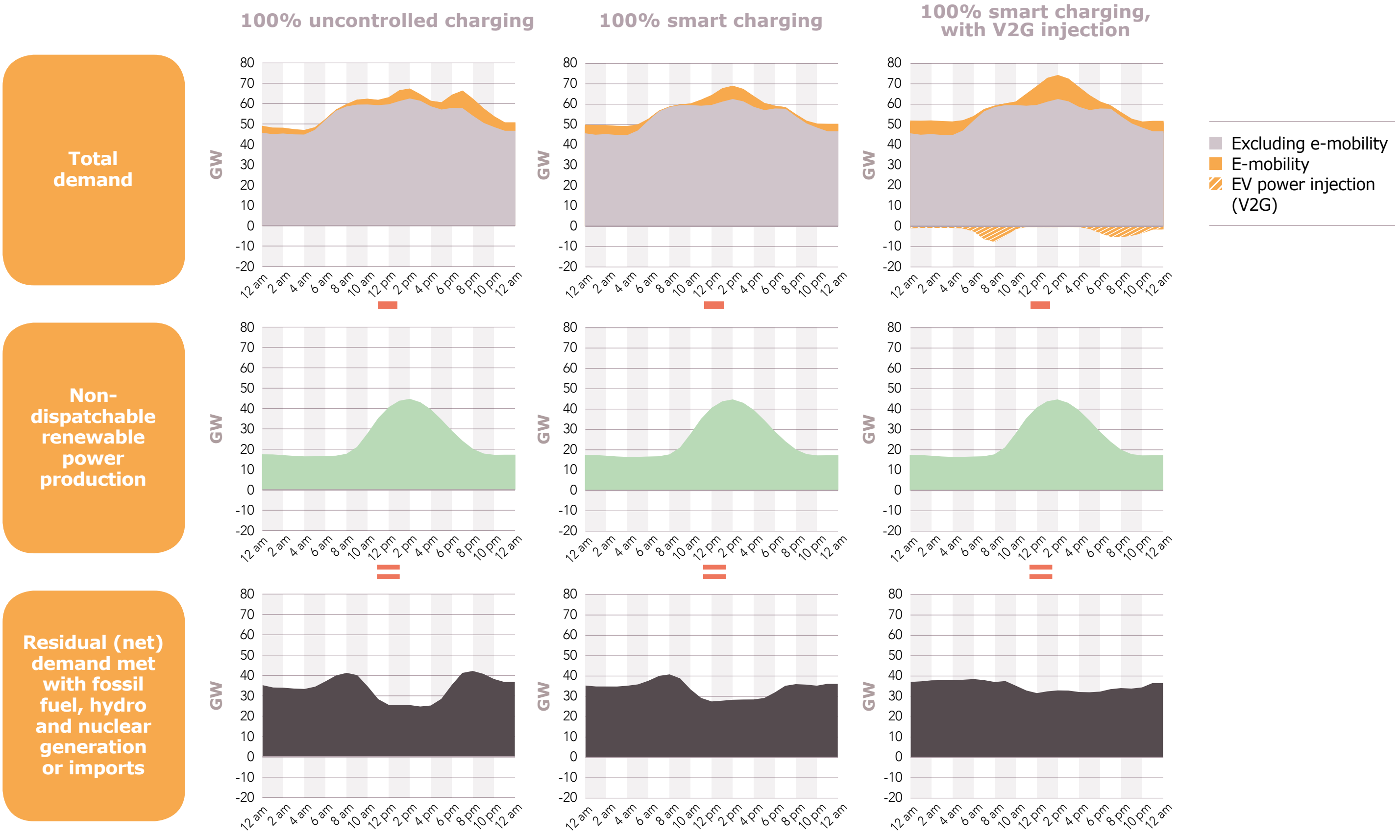
4.4 Smart charging can be used to reshape the load curve to follow renewable energy production

In France, with the electricity mix composed mainly of renewables and nuclear outlined in the MEP, all the flexibility solutions allowing electricity consumption to be shifted to high-availability periods for nuclear and renewable energies will be relevant for balancing the system and for leveraging low-carbon electricity generation.

In particular, EV smart charging offers the potential for substantially modulating the national consumption curve and adapting it to renewable energy production, whilst continuing to meet the mobility needs of EV users. **This significantly reduces daily and weekly variations in residual demand (i.e. the total national electricity consumption minus non-dispatchable renewable power production) which can be met by dispatchable generation (nuclear, fossil fuel and hydropower plants).**

Use of the generation fleet can therefore be optimised, by considerably reducing the periods when renewable energy production needs to be curtailed due to an absence of outlets and by limiting variations in nuclear energy production. This optimisation lowers the demand for power generated by fossil fuel plants, and even reduces the need for back-up capacity to ensure security of supply.

Figure 11. Total electricity demand in France and residual demand (total demand minus non-dispatchable renewable energy production) in different EV smart charging configurations for an average weekday (*Crescendo* intermediate 2035 scenario)



4.5 The widespread development of smart charging is not actually a prerequisite for e-mobility integration…

One of the recurring questions in the public debate about electric vehicle development concerns the capacity of the electricity system to meet the power demands associated with charging EV batteries. This issue relates in the first instance to the evening peaks in winter (around 7 pm), which are already characterised by high power demands, and which are likely to see a high future EV charging demand concentrated around the same period as commuters arrive back home after work.

The *Forte* scenario studies a deliberately challenging configuration in terms of security of supply, in which users will have limited access to charging stations away from home and where the majority of EV charging is uncontrolled.

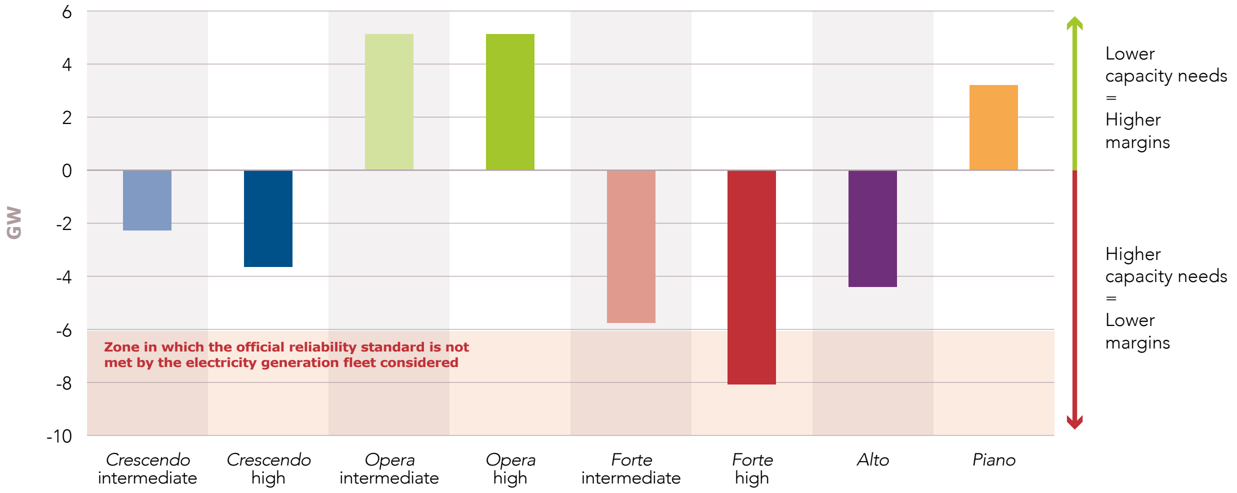
However, even with these modalities of e-mobility development, and assuming a development trajectory consistent with the PFA's *Green Constraint* scenario – of 11.7 million electric vehicles by 2035 – the security of electricity supply criterion[6] will still be met.

The reason for this is two-fold:

(i) Staggered departure and arrival times and the diversity of vehicle use profiles (workers who may or may not return home at lunch time, non-workers, etc.) mean that charging patterns are inherently varied, which helps to limit the peaks in consumption associated with EV charging: in much the same way as people today do not all turn their ovens or electric hobs on at the same time, even if EV charging was not controlled, there would still be a natural spread of charging over time.

(ii) The projected electricity generation mix detailed in the MEP offers comfortable capacity

Figure 12. Effect of e-mobility development on capacity margins according to the different scenarios (compared with a scenario of no e-mobility development by 2035)



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[6] The reliability standard defined by public authorities does not correspond to an absence of shortfalls, but to a level of loss of load limited to an expected value of less than three hours a year. The analyses presented in the 2018 RTE long-term adequacy report and in the additional analysis report submitted to the French government in April 2019 give more detailed information on the reliability standard

margins in relation to the reliability standard by 2035, due in the most part to maintaining a solid nuclear base, developing renewable energy sources and increasing interconnection capacity.

Only the high variant in the *Forte* scenario, with 15.6 million electric vehicles by 2035 and limited development of smart charging, is likely to exhibit a slight deficit in capacity compared with the reliability standard. Nevertheless, this situation can be rectified by limited additional participation in simple smart charging solutions (to achieve 55% smart charging instead of 40%).

Hence, if government objectives for the future electricity generation fleet are met, security of supply could be assured at the current criterion level, without the need for large-scale development of EV smart charging. **A radical change in mobility patterns or the widespread uptake of smart charging therefore cannot be considered as technical prerequisites for extensive electrification of the automotive industry.**

This conclusion is conditional upon the effective implementation of the MEP scenario (particularly the trajectories for renewables and energy efficiency) and a minimum level of smart charging.

4.6 … yet smart charging is a no-regret option for enhancing the resilience of the electricity system

If development of smart charging on a mass scale does not appear to be a prerequisite for e mobility integration, it does nevertheless offer a no-regret option for the electricity system. Even some very simple and inexpensive measures – such as setting up "static" time-of-use tariff controls based on the day of the week – can help generate high capacity margins.

In the intermediate variant of the *Crescendo* scenario, for instance, the difference between simple time-of-use charging for all vehicles and no smart charging at all is an estimated 6 GW at peak times in 2035. With the theoretical assumption of widespread development in vehicle-to-grid technology, this would deliver far greater additional margins (around 7 GW more compared with simple time-of-use charging) in 2035.

In a scenario like *Opera*, where smart charging is highly developed (80% in total, with 20% being vehicle-to-grid) this even leads to a situation where e-mobility development actually reduces peak load.

These levels of smart charging may seem high, yet they are attainable: it is estimated that around 80% of water heater charging today is controlled, without causing any inconvenience to the user.

Even without concerns for security of supply, the technical and economic benefit of smart charging is high:

- **It bolsters grid resilience in the face of structural uncertainties (such as the failure to meet MEP projections on renewable energy sources, or lower availability of the nuclear fleet due to unforeseen events) and circumstantial uncertainties (such as delays in setting up new facilities or interconnections, unexpected unavailability of certain generators, or cold spells, for example).**
- **It extends the range of choices available to society in terms of adapting the electricity mix with an unchanged climate policy, or stepping up the transition of energy use to electricity in an unchanged mix.**

Both these outcomes could have potentially differing impacts over the long and medium term.

Long term (2030-2035)

The MEP scenario offers substantial capacity margins through the major development of renewable energy sources (which more than offsets the reduction in nuclear capacity) and interconnections. Nevertheless, several factors – including difficulties in following the trajectories for renewable energies, delays in creating new cross-border interconnections, accelerated closure of thermal production facilities in neighbouring countries, and lower availability of the nuclear fleet – could come into play in practice, which would lead to a less favourable situation. In this case, the benefit of smart charging would be greater, all things being equal, due to the lower capacity margins.

The additional margins generated by smart charging could also serve to accelerate decarbonisation of other uses by facilitating their transition to electricity. For example, the potential 6 GW margin that could be generated by widespread implementation of the first level of smart charging in the *Crescendo* scenario would provide the possibility of electrifying the heating systems of around 4 million households in France (using a mix of heat pumps and Joule heating), and cut CO_2 emissions by around 3 million tonnes a year.

Medium term (2020-2025)

Security of supply over the medium term period 2020-2025 may appear more uncertain due to the closure of a certain number of power plants (including the Fessenheim nuclear power plant and the last coal-fired power stations) whilst waiting for other facilities (like the Flamanville EPR, offshore wind farms and interconnections) to come on-line. This situation was the subject of detailed analyses in the 2018 RTE long-term adequacy report and the additional analyses submitted to the French government in April 2019.

E-mobility development will be limited over the 2022-2023 time horizon, however the electric vehicles already in use could be able to make a valuable contribution to the security of electricity supply. Universal smart charging of one million electric vehicles (which corresponds to the target laid down in the "strategic contract" for the French automotive industry) will generate an additional 200 MW capacity margin. The widespread development of vehicle-to-grid technology – assuming it is accessible[7] – could theoretically add a further 2 GW margin.

However, considering this technology is still in its infancy in terms of commercial roll out, this does not appear to be realistic within such a short time frame.

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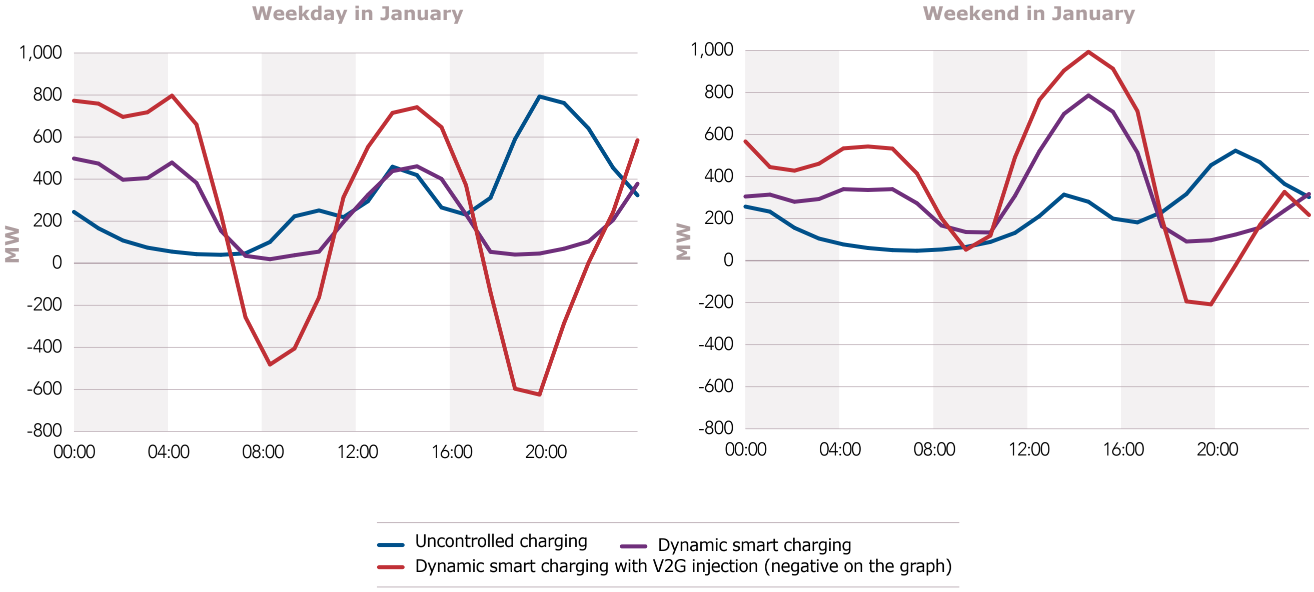
[7] The widespread development of vehicle-to-grid technology poses its own challenges: these include technical challenges (equipment compatibility, especially for charging stations; operation of the smart charging system; impact on battery life), economic challenges (cost of converters; expected returns for users and aggregators) and challenges associated with user acceptance (perceived impact on mobility requirements; the need for more active user participation; and perceived risk of shortened battery life)

Figure 13. Charging curves for one million electric vehicles in the *Crescendo* intermediate scenario, as a function of the type of smart charging



ECONOMIC ANALYSIS FROM THE PERSPECTIVE OF THE ELECTRICITY SYSTEM : A HIGH DEGREE OF CONSISTENCY BETWEEN THE ELECTRIFICATION OF TRANSPORT AND THE ENERGY ROADMAP, AND LEVERS FOR REDUCING COSTS

SUMMARY OF THE ECONOMIC RESULTS

In the MEP scenario, France has a low-carbon production capacity that grows significantly by 2035 compared to today (around 615 TWh – 320 from nuclear and 295 from renewable sources, as against 505 TWh today – 395 from nuclear and 110 from renewable sources). **The economic analyses show a high degree of economic consistency between this type of change in the electricity mix and the development of e-mobility.**

First, the report provides an exhaustive assessment of the cost of generating electricity for the development of e-mobility.

This costing can be put into perspective:

1) In relation to the overall cost of mobility: the generation of electricity for charging electric vehicles (the equivalent of fuel) is a very small part of the total cost, and a cost item that is considerably lower than the supply of petroleum products.

2) In relation to the overall cost of the electricity mix: the generation of electricity for charging electric vehicles only accounts for around 5% of the overall cost of electricity generation by 2035, and is achieved with no additional cost in relation to the existing assessments, which already include this consumption.

3) For an equivalent level of transport electrification, this cost item varies according to the scenario, and depends first and foremost on the factors studied in this report, such as the level of smart charging.

The report includes a detailed analysis (by means of the five scenarios studied) of the opportunities for optimising the cost of generating the electricity required for electric vehicles. This cost may vary as much as 100%, depending on the level of smart charging:

4) The widespread deployment of even simple smart charging appears to be a "no regret" option, leading to collective savings of around a billion euros a year.

5) Sophisticated smart charging between the system and vehicles leads to significant additional savings, but these are more variable depending on the scenario.

6) The contribution of electric vehicles to frequency regulation should theoretically enable optimisation to be taken even further, but it is expected to remain a niche market and does not make sense on a large scale.

7) The profitability of second life batteries as flexible storage is uncertain, depending on their cost.

This shows that development of e-mobility coordinated with variations in the power generation fleet is a guarantee of optimisation and consistency of the overall scenario. The associated savings can be seen at various levels. Effective coordination of the deployment of e-mobility and the changes to the mix result in:

8) For public finances: a reduction in needs for government support for the development of renewable energy sources (with unchanged objectives).

9) For producers: more stable electricity prices and fewer situations where there are low or negative prices.

10) For consumers: charging at times when the electricity costs are lowest, with an annual saving (with simple smart charging) of around 60 to 170 € *(Chapter 6).*

5.1 The generation of electricity for charging electric vehicles only represents a very small part of the overall cost of mobility…

The economic assessment of the changes needed to decarbonise the transport sector is the subject of an increasing number of discussions and studies – and a recent publication from OPECST (Parliamentary Office for Scientific and Technological Assessment) quotes the figure of 500 billion euros over 20 years to achieve the objective of ending the sale of ICE vehicles by 2040.

The assessment of the costs associated with a change scenario poses significant methodological questions. It requires a distinction to be made between:

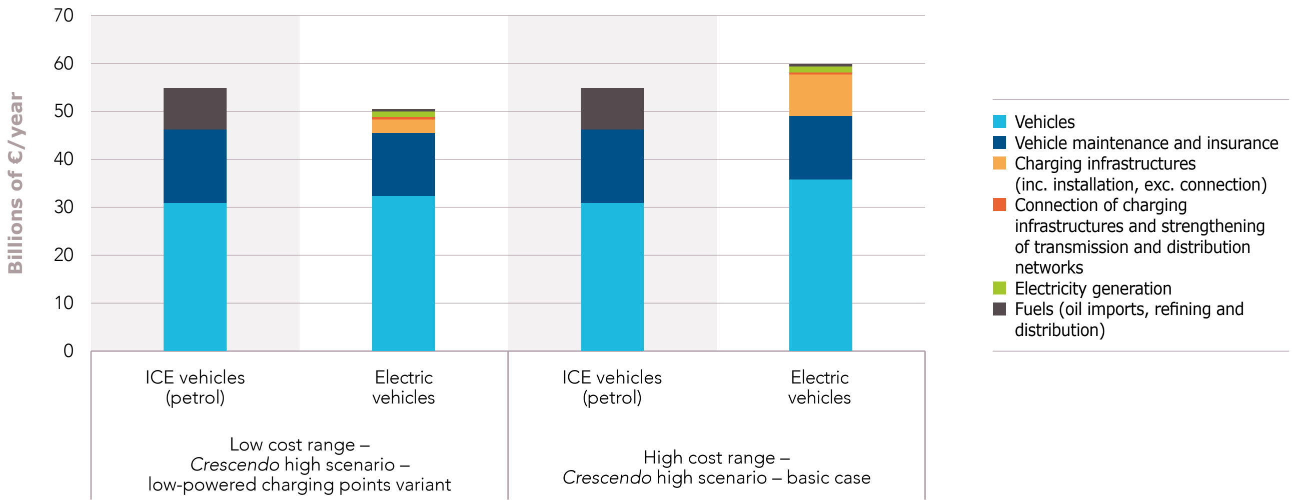
- The overall cost of the vehicles themselves (initial cost, cost of maintenance and insurance)
- The cost of the charging infrastructures
- For ICE and plug-in hybrid electric vehicles: the costs of fuel supplies (oil, refining and distribution)
- For electric vehicles: the cost of adapting the electricity system, integrating the grids (connecting the charging infrastructures and adapting the grids upstream) and electricity generation

The RTE's new study gives precise estimates of a specific cost item associated with this change: the annual electricity generation cost.

This cost item represents part of the cost of adapting the electricity system, which is itself only a fraction of the overall cost of a mobility scenario.

The annual electricity generation cost is estimated to be 1 to 2 billion euros by 2035 *(see Sections 5.2 and 5.3)* for a volume of 15.6 million light-duty electric vehicles and 156,000 electric buses and trucks: **electricity generation is therefore only a very small cost item in the overall cost of transport, much lower than that of fuels if this mobility were based on ICE vehicles.** This low energy cost, in comparison with that associated with fuel imports for ICE vehicles, is likely to facilitate the transition to electric vehicles.

Figure 14. Total annualised costs for 15.6 million vehicles by 2035 by engine type



For comparison, France's oil import trade balance in 2016 showed a deficit of 24 billion euros. **The crude oil imports which would be avoided by 2035 by 15.6 million electric vehicles represent more than 5 billion euros a year (price assumptions taken from the IEA's New Policies scenario), i.e. around 3 to 8 times (depending on the e-mobility parameters) the cost of generating electricity for vehicle charging.**

This is an important factor to take into account in the economic comparison of the various options for changes in the forms of mobility.

At the moment, the overall cost (for society) of electric vehicles is greater than that of ICE vehicles. This is mainly due to two cost items: the production of the vehicles themselves (cost primarily related to the batteries) and the cost of the charging infrastructures. The competitiveness of electricity in relation to oil as a fuel does not make up for this difference: electric vehicles are therefore given government subsidies to make them more attractive to consumers.

The differences between the cost of producing an ICE vehicle and an electric vehicle should gradually lessen in the future, with the expected decrease in the costs of batteries and of producing electric vehicles.

According to the assumptions on the changes in these costs, the transition to e-mobility could represent no additional cost for society in the long term (favourable assumptions), or only represent a limited additional cost (10% additional cost with less favourable assumptions). By that time, when the overall costs of both technologies will be similar, assessment of the "electricity generation" aspect makes perfect sense – especially in the context of a decrease in government subsidies.

5.2 … and a small part of the overall costs of electricity generation by 2035

The costing of the "electricity generation" aspect is part of an approach introduced in 2017, to ensure that the analyses carried out by RTE on the prospective scenarios contain systematic economic costings.

These costings incorporate strategies for scalability, are based on government cost references and/or references from a public consultation, and are given with several variants in order to rank the parameters and understand the relevant orders of magnitude. This method was presented in the reports on smart grids (July 2017) and described in greater detail in the 2017 RTE long-term adequacy report (which gives a costing of the "generation – supply – import/export" aspect of the scenarios). The costings have been extended to cover the grid aspects in the context of RTE's latest 10-year electricity grid development plan (SDDR 2019).

The e-mobility report provides precise estimates of the cost item associated with generating electricity for powering the vehicles and public transport projected in the various scenarios. The assessment of the generation cost includes the initial investment expenditure and the fixed and variable operating costs, and is not therefore restricted to the variable operating costs of the power plants. **Using this method, the annual production cost associated with the development of e-mobility (light-duty electric vehicles, electric buses and trucks and modal shift to electric rail transport) is between 0.6 and 2 billion euros.**

This production cost is within around 5% of a scenario such as *Ampère* and *Volt* (based on estimates in the 2017 RTE long-term adequacy report) or the MEP (based on the draft MEP). It is therefore a reduced budget, once it is compared to the overall cost of an electricity mix.

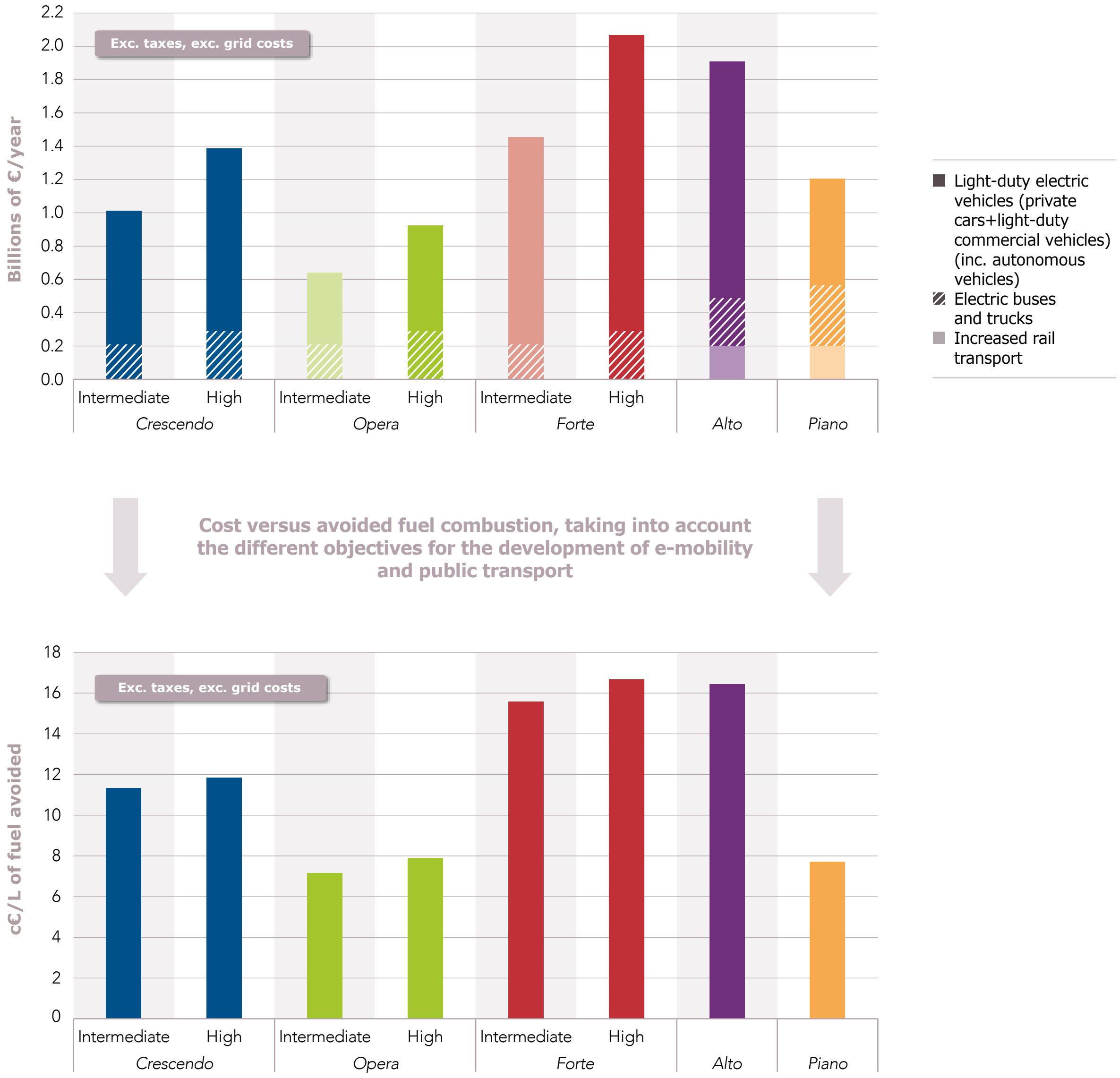
The development of e-mobility can be based on technologies (existing nuclear, wind or solar) which are competitive or close to being so, in comparison with new fossil fuel thermal facilities.

The cost is already largely integrated in the existing costings of the MEP scenarios or similar scenarios. The generation facilities described in the draft MEP, associated with the European mix, are sufficient to power all the mobility scenarios considered in this study, and the electricity consumption of a large number of vehicles is already incorporated in the consumption options in the MEP and the National Low Carbon Strategy. **As the consumption of electric vehicles is incorporated in this type of scenario, there is no additional cost in relation to the assessments already published.**

5.3 The cost of electricity generation varies according to the scenario: it can be optimised using various levers

Although the "electricity generation" cost item only represents a small part of the overall cost, its optimisation can be sought by activating the various levers described in the scenarios. The various configurations for the development of e-mobility (share of plug-in hybrid electric vehicles, widespread use of smart charging, access to charging points other than in the home, development

Figure 15. Cost of generating electricity for e-mobility



of autonomous vehicles, size of the modal shift, etc.) lead to very different results, depending on the metrics used.

The generation cost can vary by a factor of more than two for scenarios that are comparable in terms of objectives for reducing the share of ICE mobility.

The scenarios thus have highly contrasting integration costs, which may vary as much as 100%, for scenarios that are comparable in terms of objectives for reducing the share of ICE mobility. The main effect is due to the development of smart charging: it must be included as the main parameter for controlling the "electricity generation" cost item in the development of e-mobility.

In comparison with a litre of fuel avoided, the electricity generation cost appears to be approximately five to ten times lower than the cost of importing and refining petroleum products (approximately 60 c€/L today), excluding those components associated with taxes and the grid and distribution costs. Adding these in, the annual electricity cost for consumers appears to be three to five times lower than the annual petrol cost (see Chapter 6). This cost is highly dependent on the conditions of the development of e-mobility.

5.4 Smart charging: the widespread deployment of simple smart charging devices leads to significant savings for the electricity system, which may reach 1 billion euros a year

Smart charging of electric vehicles enables charging to be carried out during periods when the generating costs are lowest. This can in particular be the case during periods of very high wind generation (which can occur randomly during the week), or very high solar generation (in the middle of the day).

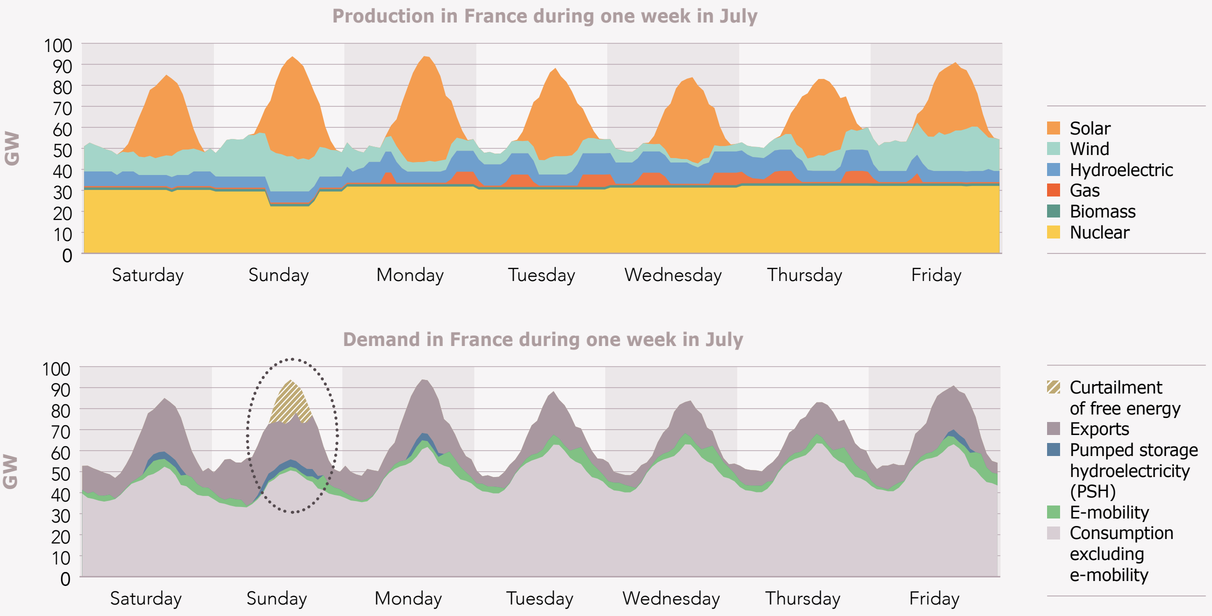
Today, there can be episodes of low-cost generation "gluts", mainly at weekends. These result in a major downward adjustment of nuclear production (with for example a 10 GW reduction in the power produced, as during the weekend of 17 March 2019) in France, or negative prices in Germany (for example, -80 €/MWh on 21 April 2019).

With the growth of renewable energies, this type of situation is expected to occur more frequently in the future. The scenarios in the 2017 RTE long-term adequacy report are thus all characterised – each with a different intensity – by an increase in the frequency of this type of situation, and by the increasing use of "curtailment" of non-dispatchable renewable production as a solution to deal with this.

Curtailment consists of an agreed or imposed reduction of renewable generation. It is a logical method for managing glut situations, but using it too often would be sub-optimal for the community, as it would lead to "free" generation not being utilised. With widespread smart control of consumption where possible (controlling water heaters, charging vehicles), most of these situations can be avoided. This enables the operation of the electricity system to be optimised by maximising the use of low variable cost generation capacities.

Figure 16. Electricity production and consumption in France during one week of high availability of renewable energy sources, in the *Crescendo* intermediate scenario with 100% uncontrolled charging or 100% smart charging

100% UNCONTROLLED CHARGING



100% SMART CHARGING

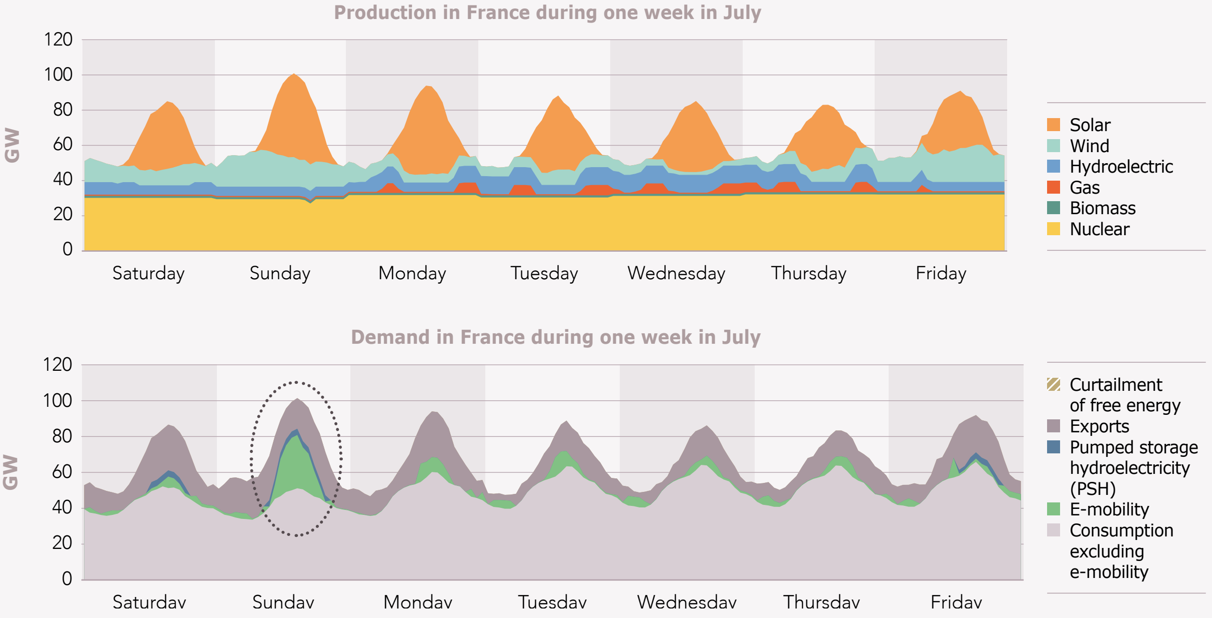
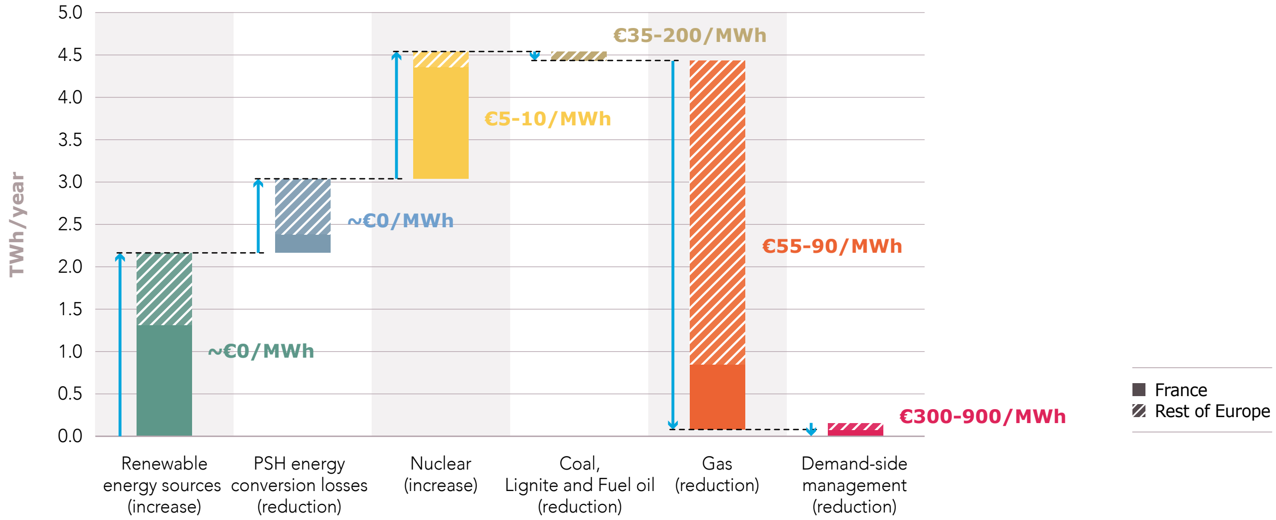


Figure 17. Effect of smart charging of electric vehicles on the energy balances by 2035 as against a configuration without smart charging (difference between the 100% time-of-use charging variant and the 100% uncontrolled charging variant in the *Crescendo* high scenario)



From a technical perspective, the benefits result in:

- In the short term, less curtailment of renewable energy production and less adjustment of nuclear production due to a lack of outlets
- In the long term, lower capacity requirements (avoiding the development or maintenance of peak capacities)

The associated savings are significant. With the development of 15.6 million electric vehicles, **smart charging can lead to an annual saving of around €0.9 billion for France as a whole. A major finding of the work carried out is that very simple forms of smart charging are sufficient to achieve this saving.** They can be based simply on connecting vehicles at weekends rather than during the week for users who can plan their charging over several days, or on control by a static time-of-use signal, etc. The current deployment of smart meters provides all the functions needed to implement this level of smart charging, and thus achieve most of the associated savings.

A significant additional saving (of around €0.3 billion a year) is possible using more sophisticated smart charging devices, consisting of adapting the smart charging each week, or even each day, to the actual operating conditions of the production mix. More complex technical solutions are required for this: they may involve some costs and require greater user involvement (for example, indicating their mobility habits on a smartphone app).

Smart charging may also have important benefits at a local level. It will be designed to be part of the "local loop" economy, incorporating the various types of self-consumption, the multiplicity of behaviour types (not everyone charges their vehicle at the same time) to limit the subscribed capacity, and local optimisation of the grid by the distributors, incorporating work carried out by Enedis and local distribution companies (LDC). These aspects are not covered in this report.

Effective coordination between national and local control is important, and forms the subject of work being carried out by RTE and Enedis.

5.5 Vehicle-to-grid technology: additional savings, for implementation on some vehicles

With reversible charging *(vehicle-to-grid)* the electricity system can be optimised still further. Here the batteries in electric vehicles are used to store energy during periods when there is plentiful low-cost generation, and feed it back into the electricity system when generation has to be provided by more costly power plants.

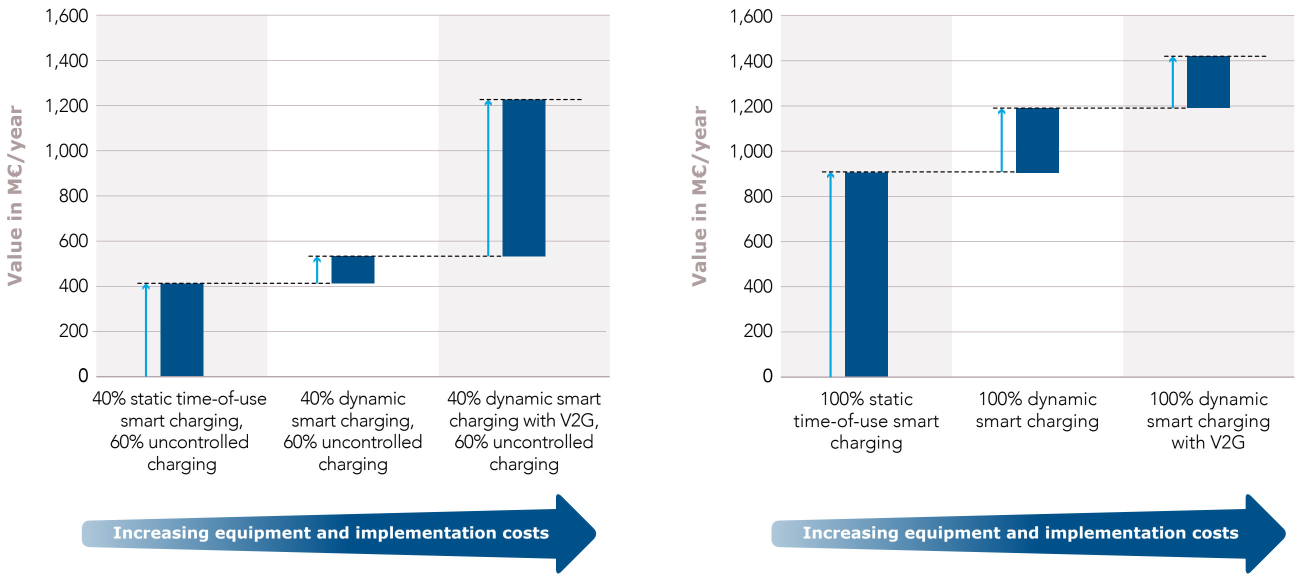
Vehicle-to-grid technology therefore increases low-cost low-carbon production (for example, around 3 to 4 TWh a year in the *Crescendo* scenario). **The economic effect, in comparison with a situation in which all vehicles would be subject to dynamic smart charging but only unidirectionally, has been estimated at 0.2 billion € a year.**

However, the effect of reversible charging can be considerably greater in a situation where only some of the charging would be controlled. **The economic benefit of vehicle-to-grid in comparison with simple smart charging can then be revalued at around 0.6 billion € a year (if the charging of only between 20% and 50% of vehicles is controlled).**

These benefits must be compared with the costs: the development of V2G requires specific equipment (in the vehicle or in the charging point) to convert the energy from the battery (produced as DC power) into AC power.

Based on this information, the potential welfare gains of vehicle-to-grid technology appear to be largely dependent on (1) the prior deployment of simple forms of charging, and (2) the additional costs it involves. Based on the shared assumptions on the future costs of reversible charging, **the economic trade-off between the benefit to the electricity system according to the number of vehicles equipped for V2G and the cost of deployment leads to a significant development (several million vehicles) making economic sense, but not one across the board.**

Figure 18. Value associated with smart charging in the *Crescendo* high scenario
(variants on the development of smart charging, compared with a situation with no smart charging)



Reversible charging may lead to premature wear of batteries due to the increased number of storage-withdrawal cycles carried out.

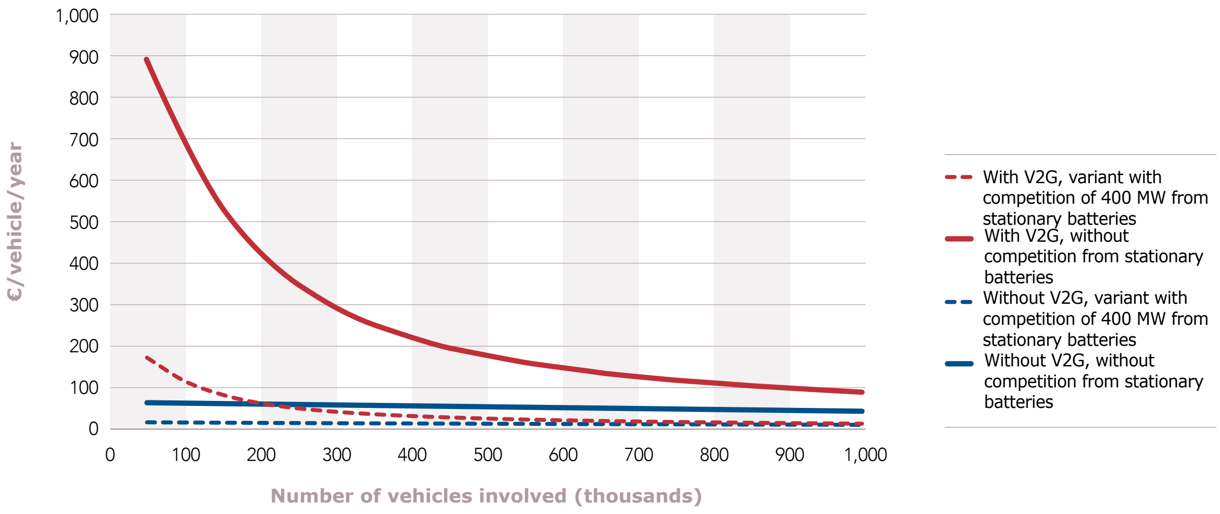
However, analyses carried out by RTE lead to qualification of this point: although the number of storage-withdrawal cycles carried out is potentially high (up to almost 100 equivalent full cycles when only some vehicles offer this flexibility), they are generally shallow: over 85% of all cycles use less than 30% of the capacity of the battery. Besides, a large part of the value can be accessed with a limited number of cycles. It is therefore possible to consider simply restricting the number of cycles with no significant loss of the potential value.

5.6 Participation in frequency regulation: useful within a niche market

Transmission system operators use "automatic reserves" referred to as "ancillary services" to balance the electricity system in as near as possible to real time and to maintain the frequency. These services are technically demanding, and involve reaction times of a few seconds (frequency containment reserve or FCR) or a few minutes (automatic frequency restoration reserve or aFRR).

The electrochemical batteries in electric vehicles are fully capable of meeting the specific requirements for providing these types of service. The market mechanisms, now open to demand-side response and storage methods, thus enable batteries to compete with generating plants in this segment.

Figure 19. Value associated with the participation of electric vehicles in frequency ancillary services (benefits generated for society divided by the number of vehicles involved) – *Crescendo* intermediate scenario



To date, ancillary services constitute the most profitable services on the electricity markets, as they involve significant additional production costs. Some of these ancillary services are currently provided by the nuclear fleet, which has to decrease its production level to keep a certain capacity margin to adjust upwards. Therefore, several studies anticipate that there will be a significant economic role for the first electric vehicles entering the market (e.g. assuming no impact of EV participation on prices).

The analyses confirm that, for a small number of vehicles, considerable value can be created per vehicle for the electricity system: around 900 € a year in current conditions, if the service is provided bidirectionally.

However, **the market size is limited as the requirements for frequency regulation services are very low** (less than 2% of the maximum power produced by all generation facilities). Thus, **the contribution from a few hundred thousand vehicles (between 300,000 and 500,000 vehicles according to the scenarios studied) would supply all the ancillary services required. The benefit for the electricity system would be less than 100 M€ a year by 2035, with the MEP mix being considered.** The benefit would depend a great deal on the development of competing flexibility solutions (storage batteries, demand-side response on other uses, etc.) on this niche market.

As the revenues per EV decrease quickly according to the number of vehicles involved, the participation of a large number of vehicles in real-time frequency balancing, while ensuring sufficient profits for the users, seems unlikely.

5.7 The use of second life batteries as a storage solution: uncertain economic prospects

The predicated growth in the number of electric vehicles must include preparation for the large-scale reprocessing of used batteries, once their performance levels are no longer compatible with being used for mobility.

Two main options are currently envisaged for dealing with this issue.

- The first consists of recycling the materials and reusing them, in particular for manufacturing new cells for the batteries of future electric vehicles.
- The second solution, envisaged by some vehicle manufacturers, consists of reconditioning used batteries from electric vehicles for storage use (less demanding in terms of energy density). In this scenario, the batteries are installed and connected to the grid, where they store energy and return it to the grid in the same way as a pumped storage hydroelectricity (PSH) power plant. This solution involves significant reconditioning costs, but the reconditioned batteries will still be less expensive that new batteries (with the same storage capacity).

With the levels of development of e-mobility considered in the various scenarios, significant volumes of end-of-life batteries would have to be dealt with by 2035-2045. The residual energy storage capacities of the cells could represent significant volumes, although not enough is known about their residual lifetime at the moment. By that time, and based on current scenarios (MEP, or scenarios such as *Ampère* or *Volt)*, the electricity system's requirements for flexibility do not seem large enough to avoid competition between the different technologies that can provide flexibility services.

Once they have been converted for storage, second life batteries would be in competition with the flexibility services provided by controlled EV charging ("first life" batteries). Current cost projections on second life batteries are not much less than the

Figure 20. Stock of second life batteries which could potentially be used in the high scenario for the development of e-mobility at different periods of time (in the absence of reprocessing and recycling, with an assumed 15-year first life period for the batteries and an average residual capacity of 65% over five years' second life use)

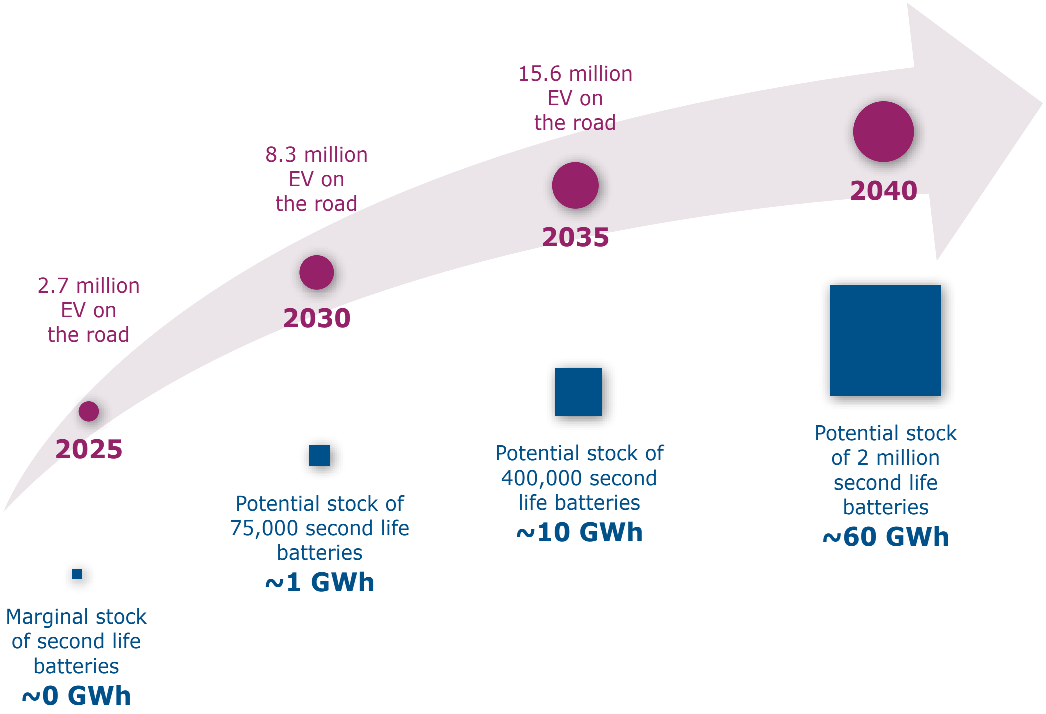
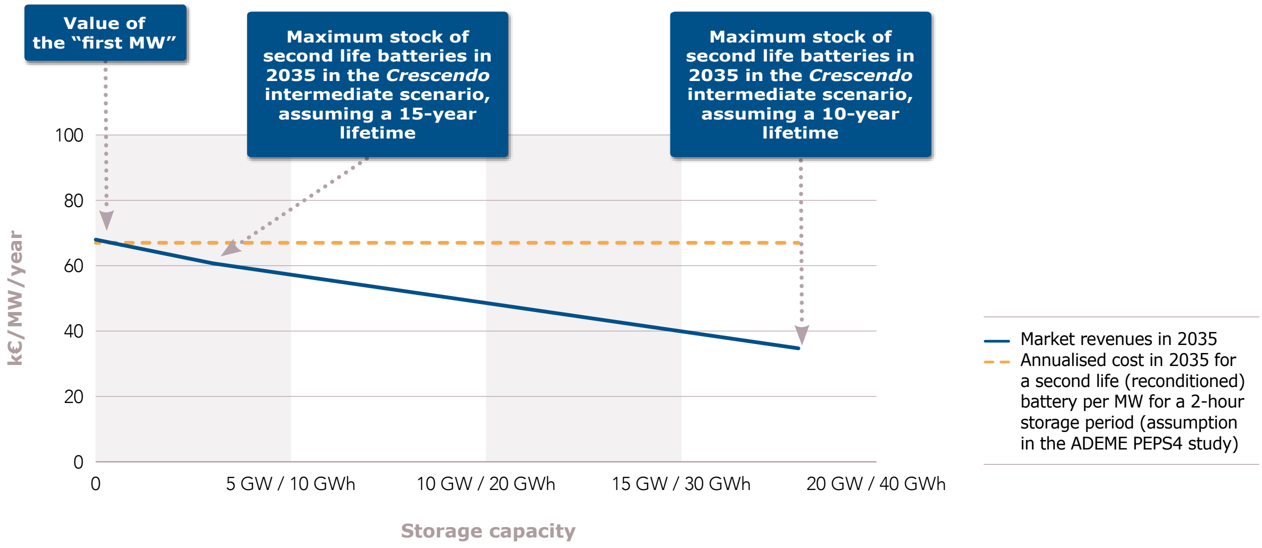


Figure 21. Annualised costs and revenue for the second life battery market by 2035 (*Crescendo* intermediate scenario) according to the available storage volume (6 GWh with an assumed initial lifetime of 15 years, 36 GWh with an assumed initial lifetime of 10 years)



costs of new storage batteries, as the cells only represent a minor part of the costs in a storage battery and significant reconditioning costs are necessary for second life batteries. As a result, the analysis suggests that the market opportunities for second life batteries for storage could be limited.

Real-life battery tests could however provide feedback on the actual costs and technical characteristics of second life batteries (residual storage capacity, lifetime, responsiveness, etc.), and thus refine the analysis of the economic value of these devices.

These studies show that the preferred option for dealing with end-of-life batteries is to recycle the materials. Environmental analyses assess the benefit of this type of recycling (see the section on environmental results).

5.8 The development of e-mobility improves the balance of the electricity system, for the benefit of all its users

Renewable energy and nuclear technologies share the common features of having high fixed costs, but very low or even zero variable costs, which thus make them competitive on the European electricity market. Except in certain cases where the market is saturated, making it impossible to use the available low-carbon energy generation, renewable and nuclear generation in France can be exported to the European market.

Nevertheless, the analyses carried out by RTE show that if there is a delay in developing interconnections or new uses of electricity, the high level of low-carbon electricity generation available in France could lead to situations of low prices. This type of situation could then result in insufficient revenue for some generation technologies (nuclear and gas power plants) and would lead to a significant level of government support for renewable energies.

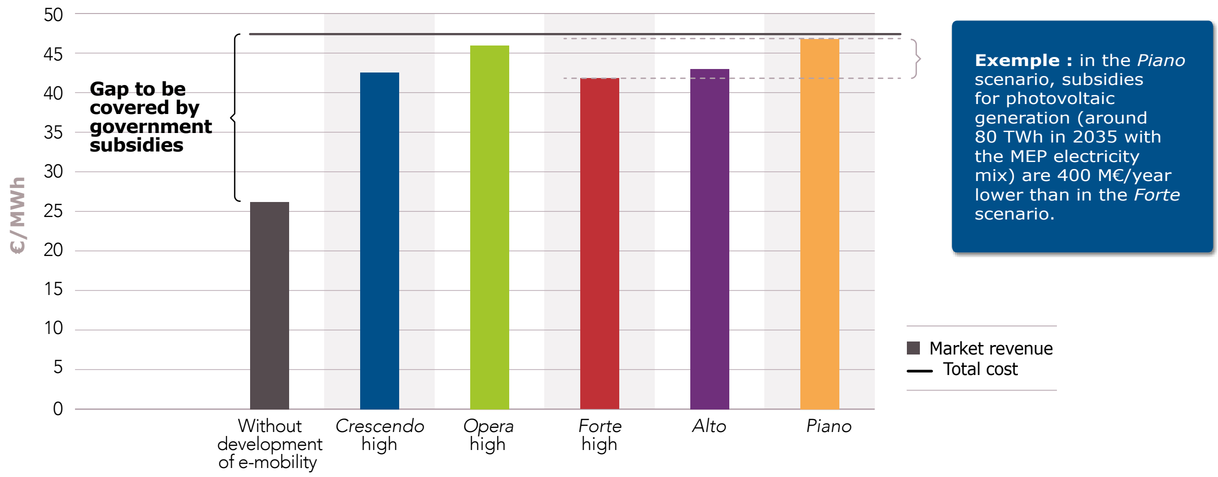
The conclusions of this report highlight two significant effects.

Firstly, the development of e-mobility per se contributes to the economic balance in the MEP scenario. It makes it possible (1) to take advantage of the capacity margins provided by the development of the electricity generation fleet, and (2) to use low-carbon energy generation to reduce emissions in the transport sector.

Secondly, the development of smart charging improves this integration, by aligning power draw-off more closely with periods of high generation. It thus has the effect of reducing both low price and high price situations (as charging is more limited during high demand periods). This reduces the use of fossil fuel power plants in France, and even more so in neighbouring countries, as the operation of the electricity system is based on a European rather than a national strategy.

This beneficial integration can be illustrated using various indicators.

Figure 22. Overall costs and revenues for ground-mounted photovoltaic plants by 2035 in the various e-mobility development scenarios with the electricity mix outlined in the MEP



Exemple : in the *Piano* scenario, subsidies for photovoltaic generation (around 80 TWh in 2035 with the MEP electricity mix) are 400 M€/year lower than in the *Forte* scenario.

In relation to producers

With the MEP electricity mix, the prices on the electricity markets will settle at low levels over significant amounts of time per year. Although it is difficult to precisely quantify the prices during these periods (it depends on many "small" parameters, and very largely on the changes in the electricity generation fleet in neighbouring countries), existing analyses indicate that this type of situation could become much more frequent by 2025. For example, by cross-referencing the MEP scenario (for the electricity mix) with a *Forte* type scenario (high variant) for mobility, the prices could be less than 20 €/MWh for 20% of the time.

Widespread use of smart charging is likely to lead to significant rebalancing. Assuming 80% smart charging *(Opera* scenario) rather than 40% *(Forte* scenario), the periods during which the prices are very low (less than 20 €/MWh) would fall by 400 hours a year.

In relation to the national budget

Adding in the electricity demand associated with charging electric vehicles also results in the price of electricity being supported and, with unchanged objectives for the electricity mix, reduction of government subsidies for certain technologies.

Therefore e-mobility, just like other transfers of use to electricity and the development of interconnections, helps to limit the government cost of subsidising renewable energy sources and makes the various electricity generation technologies economically viable, as well as making it less dependent on the choices of neighbouring countries (on their generation facilities, and on the acceptability of interconnection projects).

With the MEP objectives for the electricity mix, the development of e-mobility (in a configuration with 15.6 million vehicles) leads to a reduction of the cost of government support for the development of photovoltaic and wind technologies by around 1.8 to 2.3 billion € a year. This reduction in subsidies is a result of the effect of the development of e-mobility (additional consumption), and also the effect of smart charging (shifting consumption).

Benefits for consumers

The results are given in the next chapter.

FOR THE CONSUMER, THE COST OF E-MOBILITY CAN BE MANAGED BY LEVERAGING CHARGING FLEXIBILITY

SUMMARY OF RESULTS FROM A CONSUMER PERSPECTIVE

Several opinion surveys conducted recently have examined the attitudes of the French population towards electric vehicles. These surveys highlight that it is the supposed cost - much like the widely held beliefs about range and the ability to find a charging point - that appears to be the largest obstacle to purchasing an electric car.

Analyses conducted within the scope of the new study – which cross-reference the policies outlined by the French government in the MEP with the different mobility scenarios – investigate the cost of supplying the electricity needed to meet mobility needs from the consumer's point of view.

They show that the transition to electricity is a key factor in cutting the fixed costs associated with owning and running a vehicle. They also illustrate how the different smart charging configurations can help to reduce this cost even further.

These analyses underline the fact that e-mobility can play a major part in a whole range of solutions that could be rolled out to meet the nation's expectations in terms of the cost of mobility in general and the cost of a full tank in particular.

1) The annual cost of "filling up with electricity" today is around three times less than that of filling up with fuel, even without considering potential vehicle charging optimisation solutions and a likely rise in the carbon tax associated with petroleum products. This ratio of one to three is expected to be sustained into the long term.

2) This saving is a decisive factor in reconciling the total cost of ownership (TCO) of an electric vehicle with that of an ICE vehicle: indeed, in some cases, electric vehicles are already competitive, bearing in mind the EV purchase subsidies and lower taxes on electricity.

3) The "annual bill" for electricity depends on the specific mobility scenario. For an intermediate class of vehicle, covering distances of between 14,000 and 15,300 km a year and being charged at home only, the annual cost of "filling up with electricity" would be around €400, without smart charging and based on a mobility profile where the user charges at peak times.

4) For those households wanting and able to use smart charging options, this offers a major advantage in terms of managing electricity bills: just by using even simple smart charging methods, an annual cost benefit of €60 to €170 is achievable depending on the situation.

5) This minimum level of smart charging could be extended further to bring in some of the different smart charging and reversible charging solutions explored in the report. This could provide an additional €100 saving in some scenarios on top of those already mentioned.

6) The ultimate optimisation solution, whereby users combine reversible charging with the provision of ancillary services for the electricity system, offers the potential for a zero, or even slightly negative annual charging cost. However, this model is likely to be more of the exception than the rule.

7) Developing smart charging technology goes hand in hand with the growth of self-consumption solutions in some households. The analyses demonstrate the potential for increasing the rate of self-consumption via the introduction of smart charging, and hence illustrate the added benefit to the consumer of installing the infrastructure needed for self-consumption.

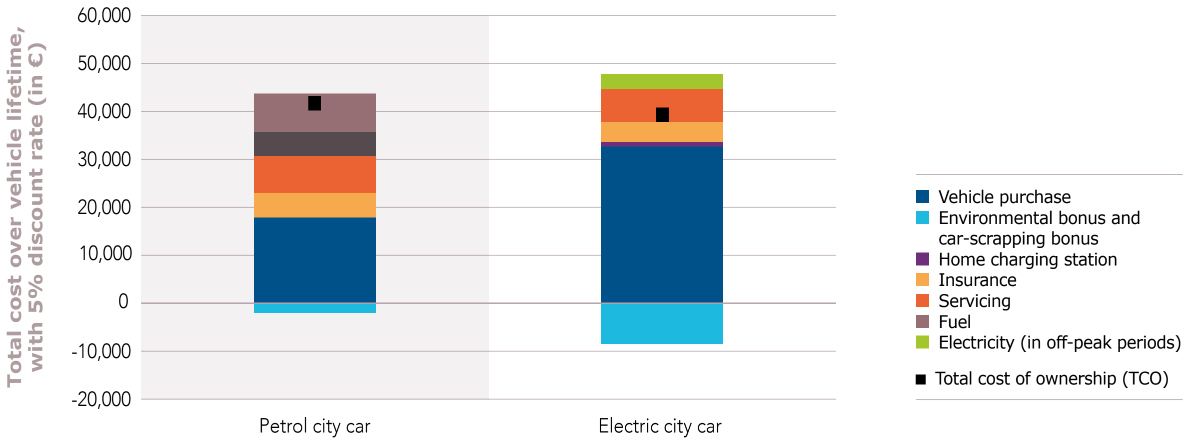
6.1 The transition from ICE to electric vehicles will significantly reduce the cost of "filling up"

The overall share of energy in the TCO is much lower for an electric vehicle than for an ICE vehicle. This is due to the lower energy consumption of electric vehicles (more efficient engine) and the lower cost of electricity (including VAT). However, electricity consumption still represents a significant amount – typically around 5 to 10% – of the TCO of an electric vehicle (versus 30% for fuel consumption for an ICE vehicle).

The annual full charging cost today is around three times less that of filling up with fuel, even without considering vehicle charging optimisation options and the likely rise in the carbon tax associated with petroleum products.

The e-mobility transition will therefore help to reduce the energy bill considerably for motorists. Whilst this reduction may be partially offset by the higher initial purchase price of an electric vehicle (although this is partly reduced at present by incentive schemes such as car-scrapping bonuses and subsidies), the price gap between ICE and electric vehicles should gradually close in the long term, especially with the expected reduction in battery costs.

Figure 23. TCO of an ICE vehicle compared with an electric vehicle (category A city car, based on a comparison between a Renault Clio 5 Zen petrol engine car and a Renault Zoe Life 41 kWh battery electric car)



6.2 Smart charging offers additional opportunities for managing bills

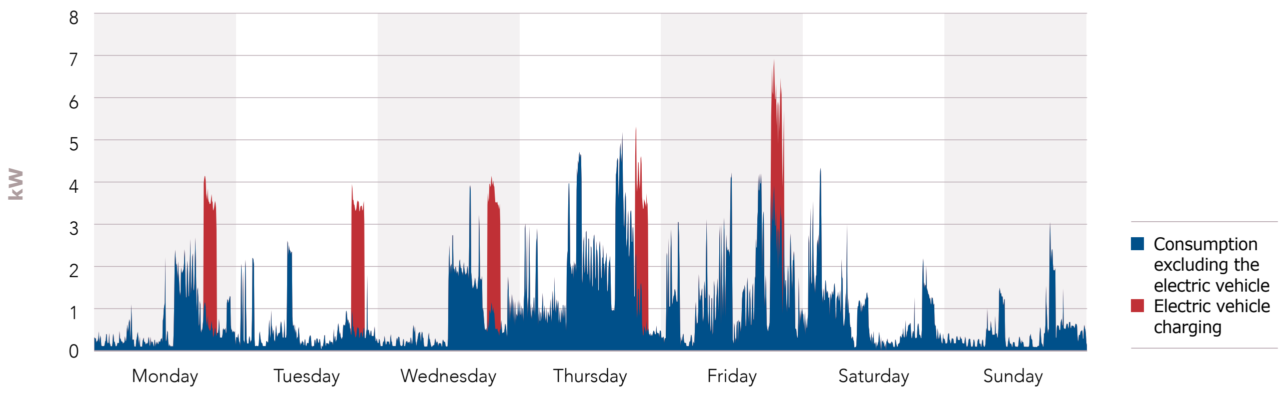
Optimising the timing of EV charging can deliver savings for consumers on their electricity bills. These savings obviously depend on the user profile, not only in terms of distances travelled, but also on the level of flexibility they have in terms of charging their vehicles.

The study explores the potential savings for several user profiles selected as being representative of the different mobility behaviours identified in the transport survey: workers using their cars for daily commutes, with or without returning home at lunchtime; workers using their car for business travel; non-workers, etc.

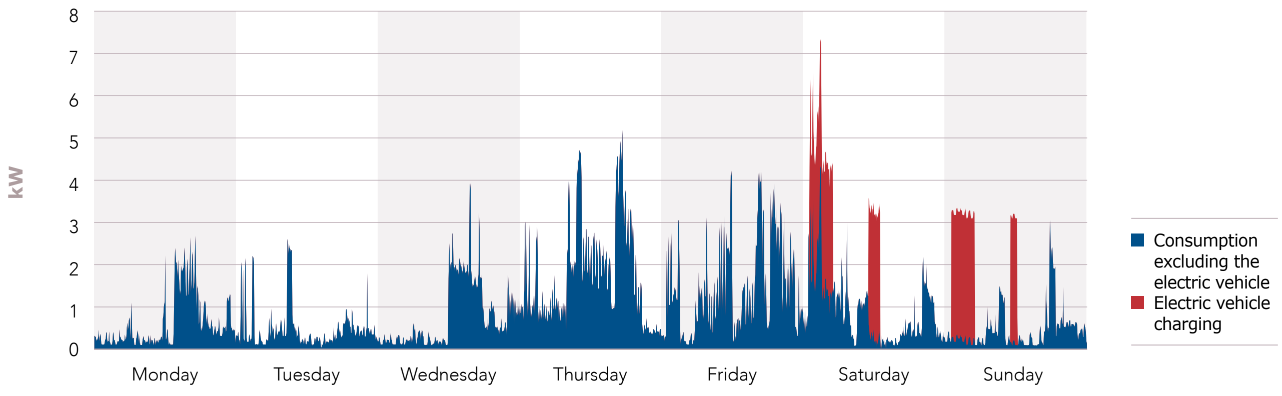
EV charging typically costs around €400 a year for an average-sized car charged at home only, and without any kind of smart charging. This estimate assumes that the bulk of charging takes place during the most expensive tariff periods, which is primarily the case for workers coming home from work in the evening and plugging their car in to charge immediately, when retail tariffs are at their highest.

Figure 24. Charge timing throughout the week using different smart charging methods, for a worker who only charges their car at home

Uncontrolled charging



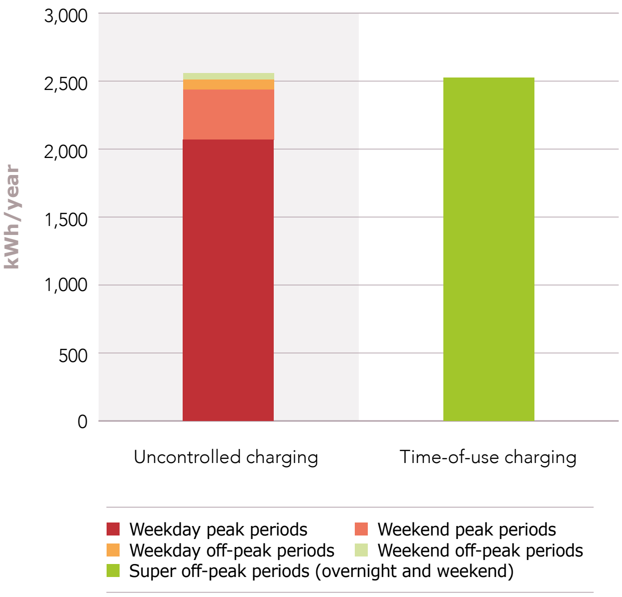
Time-of-use smart charging based on off-peak weekend signal



A simple smart charging solution, based on control via a time-of-use signal and a discerning choice by the consumer as to which day they plug their vehicle in to charge (prioritising the weekend over a weekday, whenever this is compatible with the battery charge status) allows the majority of charging to take place during periods when the retail electricity prices are at their lowest. **This results in a 30 to 35% reduction in the annual cost of charging, equivalent to €60 to €170 a year depending on the mobility profiles considered (excluding consumers who have the option to charge their vehicles at work at a more advantageous rate).**

An interesting finding from the study shows that this kind of reduction is seen on both current costs and projected 2035 costs (excluding any tax-related adjustments).

Figure 25. Charge distribution over the different tariff bands as a function of the smart charging method, for a worker commuting daily, without returning home for lunch



6.3 Different economic models for reversible charging, conditional upon mobility patterns and the regulatory framework

Reversible charging offers EV users the option to charge their vehicle batteries at times when the electricity tariff is at its lowest, with a view to using the stored energy later. The stored energy can be used for different purposes:

- It can be used to cover all or part of the consumption of other domestic electricity uses during peak tariff periods, without any net injection back into the electricity grid (known as vehicle-to-home operation). Owning an electric vehicle offers households an internal storage solution, which can provide optimum management of domestic electricity consumption.
- It can be fed back into the grid (via a vehicle-to-grid system). This essentially pools individual storage solutions on a grid scale, in much the same way as "conventional" electricity generation facilities.

The overall benefit to users of a vehicle-to-home system is highly dependent on their mobility patterns and other domestic electricity uses. It relies in particular on the vehicle being parked at home, (i) to inject energy when other domestic uses are consuming electricity and the tariffs are high; and (ii) to draw energy during periods when the tariffs are low. The additional saving for the user can vary considerably, from around €20 to €100 a year for the profiles studied (excluding those profiles with access to workplace charging at a preferential rate).

The benefit of a vehicle-to-grid system in terms of trading in the energy markets is limited for consumers at present (see the assessments in the full report). This is largely due to the retail pricing structure, which includes taxes: electricity drawn from the grid is costed at the energy price including taxes (which incorporates a contribution proportional to the amount of energy consumed for both VAT and the TURPE network access tariff), whereas the power fed back into the grid is only valued at the market price. This means that every storage-withdrawal cycle "pays" the TURPE tariff (which makes sense given that it is using the grid), but also pays tax as well.

Figure 26. Illustration of the principle of vehicle-to-home and vehicle-to-grid charging

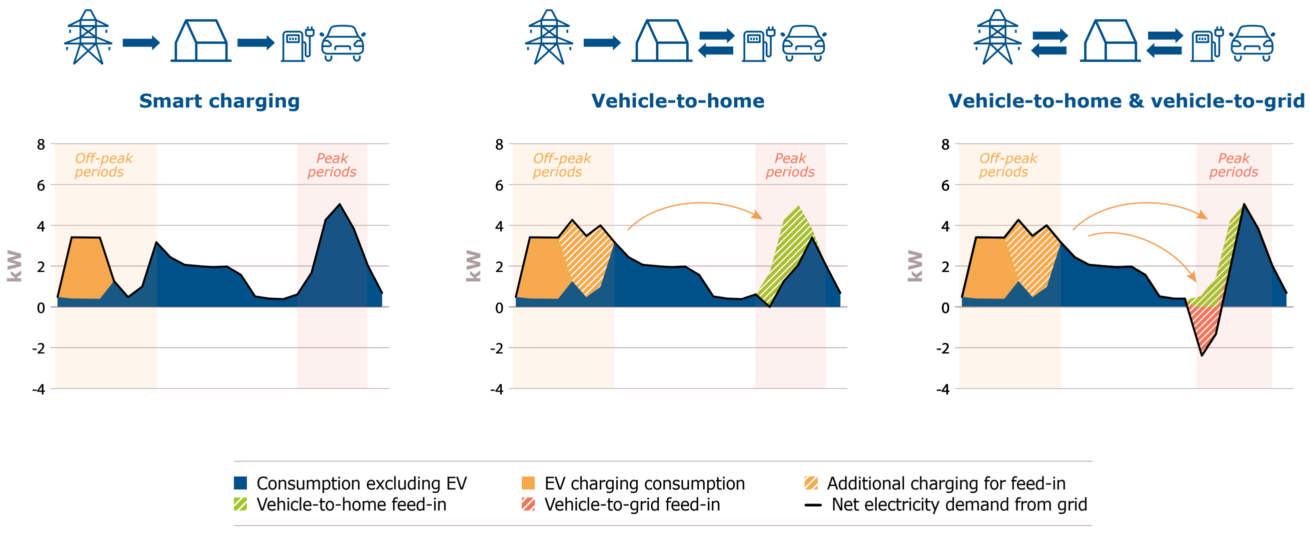
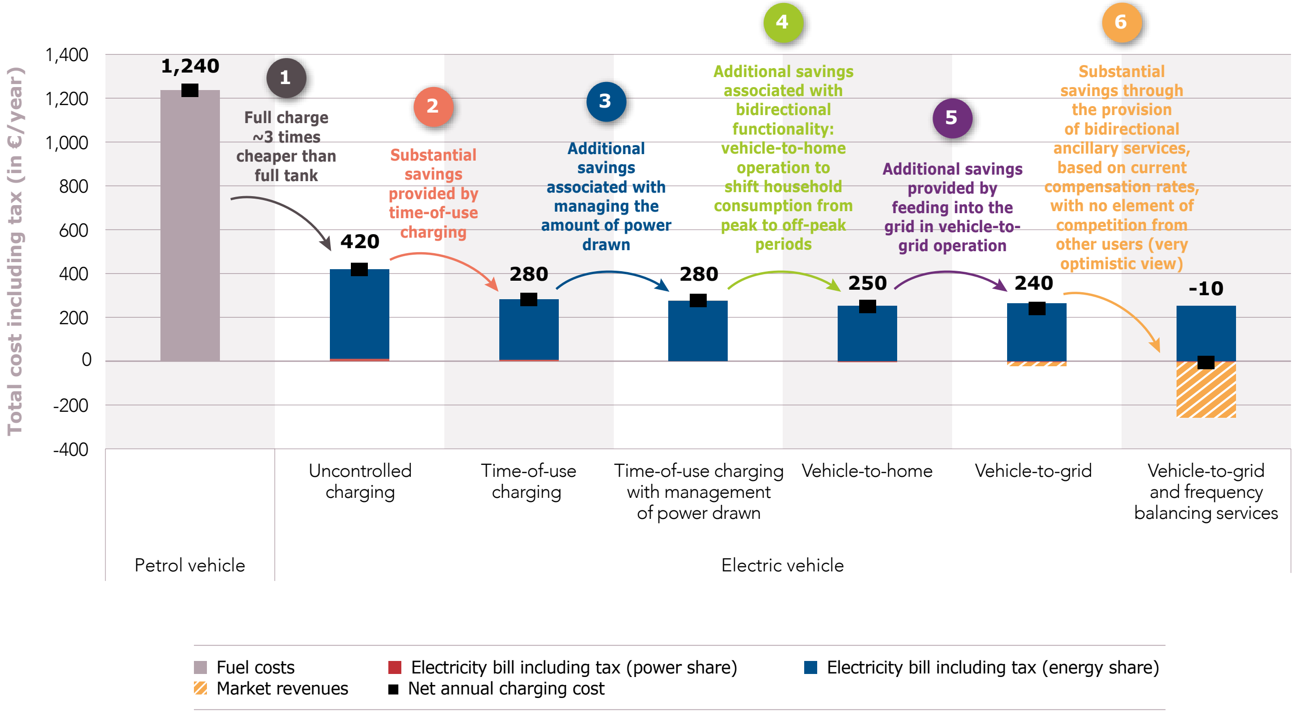
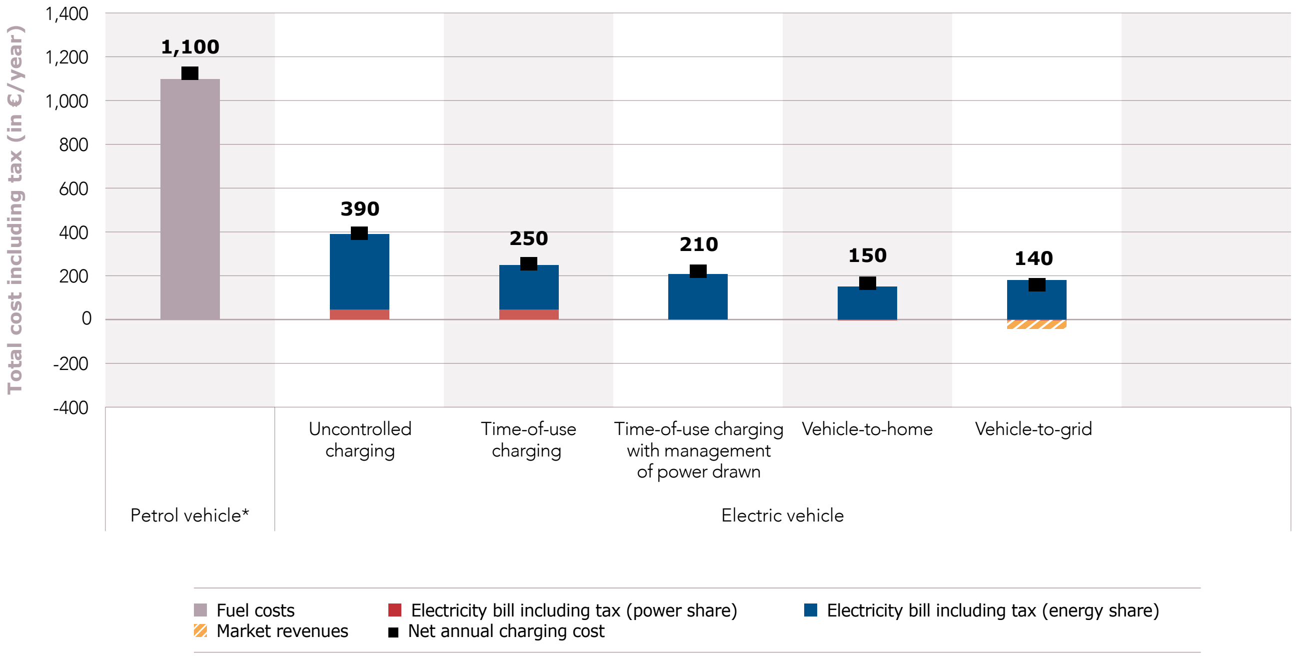


Figure 27. Annual fuel/charging cost for a motorist (worker with daily commute and total annual travel distance of 14,000 km) as a function of the smart charging method

2018 *(3 kW charging station)*



2035 *(7 kW charging station)*



** Cost assumption from the IEA's New Policies scenario, assuming no changes in taxation*

Hence, although development of reversible charging technology holds certain appeal for the electricity system from an economic perspective, the benefit to consumers is not guaranteed within the existing regulatory framework. Nonetheless, investigations could be initiated to examine the appropriateness of potential changes to the regulatory framework, even on a trial basis, provided that the level of investment in fixed grid costs and the tax contribution to public service charges are maintained.

Lastly, vehicle-to-grid technology can offer a substantial benefit from a frequency regulation viewpoint today, based on current compensation rates. However, this benefit is likely to diminish rapidly with the advent of different competing flexibility solutions, such as demand-side response and battery storage systems, specifically targeting these services.

6.4 Combining e-mobility and self-consumption makes sound economic sense

The decrease in price of photovoltaic panels in recent years has led to a growth in the uptake of self-consumption solutions based on rooftop solar panels. Although still fairly modest, the number of this kind of installation[8] is rising rapidly. Analyses published by RTE in the 2017 RTE long-term adequacy report demonstrated that individual domestic self-consumption solutions could potentially be in use by several million households within 15 years. The report also highlighted various factors that could boost, or conversely, restrict development of this method of production.

Couple a rooftop solar panel installation with the purchase of an electric car, and this is likely to offer great appeal from an environmental perspective, and hence tick the right boxes as far as the general public is concerned. Economic analyses confirm that combining ownership of an electric vehicle with self-consumption of solar power could deliver considerable consumer benefits. This conclusion is conditional upon users being able to charge their vehicles at times of photovoltaic production to maximise the rate of self-consumption and thus profitability. The actual benefit therefore depends on the vehicle use profile, and especially on it being parked at home during times of solar energy production (i.e. in the daytime). For some users, the benefit would be even greater if they were able to install a vehicle-to-home solution.

Compared with a baseline scenario, the development of e-mobility is therefore expected to result in a rise in solar power installations for self-consumption of around 1 to 2 GW. The impact of this will depend on the extent of e-mobility development, the distribution of this mobility within the various population categories and the development of vehicle-to-home smart charging technology.

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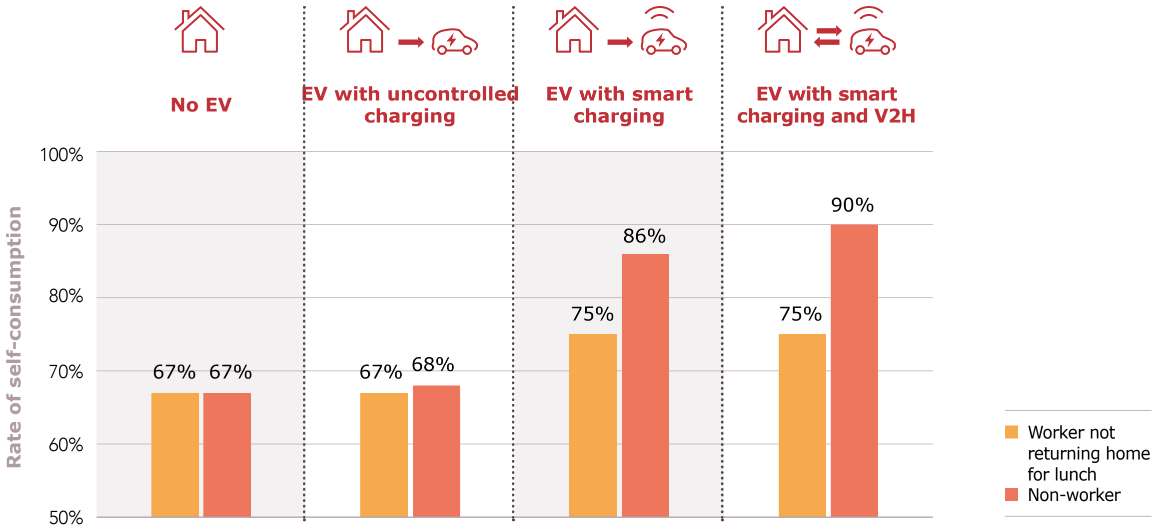
[8] 40,000 installations for a total 143 MW installed as at 1 January 2019

Figure 28. Effect of EV smart charging on self-consumption rates (*Crescendo* scenario, 2035)



ENVIRONMENTAL ANALYSIS: A SIGNIFICANT REDUCTION IN THE CARBON FOOTPRINT OF THE TRANSPORT SECTOR

SUMMARY OF THE ENVIRONMENTAL RESULTS

The development of electric vehicles is one of the main levers for reducing greenhouse gas emissions, and it can be activated right now.

By considering the life cycle of vehicles and electricity production, the study presents an in-depth analysis of the carbon footprint of each e-mobility scenario and the effects of the different parameters.

1) In France, using an electric vehicle results in virtually no CO_2 emissions: they are 20 times lower than the emissions of an ICE vehicle. This is due to the structure of the French electricity mix, which is predominantly low-carbon.

2) France is currently a major exporter of electricity, and these exports replace fossil-fuel generation in neighbouring countries. With unchanged electricity generation facilities, increasing the share of electricity in the transport sector in France competes with reducing emissions from the electricity generation facilities in some European countries. The analysis carried out shows that the greatest emission reduction is obtained by electrifying the mobility sector in France – this being increasingly the case as France's neighbours continue to decarbonise their electricity generation facilities.

3) The clear advantage of electric vehicles with regard to emissions remains true even when the whole life cycle is included, and even in the case of batteries made in China using high-carbon electricity in their manufacturing processes, in the most challenging scenarios such as *Forte* and *Alto*. A minimum annual saving of 18 $MtCO_2eq$ is thus achievable by 2035.

The study highlights the various levers that can be activated to reduce the carbon footprint further:

4) Manufacturing the batteries in France would reduce the overall footprint of transport by 2 to 3 $MtCO_2eq$ a year despite a slight increase in the emissions of the industrial sector in France, due to the low carbon content of French electricity.

5) Reducing the size of batteries (for example in the *Piano* scenario) and increasing the recycling rate (85% rather than 50%) improve the environmental performance further and account for a reduction of around 1 to 2 $MtCO_2eq$ a year.

6) The effect of widespread smart charging is very clear: it provides an additional annual saving of 5 $MtCO_2eq$. Most of these reductions would be seen in France's neighbours, through decreased use of their thermal power plants.

7) Expanding public transport and using soft mobility systematically improve the environmental performance of transport (7 $MtCO_2eq$ per year for both).

8) The study shows a contrasting carbon balance for autonomous vehicles in the *Alto* scenario, as its effect on reducing the numbers of vehicles can be counteracted by their envisaged mode of use (numerous journeys with no passengers for robo-taxis) and characteristics (large batteries, on-board electronics, etc.). This encourages identification of the most efficient methods for implementing shared autonomous vehicles and their coordination with public transport.

These results are then given in the broader context of the energy and environmental policy:

9) The promotion of low-carbon solutions for personal transport currently requires considerable government support, which includes offering subsidies for the acquisition of an electric vehicle. The study shows that the level of support required could decrease in the medium term, to a level well below the shadow price of carbon.

10) The levers presented in the *Piano* scenario also make it possible to limit requirements for supplies of rare metals, which currently raise significant environmental and ethical issues.

7.1 In all the scenarios, a significant reduction in the emissions of the transport sector in France

Electricity generation in France is already predominantly low-carbon. In 2018, the emissions associated with the electricity sector amounted to 20.4 million tonnes of CO_2, as against 274 million in Germany, 68 million in the UK and 93 million in Italy. The emissions of the electricity sector in relation to the population in France are among the lowest in the world. Only countries such as Norway (electricity production almost entirely hydroelectric) or Switzerland (nuclear and hydroelectric) are comparable.

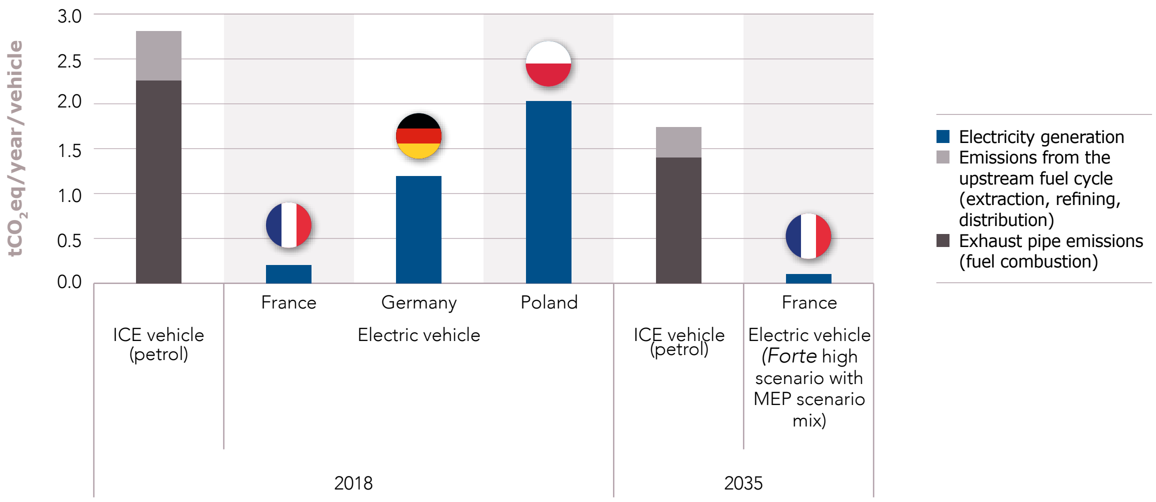
The policies outlined in the MEP will lead to still further improvement of this performance. A saving of around 7 million tonnes is expected with the closure of coal-fired power plants, planned for 2022. From 2022 on, the growth of renewable energies should also lead to a reduction in the operating times of gas-fired power plants. In the *Ampère, Volt* and MEP scenarios, the electricity system reaches extremely low annual emission levels of around 10 million tonnes by 2030-2035.

This configuration is particularly favourable for the transition towards e-mobility, even taking into account the significant fall in the consumption of ICE vehicles, projected in the next years.

Over the period 2020-2035, **electrification of 15.6 million electric vehicles avoids between 150 and 200 million tonnes of CO_2 from fuel combustion ("exhaust pipe" emissions).**

This result, which is in line with previous studies on the subject, is due to the nature of the electricity mix in France. If projected based on a mix using mainly coal as the primary fuel (Germany) or virtually all-coal (Poland), the electrification of mobility does not have such a positive effect on CO_2 emissions.

Figure 29. Annual greenhouse gas emissions associated with the energy consumed by vehicles during use (direct exhaust pipe emissions and fuel life cycle for ICE vehicles, electricity generation emissions and life cycle for electric vehicles) for a vehicle travelling 14,000 km a year

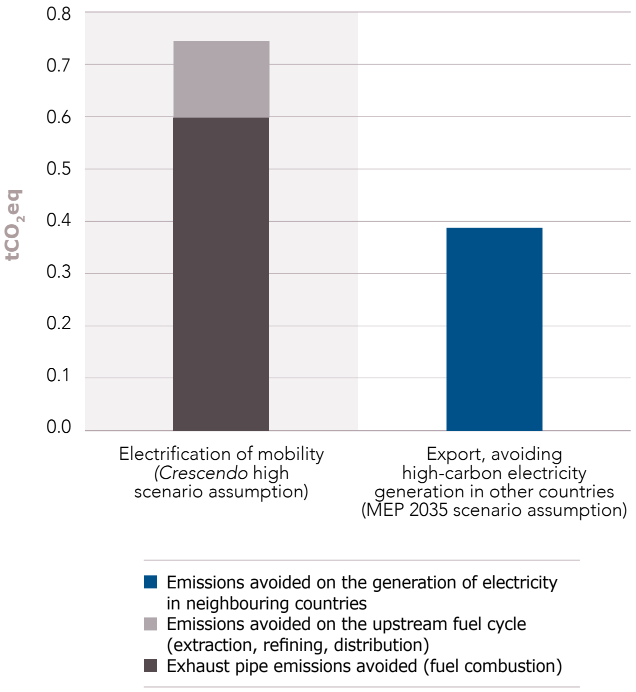


7.2 With unchanged electricity generation facilities, the downward effects on the emissions from transport in France are greater than the upward effects associated with the generation of high-carbon electricity in neighbouring countries

The development of a new use for electricity, such as electric vehicles, has an effect on the operation of the French and European electricity system and on the associated emissions.

The assessment of this effect raises methodological questions on assigning the total emissions of a production mix to the various uses made of electricity. Several approaches have been tested. In all cases, the emissions from the generation facilities in France resulting from the development of e-mobility are very low (they are barely more than 1 MtCO$_2$ a year, even in the high variant of the *Forte* scenario).

Figure 30. CO$_2$ emissions avoided by the generation of 1 MWh of low-carbon electricity in France according to its use (reference year: 2035)



However, the effect on emissions from the European electricity system may be more mixed.

Assuming unchanged electricity generation facilities, the development of a new use in France – e-mobility – competes with low-carbon electricity exports to neighbouring countries, leading to additional emissions from electricity generation in these countries.

France is currently the leading exporter of electricity in Europe (60 TWh in 2018), and these exports make a significant contribution to reducing emissions across the whole continent, as the electricity which is exported takes the place of fossil fuel generation elsewhere. If all the electricity exported by France were generated by gas-fired power plants rather than by the French mix, this would result in additional emissions of close to 22 MtCO$_2$ a year. RTE's simulations, developed during 2018 with the publication of dedicated analyses, show that these characteristics should be strengthened, with growth in net exports – in both the MEP scenario and the *Volt* and *Ampère* scenarios.

The new report compares these two effects: using low-carbon generation in France to reduce the emissions of the transport sector in France or using it to reduce emissions associated with electricity generation in neighbouring countries. It adopts an approach based on the "carbon footprint".

These analyses demonstrate unambiguously that more emissions are avoided by the electrification of transport in France than those that could have been avoided if the same low-carbon electricity had been available for export and for reducing the generation of high-carbon electricity outside France. This result is true for all the scenarios, including the configuration of the *Forte* scenario.

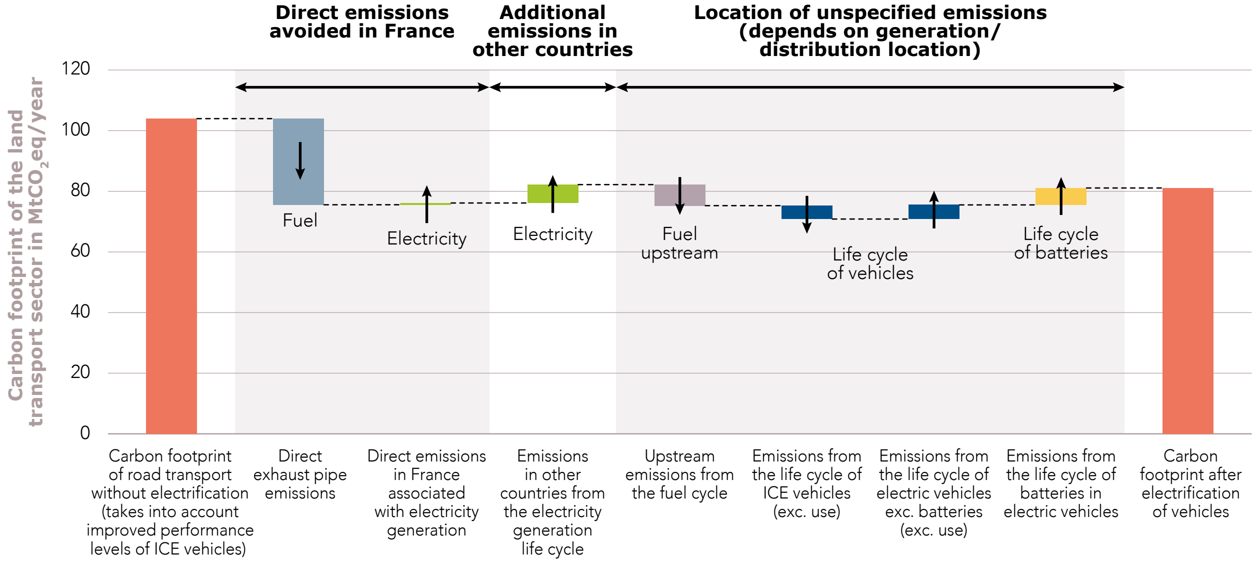
7.3 The carbon benefit of e-mobility is still significant when the whole life cycle of the vehicle is included, even with batteries that are made in China…

Current studies comparing the life cycles of ICE vehicles and electric vehicles (for example the recent study by the FNH[9]) are broadly in agreement on the environmental analysis of e-mobility. They point out that an electric vehicle has a benefit in terms of its carbon footprint in comparison with an ICE vehicle as long as the emissions avoided during use offset the carbon impact of manufacturing the batteries.

These studies thus show that, due to the low carbon content of the mix in France, the electrification of vehicles is of interest in terms of the carbon footprint as soon as a vehicle travels more than 30,000 to 50,000 kilometres over its lifetime, i.e. a level considerably below the average car usage in France (200,000 km over its lifetime).

In standard conditions, **the reductions in national emissions are not largely offset by additional emissions in other countries due to battery production, even though these batteries are produced in countries in which coal is predominantly used for energy production. Depending on the capacity of the batteries, where they are manufactured, the recycling rate and the timescale considered, electric vehicles have a carbon footprint 2 to 4 times lower than that of ICE vehicles** (according to the models compared and the timescale considered).

Figure 31. Breakdown of the effects of electrification on greenhouse gas emissions associated with the land transport sector (*Forte* high scenario – 2035)



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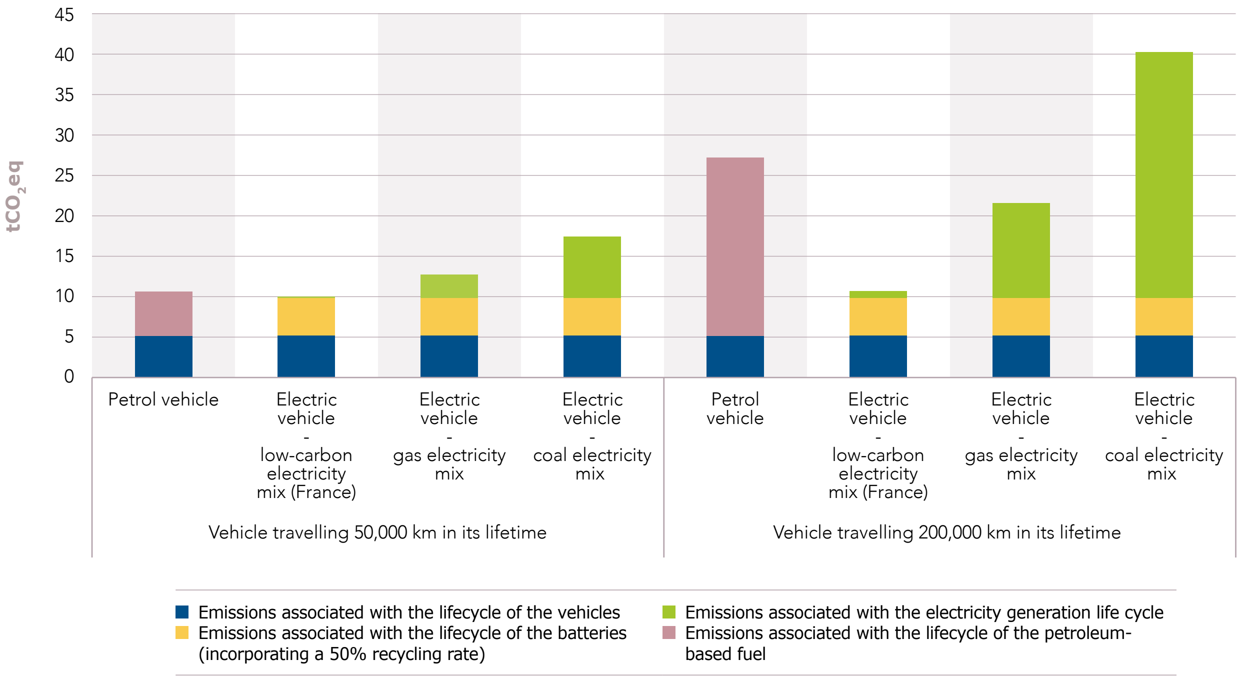
[9] Nicolas Hulot Foundation for Nature and Mankind and ECF – *"From cradle to grave: e-mobility and the French energy transition"* (2018), summary in English of the technical report *"Quelle contribution du véhicule électrique à la transition écologique en France ?"*

Figure 32. Carbon footprint of a vehicle over its entire life cycle according to the type of engine, the electricity production mix and the distance travelled (reference year: 2035)



The new report gives a consolidated analysis from the perspective of the entire vehicle fleet (including buses and trucks). It compares the different scenarios studied, via variants on smart charging, battery capacity, where the batteries are manufactured and their recycling rate, and incorporates a detailed analysis of the effects on the European electricity mix (via a simulation of electricity imports/exports between areas).

These analyses enable an exhaustive assessment of the total greenhouse gas footprint of land transport, covering all vehicles.

They give very clear results. Firstly, **the electrification of light-duty vehicles is a powerful lever for reducing the carbon footprint of transport, irrespective of how it is developed.**

The carbon footprint falls systematically, even in the scenarios in which the parameters are not the most favourable for greenhouse gas emissions, as in the *Forte* scenario (high capacity batteries, made in Asia, limited recycling rate and very limited development of smart charging).

Secondly, **this result is also true for the electrification of heavy-duty vehicles (buses and trucks).** This sector faces a significant challenge (heavy-duty road vehicles account for around 30 $MtCO_2$ a year), although the electrification of this sector is expected to be slower and less widespread than for light-duty vehicles.

However, this must not mask the fact that electric vehicles do not have a zero carbon footprint. The study tests the influence of various key mobility parameters on emissions and identifies the various levers for controlling and reducing this impact further.

7.4 … but locating battery production in France significantly improves the carbon footprint

The various assumptions tested in the study shed light on the importance of the location of battery production for reducing the carbon footprint.

Battery production is currently predominantly located in Asia (the 10 largest manufacturers of lithium-ion cells are all in Asia), in countries where electricity generation predominantly uses coal and therefore emits high levels of greenhouses gases.

Although the analysis in Section 7.3 shows that the reductions in emissions associated with the shift to e-mobility in a country like France far outweigh the additional emissions resulting from battery production in Asia, the fact remains that an effective way to optimise the reduction of the emissions of the whole cycle consists of locating battery manufacture in a country where electricity generation is predominantly low-carbon.

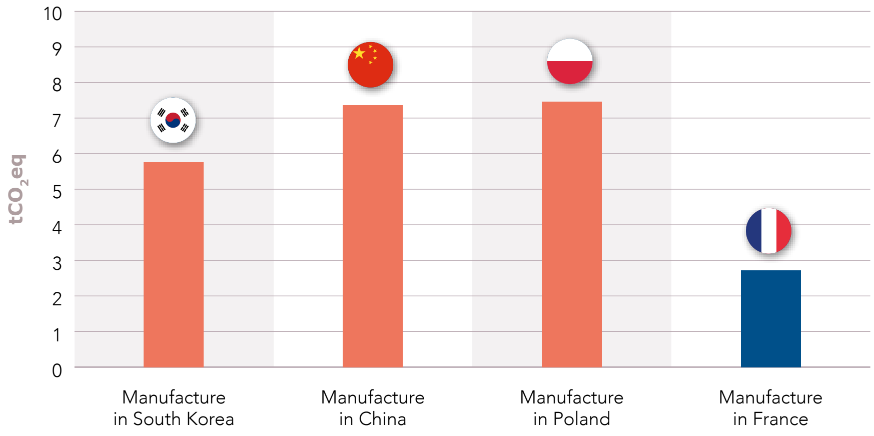
Aside from the possible associated strategic considerations, producing batteries in a country such as France would reduce annual emissions by around 2 to 3 $MtCO_2$ (according to the assumption on battery capacity) for 15.6 million electric vehicles. This assessment includes a very slight increase in national emissions associated with the electricity consumption for manufacturing batteries (less than 0.3 $MtCO_2$ a year).

Across the whole electric vehicle value chain, a shift to e-mobility together with proactive policies for the location of battery production would thus lead to a "double climatic bonus":

- Not only would emissions in France be reduced by around twenty million tonnes of CO_2 a year by moving away from petroleum-based products (depending on the scenario)
- But also, the footprint of the electric vehicle would be improved by 2 to 3 $MtCO_2$ a year, by moving battery production to virtually carbon-free electricity generation.

This type of industrial policy would seem to be particularly well-suited to the electricity generation mix in the draft MEP, potentially characterised by numerous periods of low prices on the electricity markets.

Figure 33. Analysis of the life cycle of a current 40 kWh battery according to where it is manufactured (not taking account of recycling)



CO_2 lever no. 1: manufacturing batteries in France

7.5 Lower battery storage capacity and higher recycling rates also limit the emissions associated with the extraction of materials and the manufacture of batteries

Vehicle manufacturers and battery producers are currently working hard to increase the capacity of batteries (in terms of kWh of energy stored) in order to improve the range of vehicles and encourage their adoption by users. This increase in battery capacity is the result of technological advances and expansion to an industrial scale, which (i) enable batteries to be made with a greater energy density and (ii) reduce the unit cost per kWh of batteries.

In a scenario such as *Forte*, as in other projections from various stakeholders, the average capacity of electric vehicle batteries could reach around 90 kWh, which corresponds to a range of over 500 km, as against 40 kWh for the vast majority of electric vehicles currently sold in France.

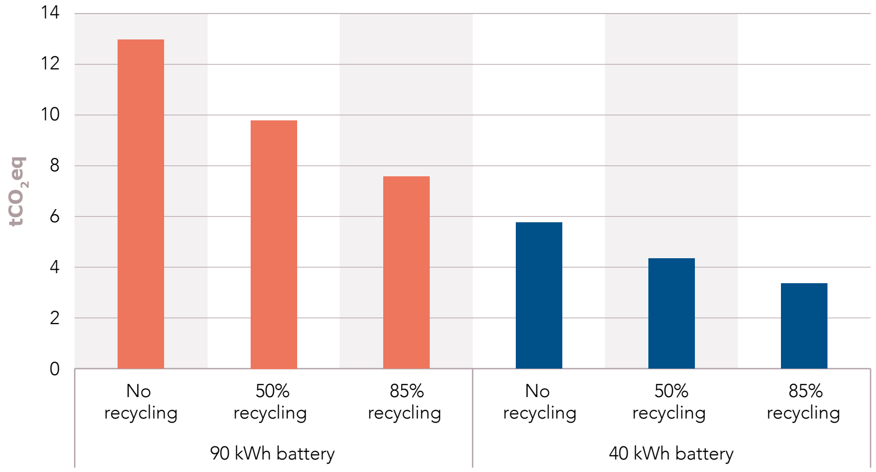
However, for a vehicle which mainly travels short distances (an average of around 35 to 40 km a day, apart from a few long distance journeys during the year), such a large storage capacity could be largely superfluous, especially as the battery size has an impact on the carbon balance of the electric vehicle. In fact, the greater the capacity of the battery, the more electrochemical components, and therefore the more materials, are needed for its manufacture.

Consequently, **limiting the increase in battery storage capacity, in particular for vehicles that are mainly used for local journeys, helps to reduce the environmental impact of electric vehicles** (for example in the *Piano* scenario).

Likewise, recycling end-of-life batteries limits the environmental impacts associated with extracting the materials.

In a scenario with 15.6 million vehicles, controlling the battery capacity and having a high recycling rate represents an impact of around 1 to 2 $MtCO_2$ a year (comparison between the

Figure 34. Analysis of the life cycle of a current battery according to its storage capacity and recycling rate (assumed to be manufactured in South Korea)



CO_2 lever no. 2: battery storage capacity and recycling

low assumption on battery capacity with an 85% recycling rate and the high assumption on capacity with a 50% recycling rate). The saving refers to batteries produced in Asia: this is less of a challenge if the batteries are manufactured in France.

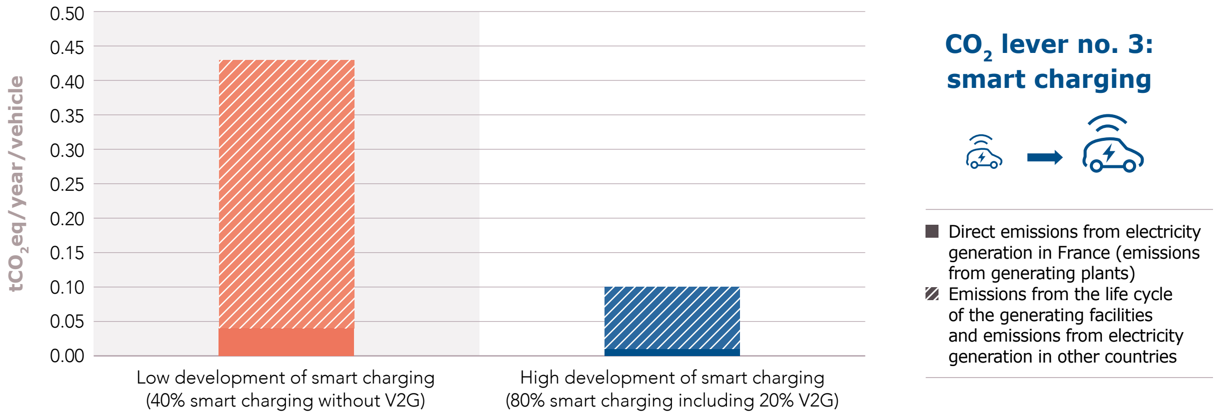
7.6 Smart charging has a major impact on the CO_2 content of the consumption of electric vehicles

Smart charging has an obvious technical benefit, and a very significant economic value. The analysis also shows that it has several advantages with regard to greenhouse gas emissions.

By improving how low-carbon electricity generation is used in France and reducing the use of fossil fuel powered thermal generation in Europe, smart charging improves the impact of charging electric vehicles on greenhouse gas emissions from the European electricity system. **Emissions of close to 5 $MtCO_2$ a year can therefore be avoided with widespread use of smart charging** (as against a scenario in which it is not used).

The associated savings are mainly located outside France. This is the result of the technical and economic fact that the electricity system operates on a European scale: the degree of implementation of smart charging in France has an effect on demand on all the dispatchable generating facilities in Europe, and in particular the fossil fuel powered generating facilities that are mainly located in other countries.

Figure 35. Emissions associated with electricity generation according to the deployment of smart charging (reference year: 2035)



7.7 The expansion of public transport and soft mobility further reduces the carbon footprint of transport

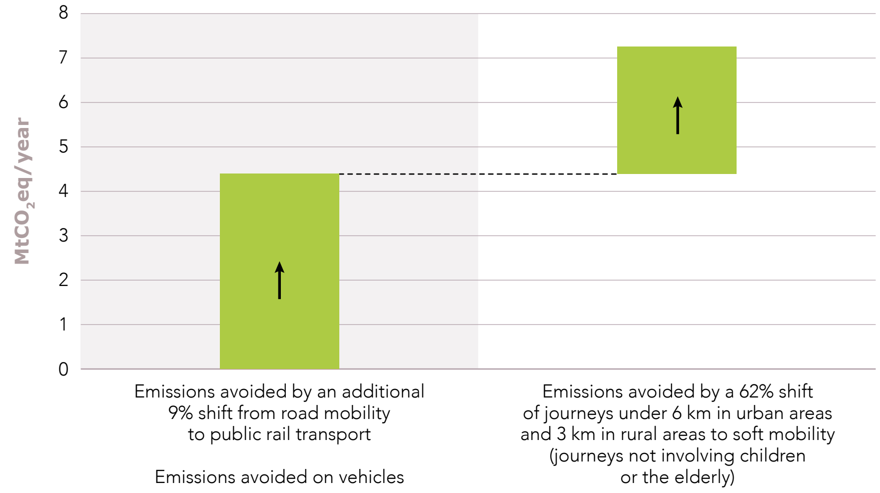
Aside from the choices of how e-mobility is developed, changes to modes of travel offer an opportunity to maximise the benefits for the carbon footprint of transport. **Options favouring the modal shift to soft mobility and electric public transport and the development of car-sharing and car-pooling have an environmental benefit, even with massive electrification of vehicles.**

The *Piano* scenario, which combines the use of the various levers, gives a total annual reduction in the carbon footprint of transport of close to 40 $MtCO_2$, i.e. a volume of emissions avoided around 40% greater than that obtained in the *Forte* scenario (high variant).

Studies carried out on the development of shared autonomous vehicles used as robo-taxis (*Alto* scenario) give mixed results on the impact on emissions.

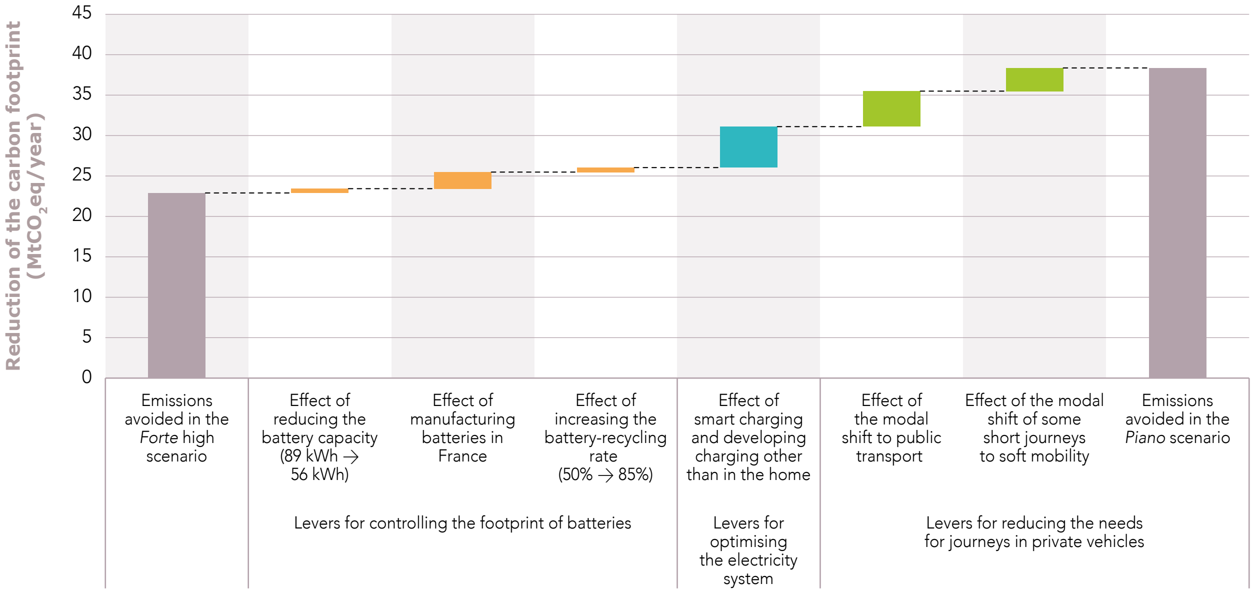
The use of robo-taxis has a positive effect on emissions, as it reduces the overall number of vehicles. Mobility services may then develop based on vehicles that are heavily used rather than ownership of private vehicles that are used very little. The development of these robo-taxis, combined with the development of public transport (the autonomous vehicles operate as "feeders" to the main public transport interconnections), may reduce the distances covered using road transport and thus improve the carbon footprint of transport.

Figure 36. Effect of the modal shift on greenhouse gas emissions (life cycle analysis)



CO_2 lever no. 4: modal shift to public transport and soft mobility

Figure 37. Levers for reducing the carbon footprint of transport



However, several impacts counteract the positive effects associated with reducing the numbers of private cars:

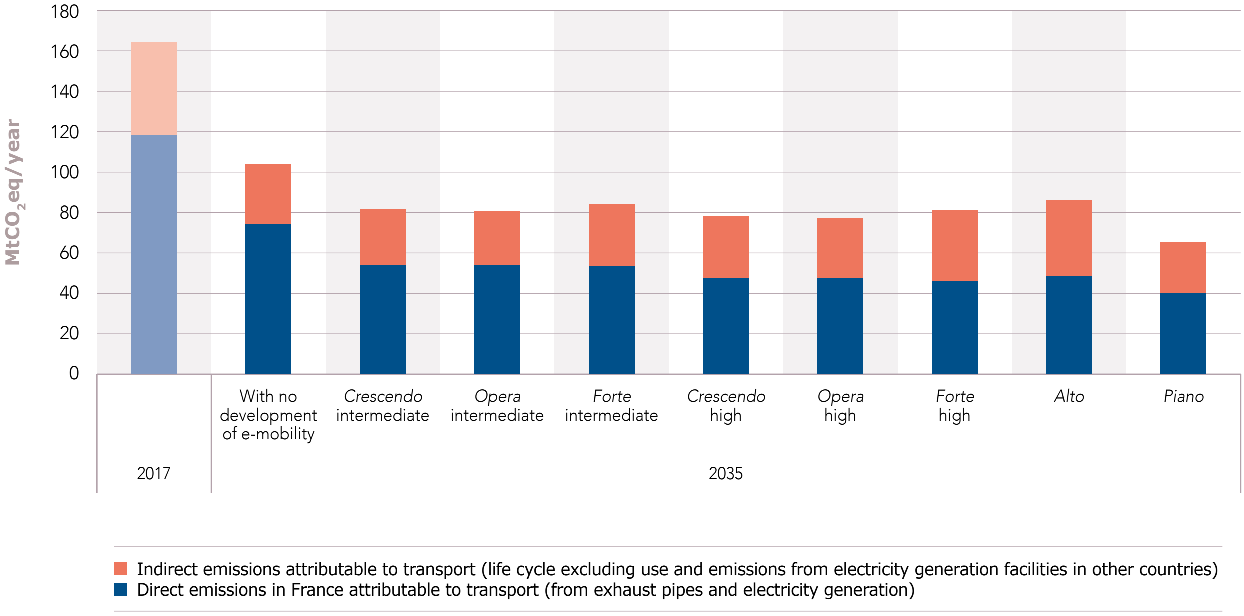
(i) The lifetime of these shared vehicles is shorter than that of a private vehicle due to the considerable distances travelled each year
(ii) The batteries are larger
(iii) The footprint of all the electronic components (computer, sensors) and the data centres for storing the data necessary for the autonomy functions have a negative effect on the overall analysis
(iv) The unit consumption per kilometre of these vehicles is higher (effect of the weight and the consumption of the autonomy functions)
(v) The distances covered without passengers (consequence of widespread, shared use) increase the consumption

This results in the *Alto* scenario giving higher emissions than the high variants of the *Crescendo*, *Opera* and *Forte* scenarios, even though there are far fewer light-duty vehicles on the road.

These first points in the analysis must be treated with caution in view of the uncertainties on the future characteristics of autonomous vehicles and their carbon footprint. They simply show that **there is no automatic correlation or obvious answer, which could lead one to assume that the development of autonomous vehicles would result in a decrease in emissions, due to its effect on reducing the numbers of private vehicles.**

These results call for further investigations, which could involve a more detailed analysis of autonomous vehicles, in the form of low capacity public transport (with higher occupancy rates than conventional vehicles). These vehicles could potentially be more beneficial from an environmental perspective. This scenario could also be based on a massive development of car-sharing without necessarily being based on autonomous vehicles. Variants of the *Alto* scenario with higher environmental performance levels therefore seem possible and could then be studied.

Figure 38. Greenhouse gas emissions attributable to land transport (excluding 2-wheelers) according to the scenarios



7.8 The cost of decarbonisation by developing e-mobility: initially high but expected to fall over time

Several recent studies[10] have looked into the total cost of owning a vehicle for users: the TCO[11] is an indicator that includes all the costs during the period of ownership of a vehicle (purchase and financing of the vehicle, maintenance, insurance, fuel or electricity, together with all the taxes paid and subsidies received).

These studies have come to the conclusion that the total cost for the consumer of an EV has become similar to, or even less than, that of an ICE vehicle. This result depends on how the vehicle is used (in particular the distances travelled), the vehicle type (some ICE models are eligible for an environmental bonus and a car-scrapping subsidy), the battery capacity (which represents a significant cost for an electric vehicle) and the tax status of the buyer – whether they are an individual person or a legal entity (the car-scrapping subsidy depends on the tax status of the household, companies are exempt from tax on company vehicles which have low CO_2 emissions, etc.).

The cost of owning electric vehicles in comparison with ICE vehicles is made competitive by implicit or explicit government financial support: environmental bonus, car-scrapping subsidy and lower

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[10] IFPEN (research & training organisation) with ADEME, UFC QueChoisir (consumer organisation), CGDD (General Commission on Sustainable Development)
[11] Total Cost of Ownership

taxes on electricity than on petrol or diesel. This government support currently seems essential for sales of electric vehicles to increase[12].

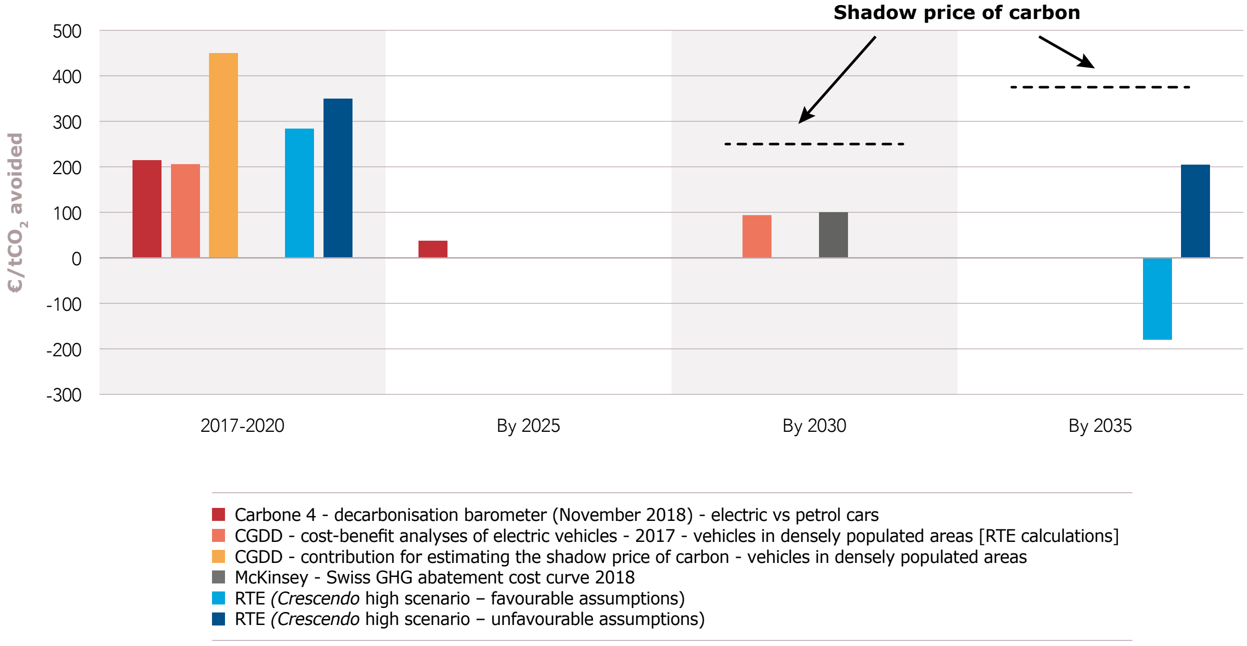
This means that the cost of electric vehicles is higher for the public than ICE vehicles. This additional cost (which is offset by public funds) represents around 10,000 € per vehicle over its lifetime.

Compared to the CO_2 emissions that are avoided, this additional cost to the public represents around 250 to 350 €/tCO_2 avoided over the whole lifetime of the vehicle – a level which must be compared with the cost of the emissions for the community (climate change) and of other external effects (electric vehicles emit fewer fine particulates than ICE vehicles and reduce the associated public health problems). This result falls in line with results from previous studies.

With the expected reduction in the cost of batteries, the additional cost of e-mobility will fall, to an extent which is subject to considerable uncertainty (dependence on assumptions on changing costs, battery capacity, the price of oil, etc.).

According to some optimistic, but plausible, assumptions there may be no additional cost for electric vehicles in comparison with ICE vehicles by 2030-2035. According to the most unfavourable projections, the cost of reducing greenhouse gas emissions by electrifying light-duty vehicles may represent up to 200 € per tonne of CO_2 avoided, i.e. a level below the shadow price of carbon by that time (ranging between 250 €/tCO_2 and 500 €/tCO_2). This illustrates the competitiveness of the possible actions for electrification of the light-duty vehicle sector, based solely on CO_2.

Figure 39. Estimated costs to the public of reducing greenhouse gas emissions by the electrification of transport



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[12] The example of Denmark, which scrapped electric vehicle subsidies at the beginning of 2016, clearly illustrates the need for financial support to encourage people to buy electric vehicles, with current vehicle costs. The scrapping of subsidies in Denmark in 2016 led to a ten-fold fall in sales of electric vehicles between the last quarter of 2015 and the first quarter of 2016.

7.9 The development of e-mobility raises other environmental and ethical issues

Issues associated with climate change are currently at the centre of public debate. Therefore, the analysis carried out mainly focuses on greenhouse gas emissions. However, the issue of climate change must not mask the existence of other environmental, ethical and strategic issues associated with the development of e-mobility.

Firstly, the development of e-mobility reduces other sources of pollution and has a significant public health benefit: reduction of certain pollutants, in particular fine particulates, which are particularly harmful (responsible for 48,000 deaths a year in France according to Santé Publique France (French institute for public health)) and noise pollution (responsible for 43,000 hospital admissions and 10,000 deaths a year in Europe, according to the European Environment Agency).

The study by the General Commission on Sustainable Development (CGDD), which incorporates a cost for this pollution, has shown that the benefits of e-mobility in terms of local pollution avoided can have a significant monetary value: over the lifetime of a vehicle, 1,000 € of external effects avoided in terms of noise related pollution and local pollution.

Secondly, the development of e-mobility increases the effect of other impacts for the environment through the production of batteries, in particular in areas where the mineral resources (lithium, cobalt, nickel and manganese) are extracted and processed.

The development of electric vehicles has an impact on ecosystems through the acidification of natural environments and the eutrophication of water, with the effect of depleting natural environments and affecting flora and fauna. The FNH (Nicolas Hulot Foundation for Nature and Mankind) study has quantified these effects: for an average European, switching to an electric vehicle results in an increase in his/her impact on biodiversity of around 8% to 15% (depending on the type of vehicle). In the context of an alarming decline in biodiversity (a million animal and plant species – i.e. one in eight – are likely to disappear from the face of the earth or from the seabed in the near future, according to the study by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services), the consequences of the development of electric vehicles on natural environments must be considered.

In addition to these environmental concerns, there are also ethical issues: the extraction of the metals (in particular cobalt) needed for making batteries, which is mainly concentrated in the Democratic Republic of the Congo, is carried out under conditions which violate workers' human rights, a situation which has been brought to public attention a number of times[13].

Discussions on decarbonising the transport sector must not overshadow these issues, or the fact that mobility based on petroleum-based products is not free from such issues. **Recycling of materials and efforts to find new battery technologies to reduce requirements for resources are therefore very important, along with the efforts to control consumption that have already been mentioned (using soft mobility, public transport and controlling battery size), which are in all cases no-regret options.**

For example, moving from the *Forte* scenario to the *Piano* scenario results in a reduction of around 35% in the total requirements for

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[13] According to UNICEF and Amnesty International, 40,000 children work there for up to 12 hours a day, in appalling health conditions and for payment of 1 to 2 dollars a day. See the Amnesty International report "*Human rights abuses in the Democratic Republic of the Congo power the global trade in cobalt*"

supplies of cobalt over the period 2020-2035 (i.e. around one year's cobalt production from the Democratic Republic of the Congo), due to control of the battery size and improved recycling. These figures are based on the current chemistry of batteries, which is likely to change, in order to limit requirements for rare metals.

FURTHER INVESTIGATIONS

The main findings presented in this document are derived from an in-depth study, the conclusions of which have been discussed in a follow-up group. More detailed results will be provided in the full report.

The study has provided answers to a number of questions, yet has thrown up several other areas requiring further investigation – both in theory and in practice – which can be further examined.

RTE and AVERE-France propose to extend the remit of the existing working group – which provides a platform for stakeholders from very different worlds to share their research – to continue working on the findings highlighted in the report, with the following aims:

1) To observe the impact of e-mobility development in practice

The findings presented in this report are derived from modelling the travel behaviour of the French population; they draw upon all the public sources of information currently available. The resulting power demand profiles could be compared with the actual charging curves available for the first wave of electric vehicle users.

However, the number of users is still not sufficient to provide consolidated feedback (and therefore the bias associated with the current panel – which is, by definition, very restricted – cannot be corrected). Hence, it is impossible to predict which scenario is likely to be the most appropriate for mobility models in practice.

It will be necessary to review all available data at regular intervals in order to refine the models and future expectations, so as to be in a better position to support the widespread roll-out of e-mobility. This will be a matter of priority for all future research relating to e-mobility.

This will involve, in the first instance, finding a way of sharing existing data to be able to derive the greatest benefit. This sharing of information needs to extend beyond the still fairly limited pool of demonstrators in France, and could even require stronger partnerships with certain authorities and large-scale trials (such as vehicle-to-grid technologies) to be set up.

2) To refine certain studies

The various different scenarios require further investigation, and may be subject to certain variants.

The *Opera* and *Forte* scenarios describe contrasting situations for the electricity system – widespread smart charging in one and very limited smart charging in the other. Feedback on actual user behaviour could allow new scenarios to be constructed based on a more refined set of parameters.

The *Alto* scenario is necessarily inherently more forward-looking (level 5 autonomous vehicles are still a long way off). Trials which could be launched within the scope of the French mobility law could provide interesting scenarios to help refine analyses from multiple perspectives: technical (charging modes), economical (charging cost, smart charging capability) and environmental (battery size, frequency of journeys made without passengers).

Within the context of the *Piano* scenario, a more detailed analysis of the interactions between different travel modes and their consequences for the electricity system could also be considered.

RTE will specify which partnerships with the relevant transport authorities are deemed necessary to augment these studies.

3) To complete the investigations

Even though the study reached a number of conclusions, several questions still remain unanswered. Further analyses may concern:

- Other examples and rationales for developing e-mobility and smart charging (such as companies owning a fleet of electric vehicles and charging them using solar panels, as proposed by several members of the follow-up group)
- Analysis of the market rules, testing the impact of alternative regulatory frameworks on system optimisation-related issues
- Integrating issues relating to the system as a whole (on a national and European scale) with those associated with optimisation at a local level, driven by Enedis and local distribution companies
- Full cost analysis (specifically for smart charging)
- Reviewing the assumptions based on the next national transport and travel survey (due for publication in 2020)
- Supporting the government and local authorities in analysing their future e-mobility strategies

However, certain aspects of the analysis of the impact on the electricity system were deliberately identified as being outside the scope of this study. This is particularly true for the grid adaptations required to accompany the widespread adoption of electric vehicles, which is the subject of separate projections prepared by RTE and Enedis respectively for the transmission and distribution networks in France.

RTE and Enedis have joined forces to tackle this particular aspect; more specifically they have agreed to conduct a joint study on highway charging infrastructure over the coming months. The results of this study are expected in 2020.

4) To guarantee open market mechanisms

The study proves that smart charging offers significant benefits. This should therefore be reflected in commercial supplier offerings – which can now be refined with the roll-out of smart meters. Some suppliers are starting to offer tariffs with a high differentiation between peak and off-peak periods, which is very much in keeping with the spirit of the report.

The study also highlights the technical benefits of reversible charging (vehicle-to-grid) for a proportion of users. There is still no commercial offer available in France today to leverage this flexibility; the technology is still very much in its infancy and the number of electric vehicles on the road is still low. Electricity suppliers, manufacturers and flexibility aggregators will all play a key role in building these offers.

In order to align the practicalities of leveraging flexibility with its theoretical potential, the market mechanisms need to be truly open and present no barriers to entry for these new offers. Two additional levels of response may be considered:

(1) Ensuring that all markets (ancillary services, balancing reserves, and capacity mechanism) are open to the supply of such services by aggregators based on the on-board batteries in electric vehicles. This would at least involve a review of the technical qualification and testing methods designed originally for stationary facilities.

(2) Establishing simplified procedures to support new business models, even for low volumes. RTE is hopeful that the "regulatory sandbox" framework set up as part of France's Action Plan for Business Growth and Transformation (known as the PACTE law) can provide the much-needed impetus to accelerate the implementation of certain flexibility measures. Indeed, RTE has built a specific procedure (a so-called "fast pass") into the balancing rules to stimulate the implementation of certain solutions with an obvious benefit to stakeholders. This device could be used to support a trial to test vehicle flexibility.

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