“From cradle to grave: e-mobility and the energy transition”

Addendum for Italy, the United Kingdom, Spain and the European Union to “*Le véhicule électrique dans la transition écologique en France*”

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List of acronyms

BEV:	Battery Electric Vehicle
CPS:	Current Plans Scenario
ENTSOE:	European Network of transmission System Operators for Electricity
EU:	European Union
EV-REX:	Electric Vehicle with a Range Extender
GHG:	Greenhouse gas
GWP:	Global Warming Potential
ICEV:	Internal Combustion Engine Vehicle
LCA:	Life Cycle Analysis
MHEV:	Mild Hybrid Electric Vehicle
PHEV:	Plug-in Hybrid Vehicle

Abstract

This addendum[1] to the study "*From cradle to grave: e-mobility and the French energy transition*" presents a detailed analysis of the environmental impacts of electric vehicles for three additional European Union Member States, as well as compares the results with a European Union average, over their entire life-cycle (from cradle to grave). Spain, Italy and the United Kingdom have been analysed.

Although electric vehicles can significantly improve air quality in cities in terms of nitrous oxide and particulate emissions, this addendum is focused on the carbon footprint of vehicles.

The Life Cycle Analysis based model that was used in the French energy transition study "*From cradle to grave: e-mobility and the French energy transition*" has been applied to these additional EU Member States in order to express and compare the carbon intensity of electric vehicle usage across the continent.

The results show that shifting to electrified vehicles does on average significantly reduce GHG emissions compared to ICEVs, in both timeframes and for all countries in the scope of the study. There are significant differences between countries, the national electricity mixes being a determining factor responsible for the level of carbon advantage compared to ICEVs. There is also a wide variation of carbon footprint among the different electrification options (fully electrified or partially electrified vehicles), yet the BEVs always have a lowest carbon impact than partially electrified vehicles, except for sedans in Italy in the present situation: carbon footprints are relatively similar. The difference among electrification options is wide today among PHEVs and BEVs; this gap tends to significantly decrease in 2030 for sedans, but remains for small city cars. The carbon footprint of EV-REX vehicles drastically decreases among 2017 and 2030 to reach the BEVs level.

[1] A. SCHULLER, C. STUART, "Addendum for Italy, United Kingdom, Spain and EU28" to M. CHERON, A. GILBERT D HALLUIN, A. SCHULLER "From cradle to grave: electro-mobility in the French energy transition", Carbone 4, 2018.

1. Context

Context of the Addendum

In the study *"From cradle to grave: e-mobility and the French energy transition"*, the environmental impacts of various types of passenger vehicles were assessed over their whole life cycle in the French context and in three prospective scenarios for 2030.

In order to evaluate whether the advantage of Battery Electric Vehicles (BEVs) still holds outside of France, the initial study has been extended to other European Union Member States, in particular to selected countries with carbon-intensive electricity mixes.

European and national energy climate objectives

The European Union (EU) has identified the need to reduce the carbon intensity of the transport sector in order to achieve its greenhouse gas (GHG) emissions reduction targets by 2050. Indeed, the transport sector represents 25% of the EU's total GHG emissions. More specifically, road transport emits the majority: at 70% of all transport emissions in 2014[2].

In July 2016, the European Commission adopted a low-emission mobility strategy in order to address this issue. The Commission's Transport White Paper sets the goal to reduce emissions from the transport sector by 60% by 2050, compared to 1990 emissions. It is noteworthy an even more drastic reduction would be necessary to be compliant with the Paris Agreement to limit climate change well beyond 2°C. The strategy includes "moving towards zero-emissions vehicles". Even though internal combustion engine vehicles (ICEVs) are becoming more efficient, electric vehicles will also be necessary in order to transition towards a low-emission transport sector.

As the carbon intensity of electricity is a key driver of the carbon footprint for electric vehicles, the diversity of the latter amongst Member States must be analysed. In addition, grid decarbonization is likely to have significant effects on the carbon intensity of electricity.

It is therefore relevant to compare, on the one hand, the impact of today's electric vehicle usage in different Member states, and on the other hand, the impact of tomorrow's electric vehicle usage.

Objective of addendum

The objective of the addendum to the "From cradle to grave: e-mobility and the French energy transition" Study is to **evaluate the risks and opportunities for electric vehicle deployment in the European Union both today and in 2030.**

[2] https://ec.europa.eu/clima/policies/transport_en

2. Analysis scope

Mono-criterion Life Cycle Analysis: global warming potential

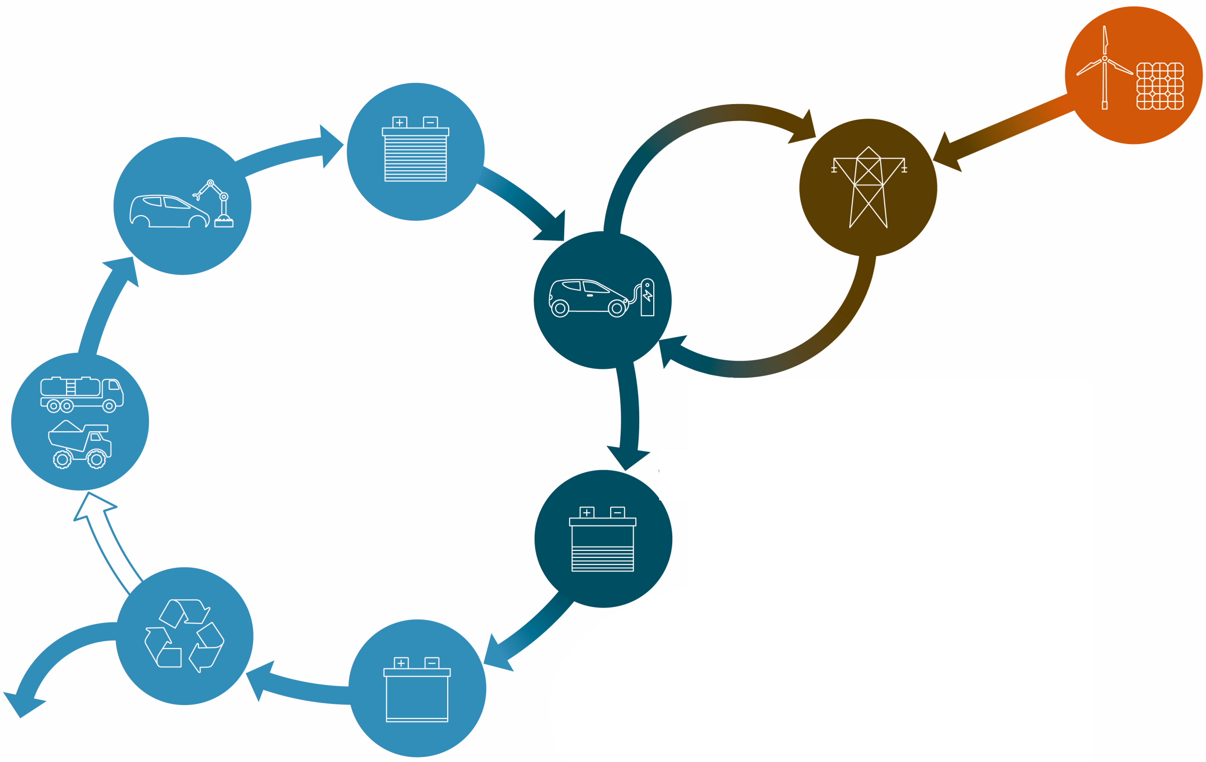
A mono criterion Life Cycle Analysis (LCA) approach is used in order to compare the carbon footprint of various vehicles across the whole life cycle. A more complete LCA, as was used for the previous study for France, would cover multiple indicators, such as abiotic depletion, water eutrophication, photochemical pollution and acidification. This addendum will however only focus on global warming.

The indicator of carbon footprint is the Global Warming Potential (GWP): that is the contribution of all GHG emitted into the atmosphere during the lifecycle of the studied vehicle. The unit used is: $kgCO_2eq$.

The analysis includes all phases from the production of the battery up until the end-of-life of the entire vehicle and the recycling processes. Studying GWP over the whole life cycle of the vehicles provides a comprehensive scope of environmental impact comparisons.

The benefits of electric vehicles in terms of air quality are not in the scope of this study. Yet it is noteworthy to recall that electric vehicles significantly reduce nitrous oxide and particulate emissions.

Fig. 1: Boundaries of the life-cycle assessment



Inter-temporal Life Cycle Analysis comparison

This LCA is being conducted for two timeframes in order to compare the environmental impact of a BEV versus an ICEV today and in 2030. By using the same model as for the study for France, the calculation of the 2030's future impacts is made possible as well as the calculation of today's impacts. Several hypotheses and assumptions are considered for the 2030 projections. More information on the 2030 scenario is explained below.

Geographic scope

In order to compare the results from the France study, this addendum will analyse the impact of electric vehicles for three additional European Union Member States, as well as compare the results with a European Union average. Spain, Italy and the United Kingdom have been analysed. The results for the European Union average have been calculated according to a weighted average based on the electricity production share by each Member State.

Types of vehicles

This addendum focuses on the GWP for seven vehicle types. Two different vehicle sizes are compared: a large sedan and a small city car, for different energy usage types: i) ICEVs, that are supposed to be Mild Hybrid Electric Vehicles (MHEVs) in 2030[3], ii) Plug-In Hybrid Electric vehicles (PHEVs), iii) an Electric Vehicle with Range Extenders (EV-REX) (for small city cars only) and iv) Battery Electric Vehicles.

In the sedan cars segment, there is a very specific PHEV that is presented separately, since it is a luxury four-wheel drive SUV, and therefore not directly comparable with other vehicles tested.

Functional unit

The functional unit of the LCA is the **circulation of vehicles over a given number of kilometres**. This mileage is differentiated between the two sizes of vehicles: **150,000 km for city cars** and **250,000 km for sedans**.

Vehicles characteristics

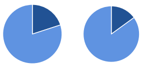
The methodology takes into account several parameters of the vehicles, including: battery capacity and unitary consumption, as well as annual mileage, driving patterns and the charging profile.

All parameters are considered constant between the main study for France and this addendum to the study, except for the electric / thermal usage split for PHEVs. Reflecting the debate upon the appropriate procedure for the determination of fuel consumption

[3] Compared to the 2017 ICEV, the 2030 MHEV produces 30% less CO_2 emissions on the sedan cars segment, and 40% on the small cars segment.

and CO_2 emissions in Europe, the hypothesis of a constant share of 50% in electric mode has been introduced[4].

Table 1: Vehicle characteristics breakdown by vehicle type and time horizon

		Motorization	**Weight** *kg*	**Electric/ thermal usage** *%*	**Battery capacity** *kWh*	**Electricity consumption** *kWh / 100 km*		**Thermal consumption** *litres / 100 km*	
		2016 & 2030	2016 & 2030	2016 2030	2030	2016	2030	2016	2030
City car	**ICE** (MHEV in 2030)	Petrol	1 138		1,5*	na	na	6,5	3,8
City car	**PHEV**	Hybrid: electric petrol	1 568		17	14	14	4,3	3
City car	**EV-REX**	Electric + range extender	1 384		35	17	14	7,5	3,5
City car	**BEV**	Electric	1 465		50	13	13	na	na
Sedan	**ICE** (MHEV in 2030)	Diesel	1 500		3*	na	na	5,8	3,9
Sedan	**PHEV**	Hybrid	1 800		24	17	16	6,5	3,8
Sedan	**BEV**	Electric	1 955		90	21	20	na	na
Sedan	**PHEV** (4x4 SUV)	Hybrid	2 360		27	21	21	9,8	5,7

 100% petrol

 100% elec.

* For electrified ICE vehicles

Charging characteristics

For this addendum, only "natural" charging is considered (i.e. not managed and not bidirectional). In addition, the potential "2nd life" battery services are not considered in this addendum to the study. The latter correspond to services that a used vehicle battery can offer, such as for stationary energy storage. For more information on "natural" charging, please refer to the study for France.

Example of Life Cycle Analysis: the case of France

Figures 2 and 3 show the warming potential of the vehicles in France in 2017 and 2030, for small and large cars respectively. At the present time, a small electric car emits 70% less greenhouse gases than a petrol car (10 tCO_2eq and 32 tCO_2eq, taking into account the

[4] I. RIEMERSMA, P. MOCK, "Too low to be true? How to measure fuel consumption and CO_2 emissions of plug-in hybrid vehicles, today and in the future", ICCT, 2017. https://www.theicct.org/publications/too-low-be-true-how-measure-fuel-consumption-and-co2-emissions-plug-hybrid-vehicles

recycling credits), and an electric sedan car produces 57% less CO_2 emissions than an ICEV of the same segment.

Fig. 2: Comparison of small vehicles' global warming potential in France in 2017 and 2030

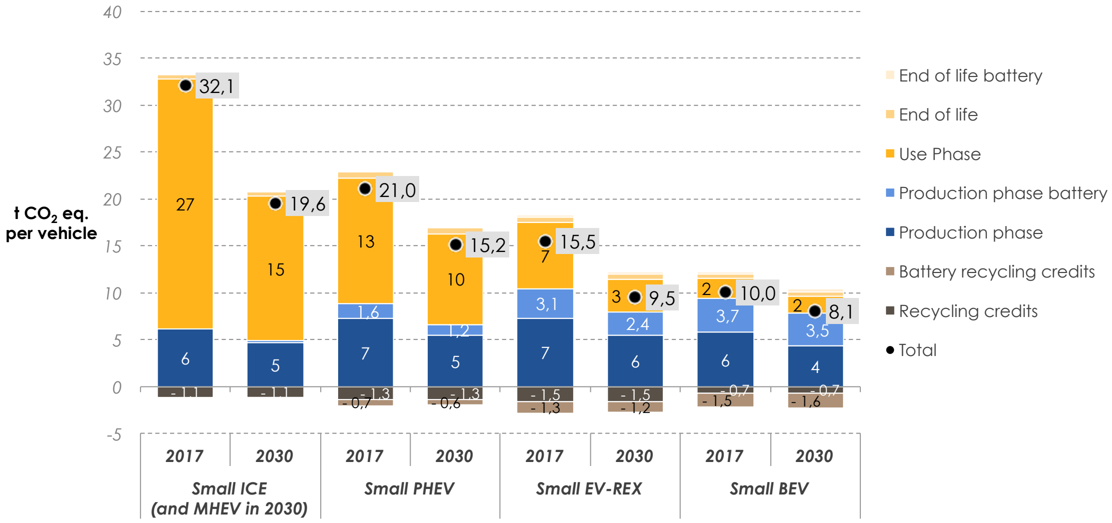
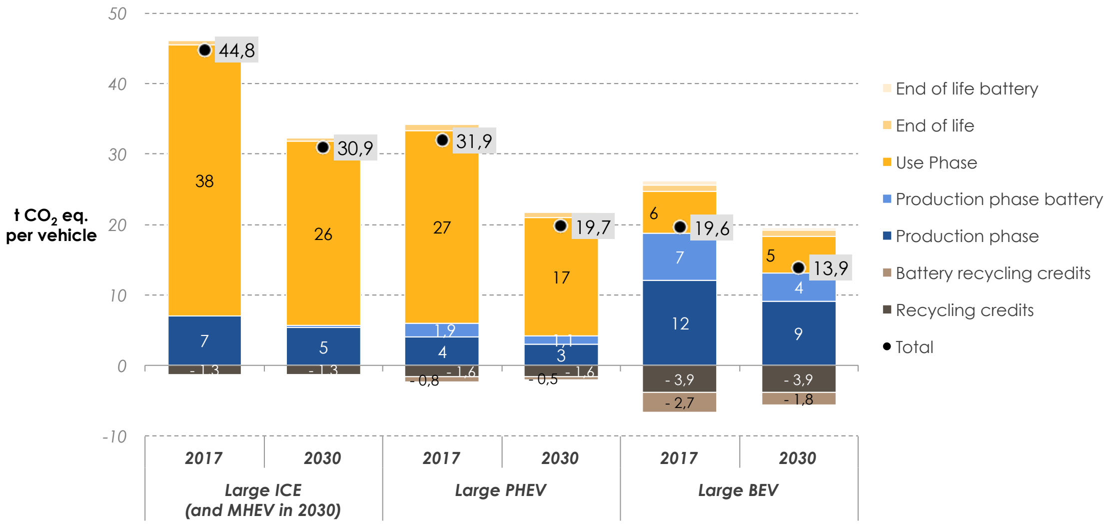


Fig. 3: Comparison of large vehicles' global warming potential in France in 2017 and 2030



For more information on the methodology please refer to the technical study for France: https://europeanclimate.org/le-vehicule-electrique-dans-la-transition-ecologique-en-france/

3. Methodology

Description of underlying model

As described in the study for France, the underlying model uses electricity generation data from different countries as input in order to provide results on the carbon intensity of different vehicles. The inputs are provided in $kgCO_2e/kWh$ generated for a specific hour.

As the carbon intensity of electricity is variable during the year and in order to conduct the analysis over a year, the inputs have been categorized into hourly generation profiles for six day-types. These correspond to three types of seasons (Summer, Winter and inter-seasonal) and to two types of days during the week (from Monday to Friday and weekends). The model then matches these hourly carbon intensity profiles with the vehicles parameters and charging profiles. This methodology is used for both the current electricity mixes and for the 2030 scenario electricity mixes.

Datasets for current scenario

Electricity generation data
The publicly available European Network of transmission System Operators for Electricity (ENTSOE) data has been used in order to produce the six day-type hourly profiles for each country in the current scenario. Hourly electricity generation data has been extracted by production type (such as, nuclear, gas or solar PV) for each country. In order to deduce the carbon intensity for each kWh generated, a different emission factor has been attributed according to the production type.

Emission factor data
The carbon intensity of electricity generation for a given hour is the combination of the hourly mix with the emission factors of electricity generation from each production type (such as, nuclear, gas or solar PV). Based on a LCA approach, these emission factors are country-dependent in order to take in to account the specificities of Member States (e.g. the yield of solar production). Multiplication of the generation data with emission factors thus results in hourly carbon intensity profiles for each country.

For the current scenario and for each country when possible, the data has been averaged over three years: 2015, 2016 and 2017. The EU average is based only on 2016 data for seven Member States. The latter include Germany, France, the United Kingdom, Italy, Spain, Poland, Sweden, the Netherlands and Belgium, and represent 80% of the total EU electricity generation in 2016. The production weighting for the EU average has been calculated according to the percentage representation of the electricity production by each Member State over the year 2016[5].

Datasets for the 2030 scenario

Electricity generation data
The model for the 2030 scenario is based on the Artelys Crystal Super Grid Software application[6]. This model uses a bottom-up approach and has an hourly and country granularity.

[5] "Production brute totale d'électricité", Eurostat, 2016.
http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&plugin=1&language=fr&pcode=ten00087

[6] "Cleaner, smarter, cheaper, Responding to opportunities in Europe's changing energy system, 2017", Energy Union Choices consortium.
https://www.e3g.org/docs/Cleaner,_Smarter,_Cheaper_Report_Web11.pdf

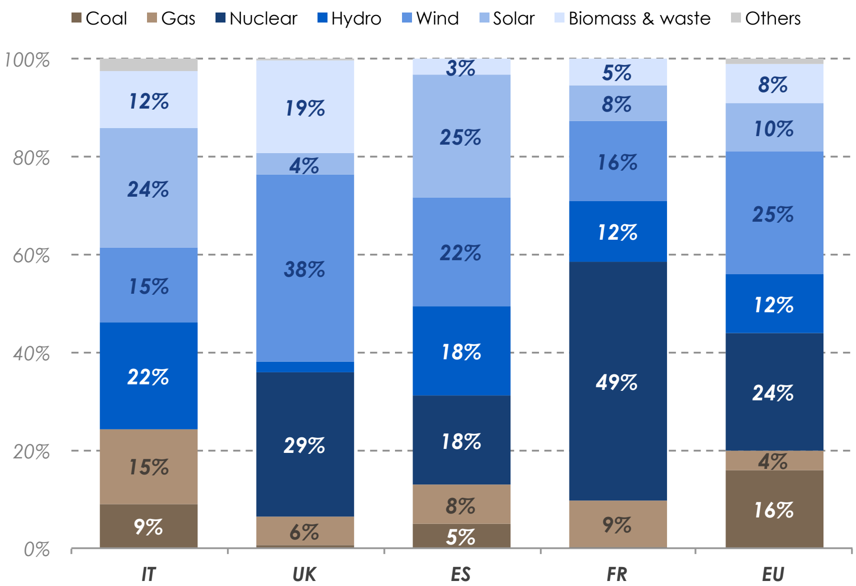
The key hypothesis that determines the 2030 scenario is that the previous climate targets of the European Commission have been met (EUCO30 scenario)[7]:

- An increase in the share of renewable energy for final energy consumption, reaching 27%
- A decrease in GHG emissions by 40% compared to 1990 levels
- A decrease in primary energy consumption by 30% compared to PRIMES 2007 baseline levels.

It should be noted that this assumption is likely to be more conservative than reality after approval of the Clean Energy Package in the co-decision process, since the updated version from the last European Council says 32% renewable energy, 45% GHG reduction, and 32.5% of energy efficiency[8].

Several policy assumptions have also been made in order to construct the specific 2030 scenario, the "Current Plans Scenario (CPS)". The CPS has integrated the policy incentives of the Clean Energy Package, which include full regional cooperation and demand side flexibility measures. This has been modelled in the Artelys Software, thanks to the consideration that 100% of inter-connectors for generation are available, that renewable energy systems are used at regional level and that reserve sharing is in play. Demand side response measures have also been integrated into the model: 100% of industrial load shedding potential is available and 25% of the industrial/commercial load shifting potential is available. This model assumes that renewable energy systems can be increased thanks to updates of the WACC, CAPEX and capacity factor data.

Fig. 4: 2030 CPS electricity mixes for six EU Member States



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[7] https://ec.europa.eu/energy/sites/ener/files/documents/20170125_-_technical_report_on_euco_scenarios_primes_corrected.pdf

[8] https://www.euractiv.com/section/climate-environment/news/eu-in-de-facto-position-to-up-emissions-reduction-from-40-to-45/

Emissions factor data

The same emission factors as for the current scenario have been used for the 2030 projections for all generation sources. The only additional emission factor that has been considered in the 2030 projections is the battery emission factor (absent for the current context). It corresponds to the discharging of batteries that are previously charged by electricity from the grid. The assumptions are the following:

Hypotheses for carbon impact at battery production:

- Carbon impact of battery production: 200 kgCO_2eq/kWh
- Charging cycles over lifetime: 5,000 cycles.

Hypotheses for carbon impact during usage/charging of battery:

- Efficiency: 90%
- Transmission and distribution losses: 6.5 kgCO_2eq/kWh
- Carbon impact of charging electricity is an average across all renewable energy sources.

Implementation of the methodology: example for the UK

As an illustration of the implementation of the methodology, figures 5 and 6 show the warming potential of the vehicles in the UK in 2017 and 2030, for small and large cars respectively.

Fig. 5: Comparison of small vehicles' global warming potential in the UK in 2017 and 2030

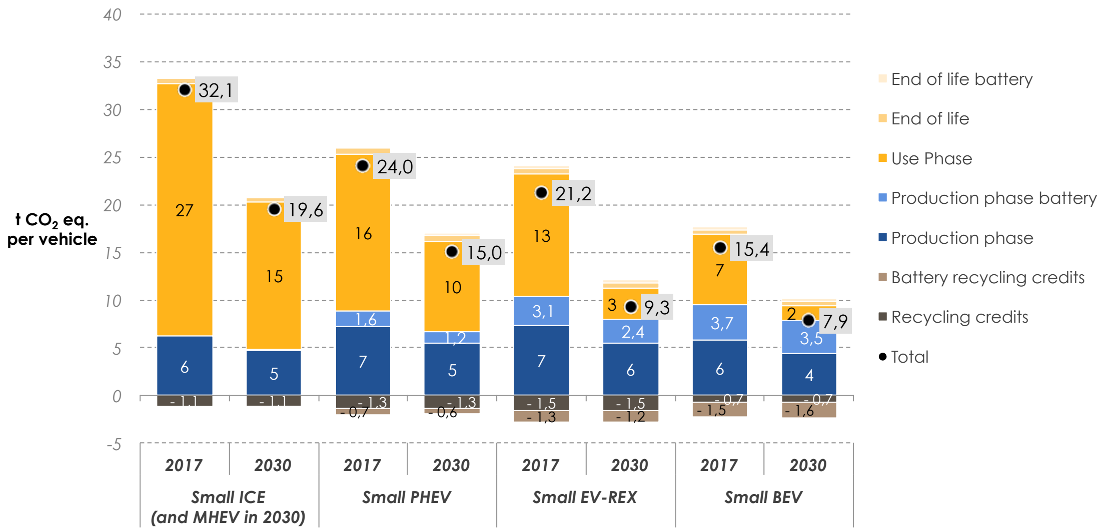
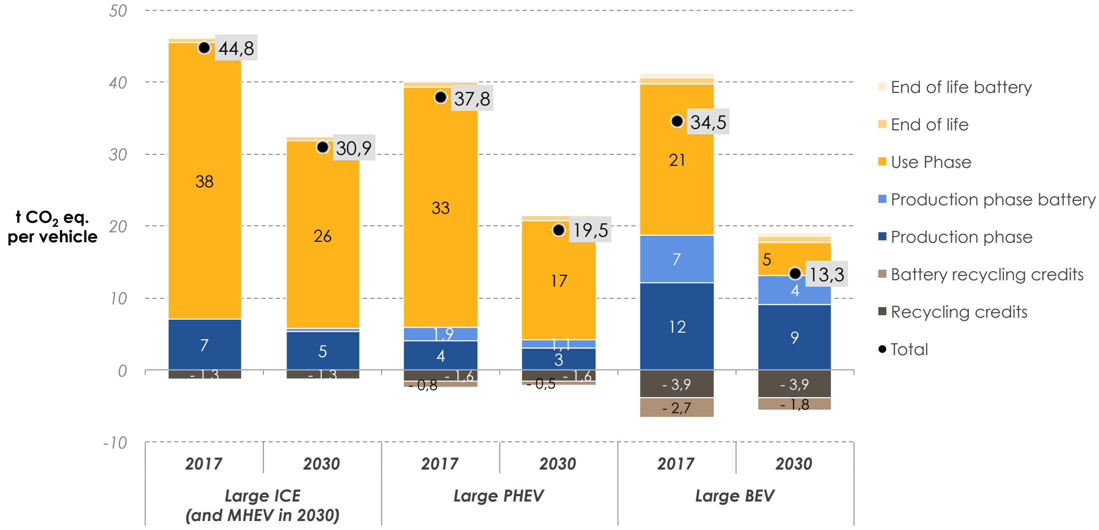


Fig. 6: Comparison of large vehicles' global warming potential in the UK in 2017 and 2030



Due to the grid decarbonization of the UK, the carbon footprints of electrified vehicles decrease drastically, especially for the EV-REX and the BEV in the small cars segments (respectively 56% and 49% reductions from 2017 to 2030) and for the large BEV (62% reduction).

Methodology limits

The major limits of this addendum to the study are related to the quality of the current publicly available data from the ENTSOE database. In order to calculate the electricity generation mixes for each country and for the EU average, no electricity exports (nor imports) were considered. For lack of data availability, the actual results for the UK are based only on the electricity mix of 2016, and results for Italy take into account 2016 and 2017 (instead of an average across three years). Finally, UK data was only consistent every two hours. Therefore, averages between every two hours for which consistent data was available have been used in order to recreate an hourly distribution of electricity generation.

Another limit can be identified for the assumptions made for the prospective emission factors. Indeed, current emissions factors have been used for the 2030 model. As conventional power plants are most likely going to increase in efficiency, keeping the emission factors constant could imply that the 2030 projections are conservative, that is to say more carbon-intensive than they will be in the real world.

4. Results and analysis

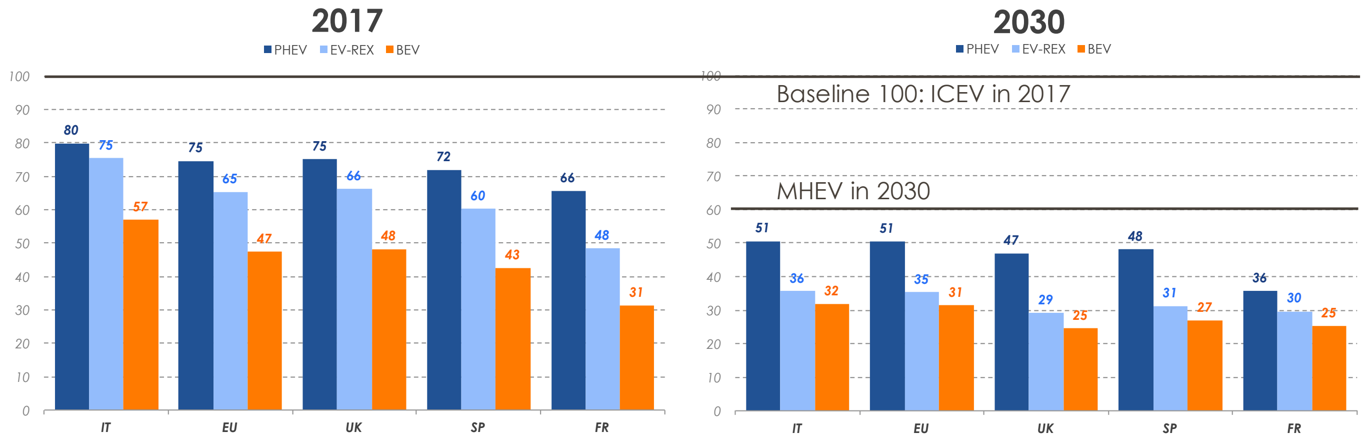
As the analysis has been made for three vehicle types, the GWP impacts of BEVs, PHEVs and EV-REXs have been compared to the GWP impacts of an ICEV today, represented by a baseline of 100 (horizontal solid grey line).

Vehicle comparison by country today and in 2030

The GWP results by vehicle type in each country show that **shifting to electrified vehicles does on average significantly reduce GHG emissions compared to ICEVs, in both timeframes and for all countries in the scope of the study**. Among the different electrification options (fully electrified or partially electrified vehicles), **the BEVs always have a lowest carbon impact than partially electrified vehicles**, except for sedans in Italy in the present situation: carbon footprints are quite similar. The difference among electrification options is wide today among PHEVs and BEVs; this gap tends to significantly decrease in 2030 for sedans, but remains for small city cars. The carbon footprint of EV-REX vehicles drastically decreases among 2017 and 2030, and reaches the BEVs level.

Figure 7 shows the GWP vehicle breakdown by country for a city car. Carbon footprints are expressed in comparison with the 2017 ICEV baseline. The value of 100 corresponds to the carbon footprint of a petrol car that weighs approximately 1 140 kg and emits 150 g CO_2eq/km (tailpipe emissions in real-driving conditions).

*Fig. 7: Carbon footprint of small city cars in 2017 and 2030**



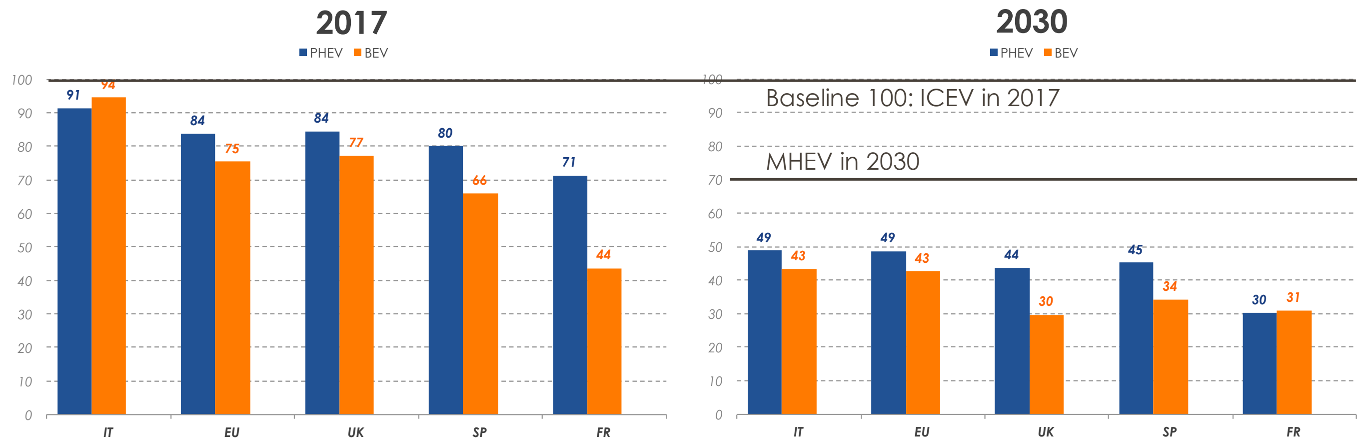
** baseline 100 compared to an ICEV in 2017 / carbon footprint with recycling credits*

In 2017 for small city cars, in all countries the small city BEVs have a significantly lower carbon footprint compared to the baseline (from 40% reduction in Italy up to a 70% reduction in France). The advantages of PHEVs are relatively minor, representing on average only 25% less emissions than an ICEV. In general, EV-REXs emit less carbon emissions than PHEVs and they represent a significant carbon advantage compared to ICEVs (at least 30% reduction in emissions) except in Italy. On average, a small city BEV emits half of a small city ICEV, whilst partially electrified vehicles emit on average 30% less than their ICEV counterparts.

In 2030 compared to 2017 for small city cars, carbon footprints are significantly reduced. As a whole, it is a higher decrease for vehicles with a higher initial point in 2017 (i.e. PHEVs) and for vehicles in the UK. On average, small city BEVs in 2030 enable a 70% reduction in emissions compared to ICEV in 2017, and a 50% reduction in comparison with the MHEV baseline of 2030. Partially electrified vehicles only enable a 30-40% emission reduction compared to the MHEV in 2030.

Figure 8 shows the GWP vehicle breakdown by country for a sedan. Carbon footprints are expressed in comparison with the 2017 ICEV baseline. The value of 100 corresponds to the carbon footprint of a diesel sedan that weighs approximately 1 500 kg and emits 150 g CO_2eq/km (tailpipe emissions in real-driving conditions).

*Fig. 8: Carbon footprint of sedan cars today and in 2030**



** baseline 100 compared to an ICEV in 2017 / carbon footprint with recycling credits*

In Italy in 2017, associated GHG emissions levels of BEVs, PHEVs and ICEVs are relatively similar, due to the carbon impact of electricity generation from fossil fuels. In Spain, the BEV sedan allows a significant reduction of carbon footprint compared to ICEVs (more than a third). In the case of France, it is even more with a 56% reduction. Sedan PHEVs as a whole emits slightly less than ICEVs: 9% less in Italy, and 30% in France. On average, a sedan BEV emits 25% less than a sedan ICE vehicle (and 16% less for PHEVs running 50% of time in depleting mode) and acknowledging that there is great inequality between countries.

In 2030 compared to 2017, in all countries the carbon footprints of electrified sedans are significantly decreased, especially in Italy, the UK and Spain where the carbon footprints of PHEVs and BEVs are approximately halved between 2017 and 2030. On the contrary, the BEV's carbon footprint remains relatively stable in France. As a result, in 2030 BEVs' carbon footprints in the UK, Spain and France represent less than a third of an ICE's footprint in 2017, and less than a half of a MHEV's footprint in 2030.

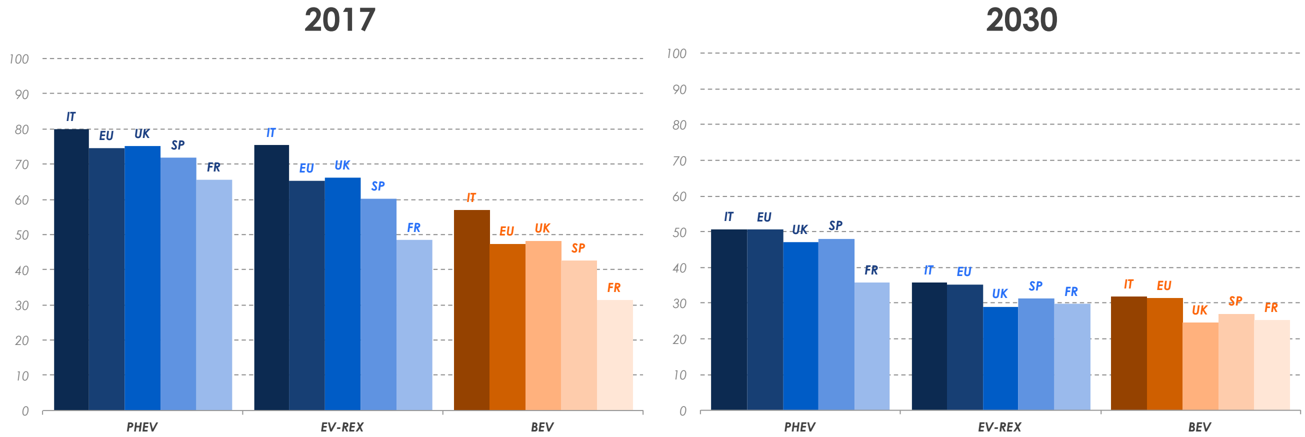
On average, in 2030 the European carbon footprint of BEVs is 60% less than that of an ICE of 2017, and 40% than an MHEV in 2030.

Country comparison by vehicle type today and in 2030

A carbon footprint country comparison by vehicle type enables another vision of these carbon evolutions. Each BEV, PHEV and EV-REX model can be more closely compared using the figures below. However, there is a wide variability among the present carbon footprints among countries, that tends to considerably decrease in the 2030 horizon.

Figure 9 shows the GWP country breakdown by vehicle type for both a city car. Carbon footprints are expressed in comparison with the 2017 ICEV baseline. The value of 100 corresponds to the carbon footprint of a petrol car that weighs approximately 1 140 kg and emits 150 g CO_2eq/km (tailpipe emissions in real-driving conditions).

*Fig. 9: Carbon footprint of small city cars today and in 2030**

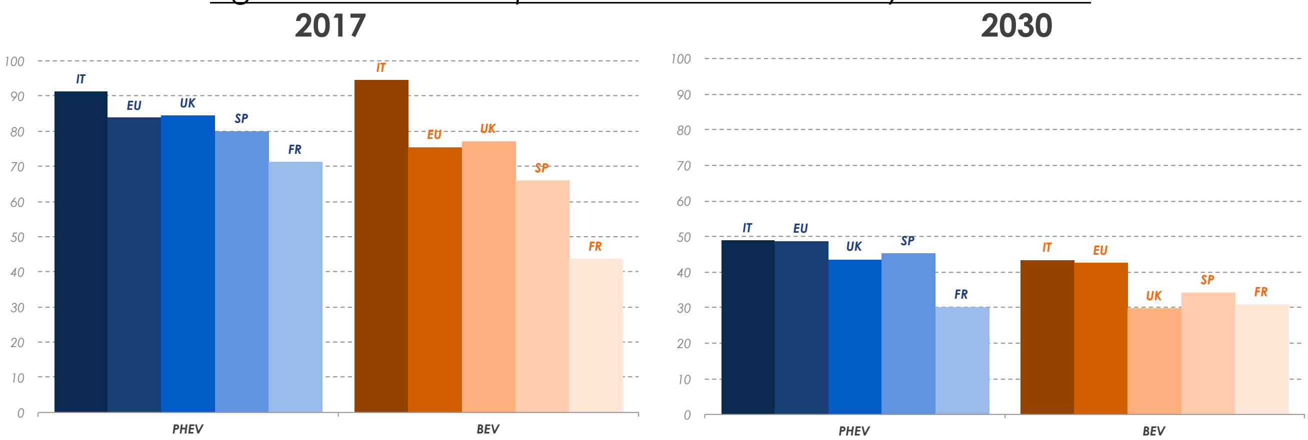


** baseline 100 compared to an ICEV in 2017 / carbon footprint with recycling credits*

Today, the carbon footprints of entirely electrified small city cars (BEVs and EV-REXs) differ significantly between countries for both time horizons. For each vehicle type and time horizon, small city cars in France by far have the lowest carbon footprints.

Figure 10 provides details on the GWP country breakdown by vehicle type for both a sedan. Carbon footprints are expressed in comparison with the 2017 ICEV baseline. The value of 100 corresponds to the carbon footprint of a diesel sedan that weighs approximately 1 500 kg and emits 150 g CO_2eq/km (tailpipe emissions in real-driving conditions).

*Fig. 10: Carbon footprint of sedan cars today and in 2030**



** baseline 100 compared to an ICEV in 2017 / carbon footprint with recycling credits*

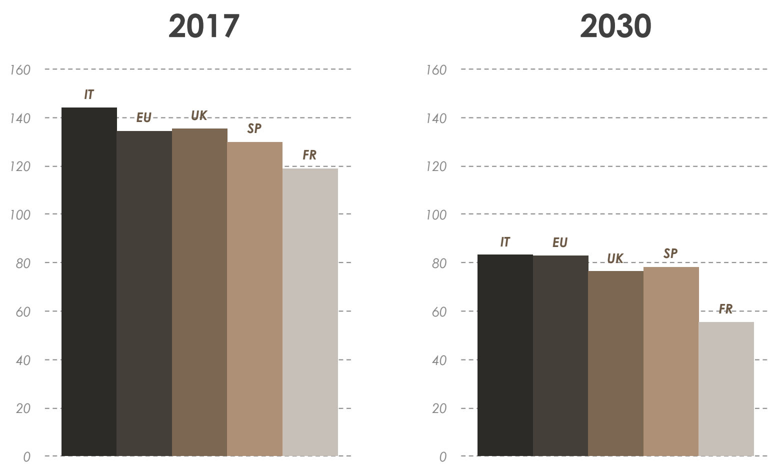
For sedans in 2017, the BEVs in particular show a significant difference concerning the carbon footprints per country. Like for small city cars, sedans in France emit the least carbon emissions.

In 2030, the disparities between countries are somewhat reduced. In general, as sedan PHEVs gain in efficiency, in 2030 their carbon footprints become quite close to those of BEVs. It is also important to note that by 2030 other countries such as the UK and Spain have or almost have caught up to the low carbon level of French BEVs.

SUV – 4x4 – PHEV model

Since it is a luxury model and a heavy vehicle, the SUV PHEV model is represented apart from the other sedans. Figure 11 shows the carbon footprint of this model expressed in comparison with the 2017 ICEV baseline. The value of 100 corresponds to the carbon footprint of a diesel sedan that weighs approximately 1 500 kg and emits 150 g CO_2eq/km (tailpipe emissions in real-driving conditions).

*Fig. 11: Carbon footprint of 4x4 SUVs today and in 2030**



** baseline 100 compared to an ICEV in 2017 / carbon footprint with recycling credits*

In 2017, the SUV PHEV produces more CO_2 emissions than a current ICE sedan in all countries in scope. The gap is the biggest in Italy. In 2030 the carbon footprint is significantly reduced, but remains similar to the 2017 ICEV for most countries and for the average in EU. In comparison with the 2030 MHEV (which emits 30% less than the 2017 ICEV), it produces more emissions except in France.

Conclusion

This study confirms the environmental advantages of today's and future battery electric vehicles over their lifetime (from cradle to grave) compared to internal combustion engines in the UK, Italy, Spain and France, as well as for the European average. On average small BEVs produces just half of the greenhouse gas emissions of an average European urban petrol car (small ICEVs) and a large BEV produces 75% of the emissions of an average European diesel sedan (large ICEVs).

In countries where coal is still part of the energy mix, like in Italy, the climate benefit of BEVs compared to ICEVs is 20% lower on the small segment (they produce 40% less CO_2 than ICEVs). Although still cleaner, large BEVs do not produce substantial climate benefits in countries where coal fuels a substantial share of the domestic energy demand.

Grid decarbonization offers a significant opportunity to further improve the comparative advantage of BEVs. In the UK or Spain, a large BEV is expected to produce around 50% less CO_2 in 2030 compared to 2017, reaching the same level as large BEVs in France. An electric car using average European electricity in 2030 is almost 40% cleaner over its life cycle compared to even the most efficient internal combustion engine vehicle, equipped with the latest mild-hybrid technologies.

Even as electric vehicles use larger batteries to allow longer electric-range travel, the study confirms large electric cars' life-cycle advantage over internal combustion engine vehicles. Regardless of powertrain configuration, smaller vehicles nevertheless tend to be more energy efficient during operation and generally have lower GHG emissions than larger ones.

Despite imperfect data availability on vehicle use in electric mode, Plug-in hybrid electric vehicles (PHEVs) represent significant GHG emissions gains when compared to internal combustion vehicles in the urban and sedan segments. However, this is not the case for very large and powerful PHEVs, compared to the average ICE sedan. A large 4x4 SUV produces more emissions in each country tested even when compared to today's large diesel vehicles.

Although this addendum has not explored the integration vehicles into the electricity grid, plug-in vehicles remain key to accelerate the transition of the power sector. Together with controlling energy consumption (efficiency and restraint) and intelligent management of charging and development of storage capacities, battery electric vehicles can go hand in hand with the energy transition, development of renewables, and a progressive exit from fossil fuels in European energy mixes.

Last but not least, this study is focused on the carbon footprint of vehicles, but it should be noted that driving electric vehicles can cut NOx emissions to zero and can massively reduce particulate emissions, therefore improving air quality in urban areas.