ECONOMIC AND ENVIRONMENTAL BENEFITS OF ELECTRIC VEHICLE SMART CHARGING IN A LARGE-SCALE EV INTEGRATION SCENARIO FOR FRANCE

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Overview

Massive transport electrification is an important driver of both greenhouse gas emissions and air pollution reduction, and several countries are taking steps in that direction. More than 20 countries have already announced a ban on sales of ICE cars over the next 10-30 years [1]. For example, France has recently put into the legislation a ban on sales of ICE vehicles using fossil fuels by 2040 [2]. While the impact of EV charging on peak electricity demand needs to be carefully analysed, the flexibility of EV charging patterns can provide demand-side response opportunities to facilitate the penetration of intermittent renewable energy sources, reducing the needs for peak load power plants [3-5]. In this study, we quantify the potential economic and environmental benefits of EV load management strategies in a long-term scenario (2035) for France, with a high share of renewable electricity generation (48%) and a significant development of e-mobility (up to 15.6 million vehicles). The analyses are conducted in a welfare analysis framework, using a large-scale model of the European electricity system.

Methods

The methodology used to assess the benefits of smart charging and V2G relies on the combination of two models: a model describing the driving patterns and uncontrolled charging demand of EVs and a power system simulator. The simulation of EV behaviour and charging patterns is based on a statistical methodology, using data from the latest French national travel survey (Enquête Nationale Transports et Déplacements [6]). User profiles for daily trips are identified based on travel patterns (commuting, leisure users, commuting/leisure combination, company cars, long-distance journeys), area type (urban or rural) and day of the week (Monday to Friday, Saturday, Sunday). Different vehicles are then simulated throughout every day of the year based on a combination of user profile and vehicle characteristics, using a Monte Carlo approach with a large sample of vehicles. Three scenarios (table 1), with variants considering different numbers of EVs (fig. 1), are analysed to represent different combinations of hypotheses. For each scenario, the EV model provides the users' mobility requirements, plug-in periods, plug-in power and uncontrolled charging demand (fig. 2).

The power system is modelled using the Antares power system simulator [7], which minimises the expected operating cost of the European transmission-generation system for interconnected power grids at an hourly resolution, using a Monte Carlo approach. A detailed representation of EV behaviour is implemented to estimate the flexibility of EV charging while ensuring the satisfaction of the users' mobility requirements (plus a 30% margin, meaning that the battery state of charge can never be lower than 30% when the vehicle arrives at the next charging point). The model provides the smart-charging demand of EVs, electricity prices, CO_2 emissions and electricity generation costs.

The assumptions concerning the electricity mix in 2035 are coherent with government objectives outlined in the Multiannual Energy Plan [8] and the National Low Carbon Strategy [9]. These include an accelerated development of renewable energy sources (RES) between now and 2028 (assumed to be extended into the period 2029-2035), phase-out of coal-based electricity generation in the medium term and no new fossil fuel power station infrastructure and decommissioning of 14 nuclear reactors by 2035, bringing the share of RES generation to 48% by 2035.

Table 1 : Main parameters of e-mobility scenarios

Scenario	Description	Number of light-duty EVs• (millions)	Share of PHEV (%)	Avg. battery capacity for BEVs (kWh)	Annual distance (km/ year)	Share of EV having access to away-from-home charging stations (%)	Avg. power of home EV charger (kW)	Share of smart charging and V2G✦ (%)
Forte intermediate	Stressed power system	11.7	40	89	15 300 (21% long-distance°)	16	6.5	40% (no V2G)
Forte high		15.6	22					
Crescendo intermediate	Standard projections	11.7	40	73	14 000 (14% long-distance)	28	5.9	60% (with 3% V2G)
Crescendo high		15.6	22					
Opera intermediate	High flexibility	11.7	40	73	14 000 (14% long-distance)	45	6.5	80% (with 20% V2G)
Opera high		15.6	22					

• *out of a projected total of 38,3 million light-duty vehicles in 2035*
✦ *Share is 0 % in the case of uncontrolled charging demand for each scenario*
° *Trips of more than 80 km as the crow flies*

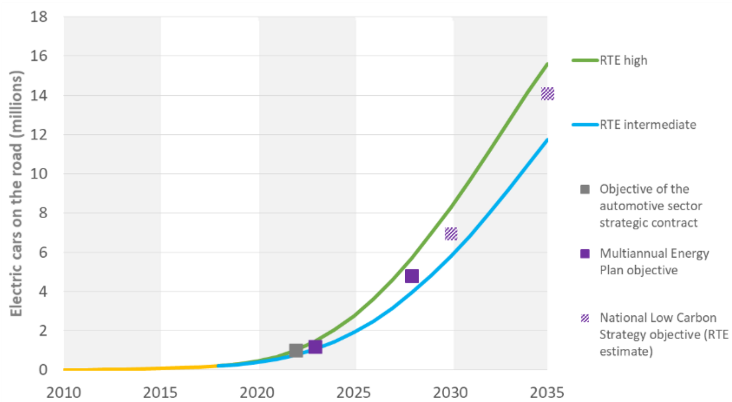

Figure 1: E-mobility development scenarios for France. Fleet of light-duty electric vehicles (private vehicles and light-duty commercial vehicles) including 100% electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV)

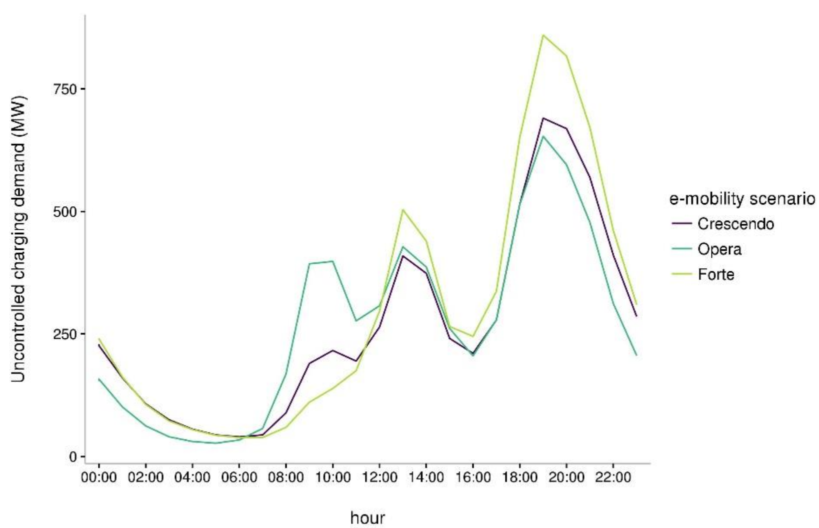

Figure 2: Uncontrolled charging demand for a weekday, for one million EVs in different e-mobility scenarios

Results

Although the electrification of light-duty vehicles in France will result in a significant rise in electricity consumption by 2035 (25 to 40 TWh in considered scenarios), this volume of energy will still represent only between 5% and 8% of total electricity consumption expected for France in 2035. Peak demand for uncontrolled charging (typically in the evening, between 7 p.m. and 9 p.m.) may cause concerns for security of supply under some circumstances, but the introduction of simple static price signal charging on a portion of the EV fleet would be sufficient to ensure that security of supply is guaranteed. For exemple, charging based on a simple static time-of-use tariff on 55% of the EVs would be sufficient in the most challenging scenario considered for the power system, *Forte high*.

Even though a minimum level of smart charging is sufficient to ensure security of electricity supply, the development of smart charging solutions represents a very interesting opportunity to reduce the costs of electricity generation and its environmental impacts. For an equivalent level of transport electrification, the cost of electricity generation for charging electric vehicles varies considerably according to the e-mobility scenario, depending foremost on the type of smart charging and its diffusion (fig. 3). This cost is calculated compared to a scenario without any development of e-mobility, supposing that the generation mix in e-mobility scenarios, and in particular the installed capacity of solar PV and wind power, is coherent with the increased energy use due to EVs compared to the counterfactual scenario. The widespread deployment of even simple smart charging appears to be a "no regret" option, leading to significant collective savings (0.6 billion euros/year when comparing Forte high scenario to uncontrolled Forte high) with low costs. Sophisticated smart charging between the system and vehicles, combined with V2G injection and high access to charging stations away-from-home, leads to substantial additional savings : the cost of electricity generation for EVs is 1.1 billion euros/year lower in Opera high scenario than in Forte high.

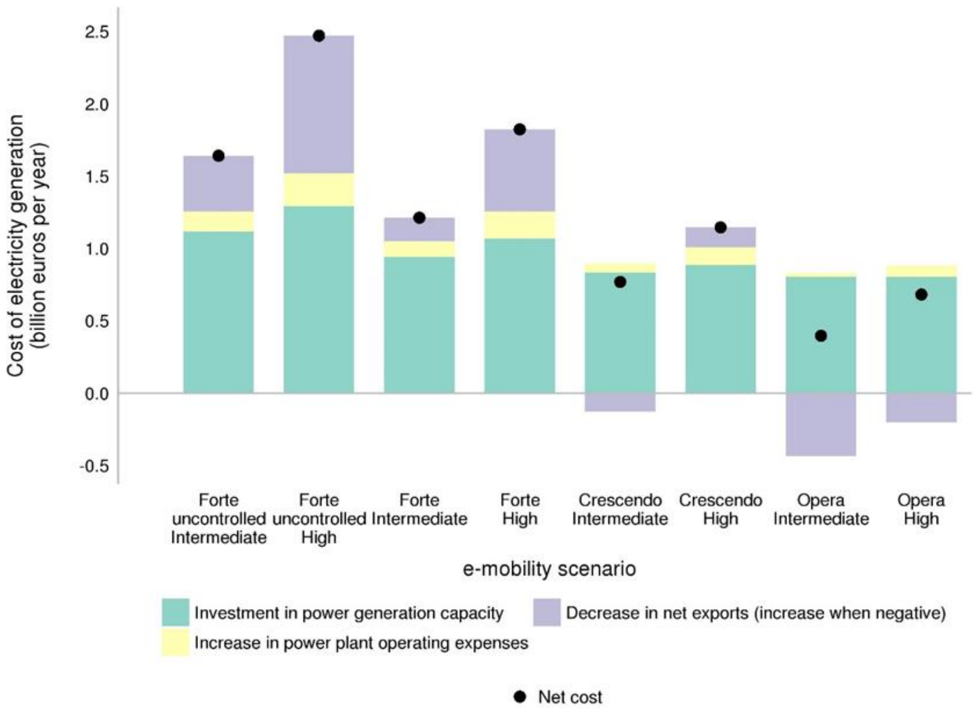

Figure 3: Cost of electricity generation for EV charging in different e-mobility scenarios, compared to a 2035 scenario without development of e-mobility

Direct greenhouse gas (GHG) emissions associated with EV charging are in all e-mobility scenarios much lower than the ones that woud occur if the EV fleet were substituted by ICE vehicles. Even in a scenario with uncontrolled charging, these are 30 to 60 times lower than the emissions from fuel combustion of their ICE counterparts, taking into account technical progress for ICE engines (figure 4 and 5). The volume of GHG emissions attributable to EV charging is estimated by comparing the emissions in e-mobility scenarios to those of a counterfactual 2035 scenario without electric vehicles, supposing that the generation mix in e-mobility scenarios, is coherent with the increased energy use due to EVs, as for cost estimation. The emissions considered are direct GHG emissions due to electricity generation. Smart charging can improve the environmental benefits of the transition towards e-mobility, by reducing even further direct GHG emissions attributed to electricity generation for EV charging. Emissions are particularly low for scenarios with a high level of smart charging and V2G (Crescendo and especially Opera), becoming even negative in some cases (fig. 4). This means that in these cases, the flexibility provided by smart charging and V2G allows for a better optimization of power generation, reducing total greenhouse gas emissions compared to a scenario without electric vehicles, despite the increase in total electricity generation.

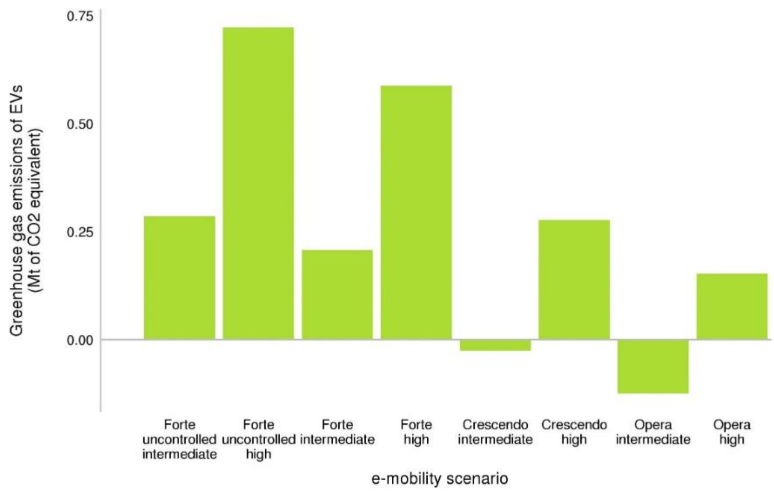

Figure 4: Increase in direct greenhouse gas emissions from electricity generation in France due to EV charging, in different smart-charging scenarios (compared to a scenario without electric vehicles)

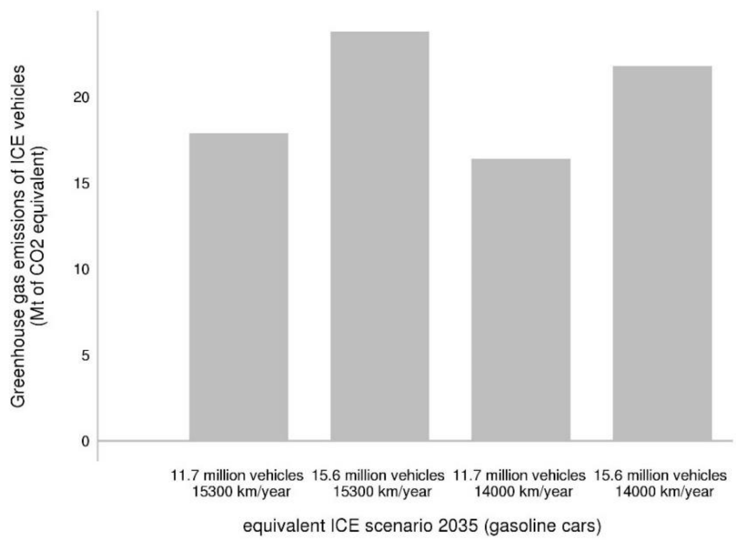

Figure 5: Direct greenhouse gas emissions from fuel combustion in ICE vehicles (gasoline), for a number of vehicles and annual distance travelled in 2035 identical to those of EVs in the e-mobility scenarios considered.

Conclusions

With an expected evolution of the power system towards a high share of renewables in the generation mix in France by 2035, the development of e-mobility can be an asset for the economic and environmental optimisation of electricity generation. The flexibility provided by smart charging and V2G leads to significant reductions in the costs and GHG emissions of electricity generation.

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