



APRIL
2018

Cross-sector review of the impact of electrification by segment

E4T PROJECT

EXECUTIVE
SUMMARY



In partnership with:



ACKNOWLEDGEMENTS

Fabrice Le Berr, IFP Energies Nouvelles

Joris Melgar Sossa, **IFP Energies Nouvelles**

Cyprien Ternel, **IFP Energies Nouvelles**

Anne Bouter , **IFP Energies Nouvelles**

François Badin, **IFP Energies Nouvelles**

QUOTE FROM THIS REPORT

IFP Energies Nouvelles 2018. Cross-sector review of the impact of electrification by segment: PROJECT E4T. ADEME. 21 pages.

This document is available online <https://www.ademe.fr/en/media-library>

Any representation or reproduction of this document, either in full or in part, made without the consent of the author or his/her successors in title or assignees, is illegal according to the French Intellectual Property Code (Art. L 122-4) and constitutes piracy punishable under the French Penal Code. Copies or reproductions strictly reserved for the private use of the copyist and not collective use are authorised (Art. 122-5), together with analyses and short quotes justified by the critical, educational or informative nature of the work in which they are incorporated, always conditional upon adherence to the provisions of Articles L 122-10 to L 122-12 of the same Code in respect of reprographic reproduction.

This document is distributed by ADEME

20 Avenue du Grésillé
BP 90406 | 49004 Angers Cedex 01

Contract number: 1566C0051

Study undertaken on behalf of ADEME by: IFP Energies Nouvelles

Technical coordination - ADEME: Maxime Pasquier
Sustainable Towns and Regions Division/Transport and Mobility Department

TABLE OF CONTENTS

Résumé.....	4
1. Project background.....	5
2. Approaches and hypotheses	6
2.1 Overall approach adopted in E4T	6
2.2 Hypotheses.....	7
2.2.1 Component part hypotheses	7
2.2.2. Powertrain hypotheses.....	8
2.2.3. Vehicle hypotheses.....	8
2.2.4. Usage hypotheses	9
3. Segment-by-segment analysis.....	9
3.1 Small urban vehicles (Segment A).....	9
3.2 Core range vehicles (Segment C)	11
3.3 High-end vehicles (Segment D).....	14
3.4 Utility vehicles (LCV)	15
3.5 Buses (12m)	15
3.6 Urban delivery trucks	18
4 Conclusion / Outlook	19
Index of tables and figures	21
Abbreviations and acronyms	21

Résumé

Ce document livre une synthèse des principaux résultats du projet « Etude Economique, Energétique et Environnementale pour les technologies du transport routier français » (E4T), segment par segment, permettant une analyse des grandes tendances sur l'électrification en cours de mise en place ou de développement. Globalement, cette synthèse montre que, hormis pour le segment du véhicule poids lourd long routier, la motorisation conventionnelle (essence ou Diesel) sera fortement concurrencée en 2030, que ce soit du point de vue de son coût total de possession (TCO) ou de son impact environnemental (émissions de Gaz à Effets de Serre (GES) et polluants). La diffusion de ce type de motorisation devrait donc fortement se ralentir d'ici 2030. L'architecture Mild Hybrid 48V (MHEV 48V), poussée au maximum de ses performances, pourrait être une solution très intéressante pour concurrencer les solutions Full Hybrid actuelles (HEV) à dérivation de puissance. Les véhicules hybrides rechargeables (PHEV) semblent les solutions les plus pertinentes du point de vue de l'impact sur les émissions de GES, grâce à leur batterie de taille limitée parfaitement adaptée à l'usage majoritaire du véhicule. Leur rentabilité économique, sans aide à l'achat, reste néanmoins un verrou pour favoriser leur déploiement. Enfin, les véhicules électriques (BEV) sont des solutions efficaces pour réduire la pollution locale et les émissions de GES, d'autant plus si elles sont très utilisées (à l'instar des bus) de façon à amortir l'impact de la fabrication de la batterie par l'usage. Néanmoins, la rentabilité économique de ces solutions reste limitée actuellement (ou le devient grâce aux aides à l'achat) mais devrait le devenir d'ici 2030 avec la réduction annoncée du coût des batteries. Enfin, la tendance actuelle à l'accroissement de la taille de batteries pour augmenter l'autonomie sur les véhicules électriques, est préjudiciable pour l'impact GES de la filière électrique. Ce point devra faire l'objet d'une attention particulière à l'avenir.

Abstract

This document presents a summary of the main results of the project "Economic, Energetic and Environmental Study Road Transport Technologies in France" (E4T), segment by segment, allowing an analysis of major trends in electrification. Overall, this synthesis shows that, except for the long-haul truck segment, conventional motorization (petrol or diesel) will struggle with more competitive technologies in 2030, whether from the point of view of its total cost of ownership (TCO) or its environmental impact (Greenhouse Gas (GHG) and pollutant emissions). The diffusion of this type of motorization should therefore slow down considerably by 2030. The Mild Hybrid 48V architecture (MHEV 48V), pushed to the maximum of its performances, could be a very interesting solution to compete with the current Full Hybrid solutions (HEV). Plug-in Hybrid Vehicles (PHEVs) seem to be the most relevant solutions from the point of view of the impact on GHG emissions, thanks to their limited size battery perfectly adapted to the majority use of the vehicle. Their economic profitability, without purchase subsidy, remains nevertheless difficult to reach. Finally, battery electric vehicles (BEV) are effective solutions to reduce local pollution and GHG emissions, especially if they are intensively used (like buses) to compensate the environmental impact of battery manufacturing by vehicle use. Nevertheless, the economic profitability of these solutions is currently limited (or becomes viable only thanks to purchase subsidy) but should become so by 2030 with the announced reduction in batteries cost. Finally, the current trend to increase the size of batteries to improve electric vehicles range is detrimental to GHG impact. This point should be considered wisely in the future.

1. Project background

For a few years now but particularly since COP21 and the recent announcements of the 2040 Climate Plan by Nicolas Hulot, France, along with its European partners, has launched into an ambitious quest to reduce greenhouse gas (GHG) emissions and particularly CO₂. Transport, the sector emitting the largest quantity of GHGs in France with almost 30% of the country's total emissions, is therefore a sector that must increase its efforts still further to reduce its impact on climate change and air quality alike by reducing polluting emissions.

An emission threshold was set in 2014 for manufacturers marketing light vehicles in Europe, entailing penalties if the manufacturer does not adhere to it (Figure 1). This threshold, currently set at 130 g/km of CO₂ on the old NEDC homologation cycle, will drop to 95 g/km in 2020 then 81 g/km in 2025 and lastly 66 g/km in 2030 (EU). These increasingly strict thresholds will oblige manufacturers to include more innovations in their vehicles and engines. Two solutions currently receiving great attention in the effort to achieve these ambitious objectives are improvements in the efficiency of internal combustion (IC) engines and electrification. Nevertheless, the future post-2020 targets, combined with a slowdown in demand for diesel engines (although their CO₂ emissions are low) will compel manufacturers to accelerate their efforts still further. Against this background, electrification, a long-standing trend, is no longer merely an option but rather an obligation in order to address climate and public health issues.

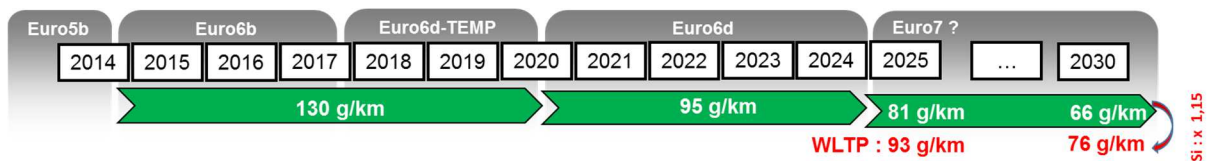


Figure 1: CO₂ emission targets (in g/km) for manufacturers' vehicle fleets. Target set on the basis of the NEDC cycle (with equivalents for the WLTP cycle from 2025) - Sources: [COM\(2017\) 676 final](#), European Commission, 08/11/17; [Appendices](#)

The other transport sectors (utility vehicles, delivery or long-haul trucks, buses etc.) are not lagging behind in this quest to reduce CO₂ emissions, all the more so as these vehicles are generally used by professionals for whom the cost of fuel is critical to the profitability of their business. The reduction in consumption is a sales argument that is therefore always actively invoked. Since 2010, the truck sector has reduced its CO₂ emissions by about 1% per year and intends to accelerate its efforts still further (target of 2.5% per year in the USA between 2018 and 2027), by working on improving vehicles (particularly SCx) and engine efficiency. For some time, the bus sector has been committed to electrification, adopting hybrid solutions in many cities and now intending to go still further with the all-electric bus.

In addition, the progressive elimination of polluting vehicles in some cities (London and Paris amongst others) is tending to accelerate the introduction of new low-emission engines locally. This type of announcement, combined with the ongoing tightening up of pollution standards, the "Diesel-Gate" affair (involving Volkswagen in late 2015) and the announced end to taxation benefiting diesel fuel in France has precipitated the drop in sales of diesel engines in favour of petrol, and probably hybrid or electric, engines in the future.

This is a time of great upheaval for the transport sector. New partially or totally electrified technological solutions will help to address the issues of public health and climate change whilst also meeting economic criteria and issues relating to the supply of potentially critical materials. It is becoming crucial to have forecasting and analytical tools so as to objectively assess certain trends in order to help with decision-making and the deployment of promising solutions. These tools must incorporate specific features required by the various transport sectors in terms of both usage and the technological developments envisaged. They must incorporate certain known trends such as the standardisation of the 48V network and the roll-out of charging infrastructure.

With this in mind, IFPEN and ADEME have collaborated on the E4T project (Economic, Energy and Environmental Study of French Road Transport Technologies) in order to develop a number of tools to undertake energy-related, economic and environmental analyses. These tools have achieved a certain level of maturity that now makes it possible to strengthen roadmaps up to 2030. The E4T study confirmed certain trends that are already well-established, such as the drop in energy consumption due to hybridisation and electrification, the improvement in efficiency of conventional engines and other vehicle design initiatives. The project helped in the assessment of the economic viability of electrified vehicles by 2030, in order to estimate their profitability from the point of view of TCO (total cost of ownership), a function of their technical definition and the assistance provided to the sector. From the point of view of the life cycle analysis, the E4T study highlighted the balance needed between usage and the level of electrification (battery sizing) in order to ensure the achievement of the

expected environmental gains. It also identified certain technological systems that are potentially more beneficial to the environment than long range electric vehicles, which is currently a strong trend in this sector. This sensitive point has been strengthened by a detailed extensive analysis of lithium resources, which revealed a probable criticality in the supply of lithium by 2050 if there is large-scale development of electric vehicles (BEV).

The aim of this summary is to highlight the main conclusions of the project, sector by sector, in order to be able to consolidate the roadmaps and orientations for each sector. The summary will nevertheless not address certain specific points such as the environmental impact of electrification on some non-GHG emissions or criteria, or the criticality of the lithium supply by 2050. For more information, the reader may refer to the detailed project reports addressing these various issues.

2. Approaches and hypotheses

2.1 Overall approach adopted in E4T

In order to provide keys to understanding the main current or future orientations in the transport sector, the E4T project firstly undertook a systematic assessment of the energy consumption of vehicles for the various sectors analysed in the project (Figure 2), i.e.:

- The light vehicle segment with three vehicle ranges: urban (Segment A), core range (Segment C) and high-end (Segment D)
- The utility vehicle segment (Renault Master-type)
- The truck segments, including primarily urban delivery vehicles and long-haul trucks
- Lastly, the bus segment (12m)



Figure 2: Segmentation of the transport sector studied in the E4T project

Each segment was broken down into different engine types with variable rates of electrification, from IC to hybrid (several systems and levels of hybridisation) to rechargeable hybrid to all-electric. Each component part of the powerchain (IC engine, electric motor, battery etc.) was assessed from the energy point of view whilst taking into account the main trends and improvements to be introduced by 2030. In the same manner, each vehicle was assessed taking into account a future vision of its main characteristics (aerodynamics and tyre friction) and its mass (lightening of bodywork and chassis, impact of the improvement of energy density and energy of electrified component parts). These models made it possible to evaluate energy consumption (fuel and electricity) in different usage cycles.

After this initial energy-related approach ‘from tank to wheel’, each type of vehicle and powertrain was evaluated according to economic considerations including the total cost of ownership and environmental considerations resulting from a lifecycle analysis approach that included the production of both energy and the vehicle.

The lifecycle analysis was undertaken in accordance with ISO 14040 and 14044 standards using the commercial lifecycle analysis program SimaPro®. The database used was Ecoinvent v.3.1. The default model chosen was “allocation, recycled content”.

Lastly, some of these elements were included in an overall analysis of the criticality of the supply of lithium worldwide (not addressed in this report).

A summary of the various hypotheses taken into account in these different stages is given below.

2.2 Hypotheses

2.2.1 Component part hypotheses

In the E4T project, each component part of the powertrain (IC engine, electric motor, battery etc.) was assessed according to a number of criteria, so as to take full account of the impact of these different components and their development from the energy, economic and environmental points of view. Firstly, each component was assessed using a classic energy-related approach, enabling its intrinsic efficiency to be taken into account in the powerchain being evaluated. With this aim, maps of specific consumption or output of power converter component parts (such as the IC engine or the electric motor) were used, together with assessments of the open circuit voltage and internal resistance of the battery. Associated with these hypotheses, the energy density or energy of the different component parts was also taken into account so as to fully evaluate the total mass of the powertrain for each of the two time horizons being considered (now and 2030). In this time interval, significant improvements in performance have been taken into account for the key component parts: an increase of 6 to 10 points of maximum efficiency in the IC engine, a doubling of the energy densities or energy of the electrical component parts (specifically the electric motor and the battery). By way of example, the energy density of the battery cells, currently set at 150 Wh/kg (reasonable hypothesis) is doubled for 2030 (300 Wh/kg).

The cost of manufacturing these component parts has then been evaluated systematically to make it possible to evaluate the selling price for the vehicle. By way of example, a scenario illustrating changes in the price of batteries is provided in Figure 3.

Each component part has also been evaluated from the point of view of its impact on the environmental ecosystem, particularly in respect of the CO₂ emissions arising from its manufacture.

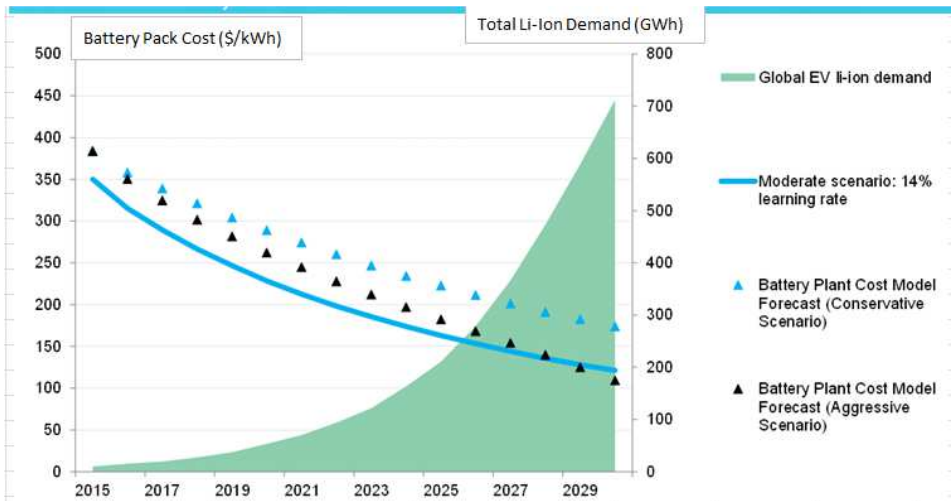


Figure 3: Scenarios illustrating changes in the price of batteries (cells + pack) between 2015 and 2030 (source: BNEF)

2.2.2. Powertrain hypotheses

In order to be able to undertake the most exhaustive evaluation possible of electrified architectures, up to 10 powertrain architectures were taken considered in the different segments evaluated in the project. Conventional powertrains (petrol and diesel) systematically equipped with the Stop & Start function in 2030 have been rolled out in a “Mild Hybrid 48V” version (MHEV 48V, parallel-type hybridisation with voltage limited to 48V, Figure 4). Three architectures of “Full Hybrid” high voltage (HEV) vehicles were assessed in a non-rechargeable version: parallel hybridisation (for light vehicles, buses and trucks), series hybridisation (for buses and trucks) and power-split hybridisation (Toyota Prius-type only available in the light vehicle segment). This hybrid architecture, operating at high voltage, was evaluated only with petrol engines for light vehicles, and diesel engines for buses and trucks. Rechargeable hybridisation (PHEV) was modelled in the light and utility vehicle segment, with series hybrid architecture for the small urban vehicle segment, two architectures (parallel and power-split) for the higher categories (Segments C and D) and lastly a parallel hybrid architecture for utility vehicles. Lastly, each segment (with the exception of long-haul trucks) included one or two versions of electric vehicles, differentiated according to the range delivered by the battery (moderate or extended range).

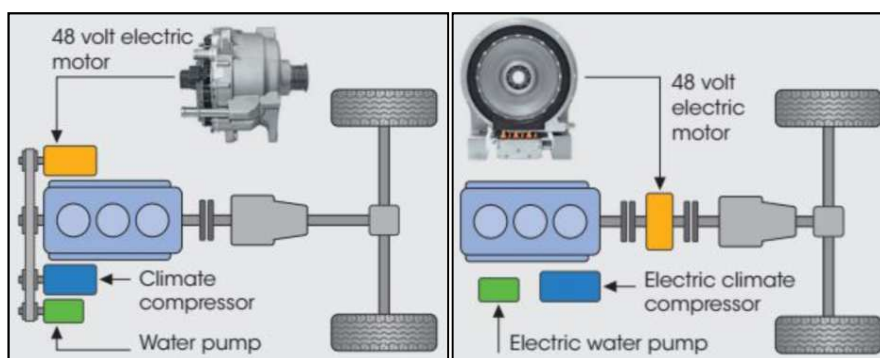


Figure 4: parallel hybrid architecture used in MHEV vehicles operating at 48V

Left: type P0 (non-declutching electric motor) for current vehicles

Right: type P2 (declutching electric motor allowing all-electric operation) for 2030 vehicles

2.2.3. Vehicle hypotheses

Each vehicle has been assessed following a classic approach, taking into account its “empty” mass (no passengers or load), additional onboard mass (averaged according to usage), aerodynamic characteristics (frontal area and drag coefficient) and tyre friction. The powertrain mass has been calculated using the knowledge of the powertrain architecture onboard the vehicle and the mass of each component.

Changes in the different parameters between now and 2030 have been taken into account. The E4T project considered a moderate change in the empty mass of light vehicles (less than 5%) but a more ambitious change in the other segments (around 15%). In the same way, a moderate change in the aerodynamic characteristics was considered for the light vehicle segment (10% reduction in Cx) but it could be as much as 30% for long-haul trucks. The tyre friction coefficient was improved by 20% for all segments.

A bottom-up approach was used to assess the new selling price of the different vehicles in the study (including 2030). The cost of the technologies specific to each of the vehicles was therefore added to the cost of the chassis and the bodywork, these costs depending on the segment under consideration (see Figure 5). Other elements were also assessed such as infrastructure, personnel, marketing and sales network costs etc. The cost of energy (fuel, electricity) was also taken into account, together with any anticipated changes between now and 2030.

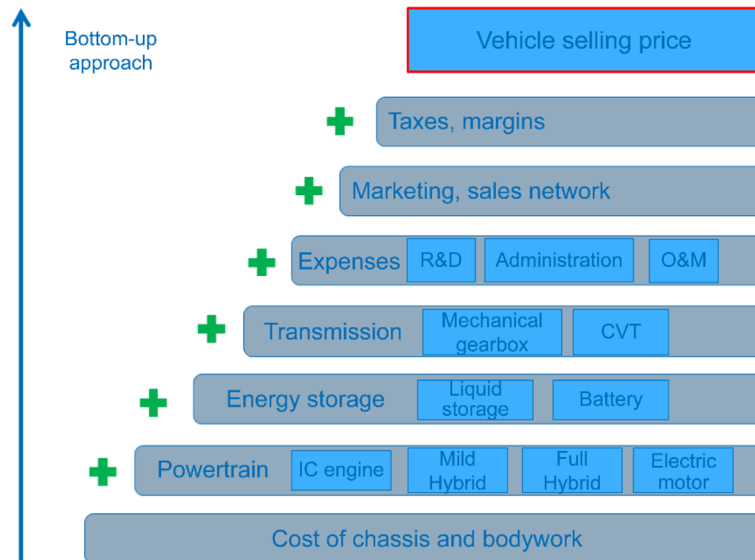


Figure 5: Representation of the bottom-up approach used to determine vehicle selling prices

Vehicle lifetime was set at 10 years for light vehicles and 12 years for the other segments at the rate of 12,000 km per year for urban vehicles, 15,000 km per year for light vehicles in other segments, 16,200 km per year for utility vehicles, 31,000 km per year for delivery trucks, 40,000 km per year for buses and lastly 62,500 km per year for long-haul trucks. Unless specifically stated, only one battery was considered for each vehicle over the suggested lifetime.

The materials composing the different vehicles have been set according to different bibliographic references, taking account of the abovementioned reduction in mass.

2.2.4. Usage hypotheses

For light vehicles, consumption was first evaluated according to homologation cycles (the NEDC cycle and also the new WLTC cycle, which is more representative of usage) and actual and specific usage (congested urban usage, free-flowing urban traffic usage, extra-urban and highway usage). For the other segments, actual usage cycles were taken into account, for example cycles representative of use in Paris or Lyon in the case of buses.

It should be noted that only the regular and daily use of vehicles achievable by all the architectures under consideration (particularly electric) were analysed, in order to be able to compare all the configurations with one another. Exceptional usage, such as long journeys when going on holiday for example, were excluded from this study because they are difficult to for electric vehicles with limited range to achieve. That is why, in light of this hypothesis, only cycles of under 50 km were taken into account for light vehicles, in order to be able to compare vehicles with predominantly IC engines with vehicles with predominantly electric motors. Only the hypothesis of a systematic daily charge has also been taken into account for PHEVs and BEVs.

For the energy mix, it was decided to focus on France and its specific mix, which is very low-carbon, due particularly to the use of nuclear energy.

3. Segment-by-segment analysis

An analysis of the main conclusions, segment by segment, is given below.

3.1 Small urban vehicles (Segment A)

The small urban vehicle is a segment that is primarily influenced by the purchase price of the vehicle, which is largely determined by the type of powertrain used. Only four powertrain architectures were considered in this segment: conventional (petrol only), MHEV (supposing widespread adoption of this

type of architecture by 2030) and electric, with or without a range extender. In the latter case, the range extender was specified with sufficient voltage to guarantee the relevant performance even with a fully discharged battery, so the size of the battery was limited to provide a range of only about 50 km. Sizing the battery to a minimum makes it possible to ensure use of the vehicle in all-electric mode for a large part of day-to-day journeys.

A battery of a reasonable size providing a range of about 200 km would appear to seriously disadvantage an electric vehicle due to its mass (of the order of 250 kg compared with a conventional vehicle). In 2030 and given the changes envisaged to the energy density and power of the electrical component parts, the excess weight of an electric vehicle will be equivalent to that of the vehicle with a range extender, and will remain limited to under 100 kg compared with a conventional petrol vehicle.

The fuel consumption of conventional IC vehicles should be reduced by about 1l/100 km between now and 2030, falling below 4l/100 km in the WLTC cycle. In this segment, 48V hybridisation delivers a significant improvement in consumption enabling an additional saving of about 1l/100 km compared with the conventional version, specifically by substantially limiting overconsumption in urban usage, particularly in congested conditions (limited to 4l/100 km in MHEVs compared with 9l/100 km in their conventional equivalents). The consumption of highly electrified vehicles (PHEVs and BEVs) will drop from 15 kWh/100 km to 10 kWh/100 km (-30%) due to substantial progress being made on the vehicle design and the mass of the electrical component parts (battery and electrical systems).

In urban usage, and due to the currently available ‘help-to-buy’ subsidy of €6,000, electric vehicles are an economically relevant solution for users (see Figure 6). In 2030, and even without the ‘help-to-buy’ subsidy, this conclusion remains valid, but the electric vehicle solution will by then be followed closely by the MHEV solution, which offers the advantage of a lower initial investment without the all-electric functionality, probably relevant in city usage in 2030. It should be noted that presupposing the continuance of the ‘race for range’ currently being pursued by manufacturers of electric vehicles, this type of vehicle could lose its appeal. In fact, the additional cost of an electric vehicle with a battery of the order of 60 kWh (giving it a range of over 500 km) would be very difficult to recover from the point of view of TCO and the initial investment. This solution remains the least economically relevant compared with all the other powertrain architectures evaluated.

The BEV solution with range extender is never well positioned economically, disadvantaged by both the cost of the IC engine and the battery. Nevertheless this solution, which is close to a purely electric vehicle in terms of functionality and performance in most day-to-day limited-distance usage, holds genuine interest from the point of view of reducing GHG emissions. In fact, due to its reasonable battery size (6 kWh), it is positioned more favourably than the electric vehicle (even with a limited range of 200 km). In addition, it offers a much greater range without the need for recharging than the electric vehicle does due to the range extender, enabling a more versatile use of the vehicle.

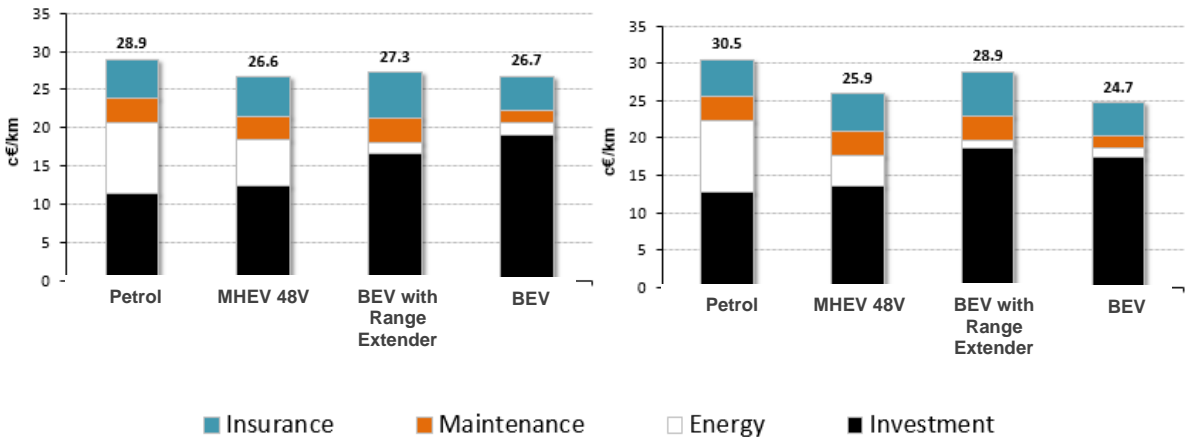


Figure 6: TCO of vehicles in Segment A in 2015 (left) and 2030 (right) in the urban cycle

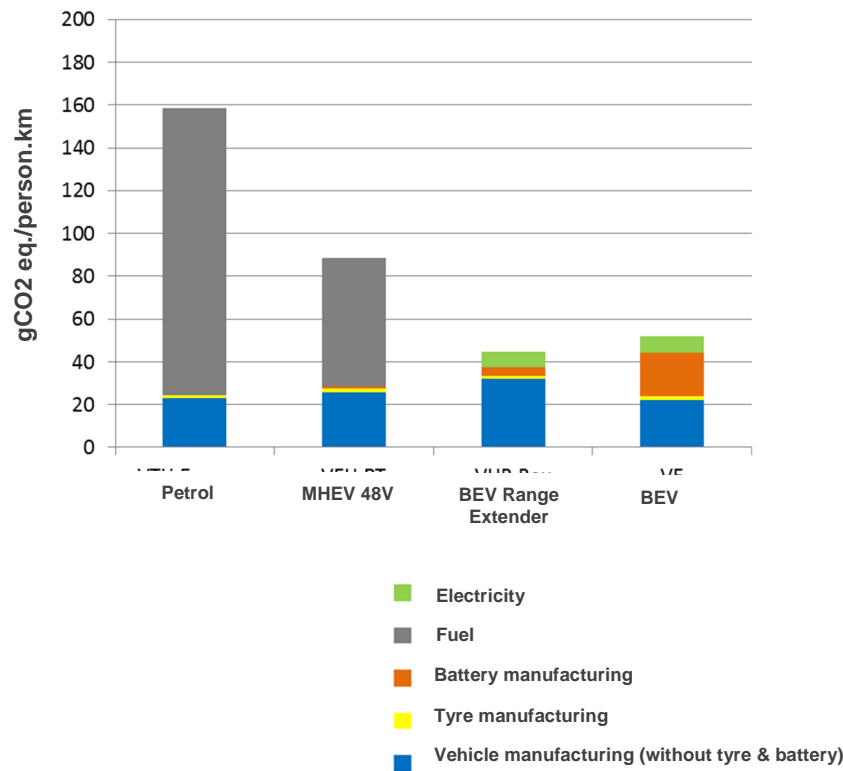


Figure 7: Impact on climate change of a person using their Segment A vehicle for urban use in 2030

Finally, and given the changes expected in the functioning of city centres (tolls or banning of polluting vehicles, parking facilities for electric vehicles), it seems that the small urban vehicle of the future is likely to be electric. Nevertheless, and given the current trend of increasing the size of the battery to increase the range of the electric vehicle, the latter could face strong competition in the future from MHEV solutions (from the point of view of TCO) or PHEV solutions (from the point of view of environmental impact). Both of these offer a much higher range without recharging than the BEV.

3.2 Core range vehicles (Segment C)

The core range (Segment C vehicle) is currently a segment in which the cost/utility balance is important because it is aimed at families who are generally very particular about these two criteria. For this segment, 10 architectures were analysed:

- Petrol or diesel vehicles in the Stop & Start and MHEV versions
- HEV and PHEV vehicles in parallel and power-split hybrid architectures
- Lastly, electric vehicles (in moderate and extended range versions).

It comes as no surprise that the mass of the vehicle is directly linked to its level of hybridisation and the size of the battery. It will nevertheless be noted that, by 2030, the masses of the vehicles under consideration (except for the BEV with extended range) are very close (a difference of under 120 kg between the IC engine vehicle and the electric vehicle) due to the substantial changes anticipated in the weights of the various electrical component parts.

In this segment and for powertrains incorporating an IC engine, hybrid power-split architecture is really the most interesting from the energy point of view, as it currently limits consumption to around 4l/100

km in all usage conditions, even urban. This conclusion backs up the choice of many taxi operators to use this type of architecture as incorporated in the Toyota Prius for example. In 2030, the gaps between the various hybrid architectures will close, with consumption between 3 and 4l/100 km in the WLTC cycle. The advantage of power-split transmission is less pronounced, particularly with regard to its complexity compared with a light MHEV-type hybridisation, but it retains an advantage from the point of view of its consumption in urban cycle, particularly in congested conditions. This trend in the convergence of consumption is explained, amongst other things, by improvements in the efficiency of IC engines and the energy density of electric batteries. The electricity consumption of highly electrified vehicles (PHEV and BEV) varies between 10 and 15 kWh/100km in the architectures and driving cycles evaluated in the project.

From the point of view of the total cost of ownership, IC vehicles are much more attractive in the petrol version than the diesel version, given an average of 15,000 km travelled per year (

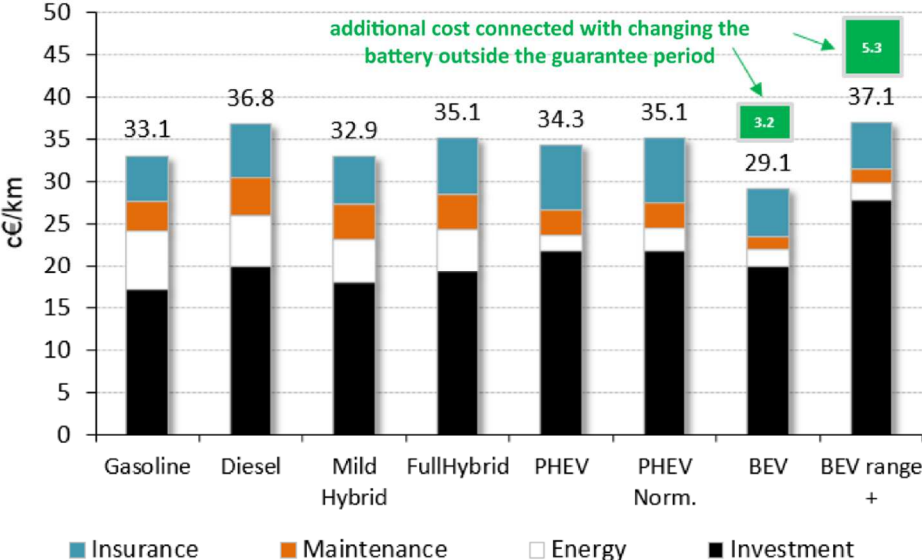


Figure 8). As for Segment A, light hybridisation (MHEV 48V) seems a very good alternative and even represents a better solution in 2030 than IC and hybrid vehicles in terms of TCO. Despite a significant initial investment, due particularly to the ‘help-to-buy’ subsidy that is currently limited to €1,000, the TCO of a rechargeable hybrid vehicle remains close to that of other hybrid vehicles, even under the WLTC procedure that increases the probability of occurrence of cycles drawing on the IC engine. As a result, HEV (non-rechargeable) architecture does not therefore seem well positioned in 2030, wedged between the two architectures with potential - MHEV and PHEV - interesting due to their TCO and range of functionality (PHEV enabling all-electric urban driving that could be substantially developed by 2030).

Over 12,000 km travelled per year, electric vehicles represent a very good economic solution compared with all other engine solutions, whether currently (thanks to ‘help-to-buy’) or in 2030 (without ‘help-to-buy’ but with a significant reduction in the cost of batteries). Nevertheless, this advantage is only possible if the battery is of a limited size (providing a range of about 250 km). In fact, a battery of twice the size (enabling a doubling of the range) makes the vehicle relatively irrelevant economically compared with the other architectures. These conclusions would need to be moderated in the event of the battery being replaced.

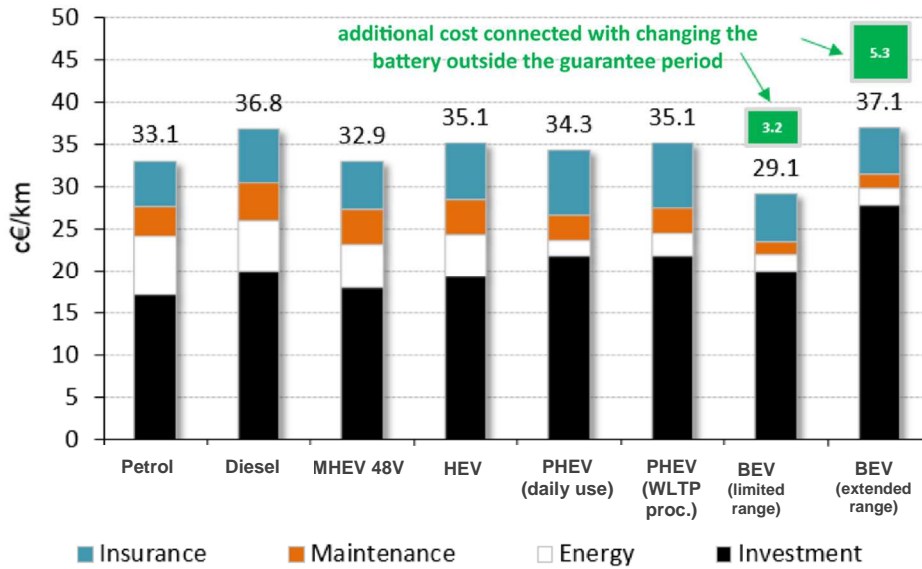
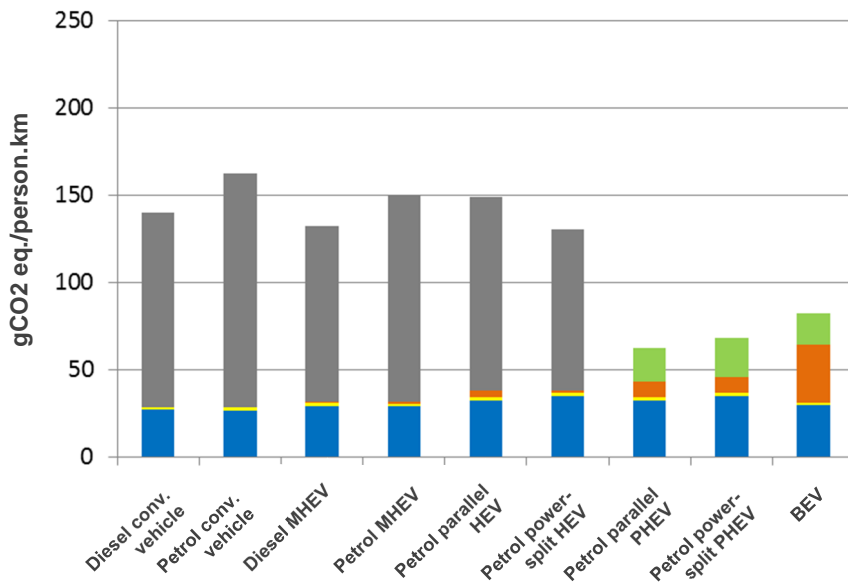


Figure 8: Comparison of TCOs of Segment C vehicles in 2030 in the WLTC cycle

According to Figure 9, the environmental results for the different vehicles show a clear improvement between 2015 and 2030. Specifically, the MHEV vehicle presents environmental results comparable with HEV architectures with a low TCO. In Segment A, PHEV remains the most eco-friendly solution due to its low GHG emissions whilst in use and its limited-size battery compared with an electric vehicle. This conclusion is all the more true if the electric vehicle has an extended range (not shown in the graphs in Figure 9) because it is all the more disadvantaged by the impact of the manufacturing cost of its substantial-size battery.



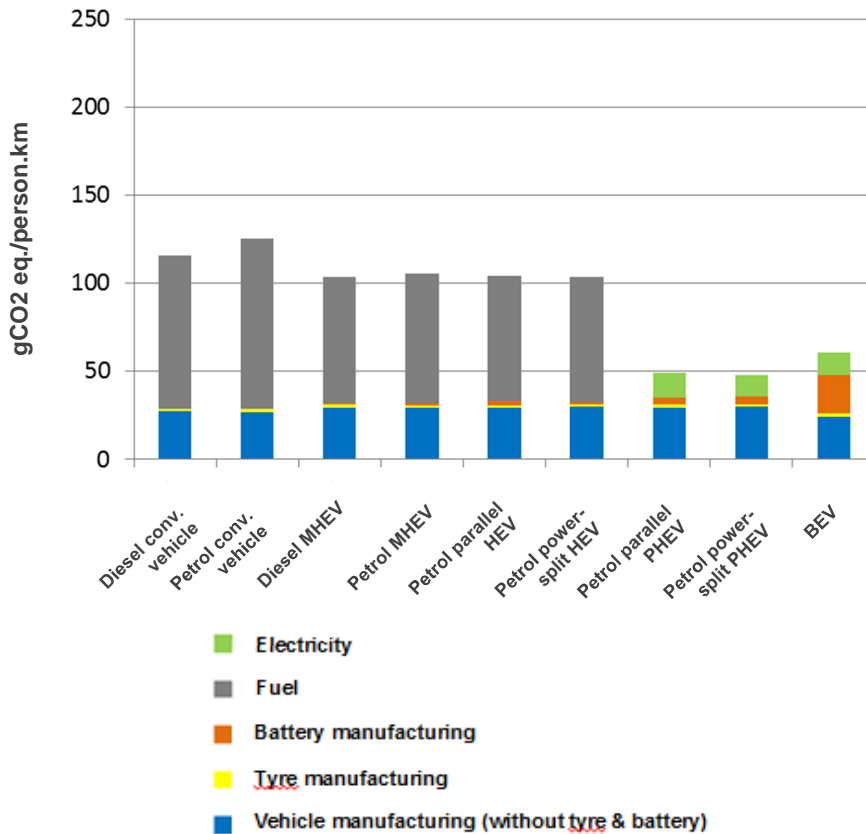


Figure 9: Impact on climate change of a person using their Segment C vehicle in the WLTC cycle in 2015 (top) and 2030 (bottom)

Finally, hybrid power-split architecture, the most widely used currently thanks to the success of the Toyota Prius, and which remains the most interesting from an energy point of view across all usage conditions, could in future meet strong competition from an optimised MHEV architecture presenting a better cost/efficiency compromise. Moreover, and even though it currently suffers from its high investment cost, PHEV architecture could also emerge relatively unscathed thanks to a very positive environmental results (if used correctly with regular recharges) and its ability to run in all-electric mode for dozens of kilometres. As in Segment A, an electric vehicle incorporating a moderate-sized battery remains a very interesting solution economically and ecologically because of its low GHG and local emissions and its range limited to 250 km. On the other hand, the current trend of increasing the size of batteries seems detrimental to the accessibility of electric vehicles and their environmental results, even though it proves to be a significant purchasing argument for more comfortably-off people wanting to equip themselves with this type of vehicle.

3.3 High-end vehicles (Segment D)

The high-end segment was analysed following the same discretization as the core range segment. The conclusions are comparable on all of the points discussed in the preceding section.

In this segment, hybrid power-split architecture is also the most interesting from the energy point of view, enabling consumption to be limited to around 4l/100 km in 2030 across all usage conditions (for a vehicle of almost 2 tonnes!). Even though this result is remarkable, it will not be sufficient to achieve the future CO₂ targets, which means that this segment must be more highly electrified (at least through a network recharge function) to impact a manufacturer's fleet positively. In a segment where buyers are less concerned with the total cost of ownership, this network recharge functionality and therefore the ability to run in zero emission mode for an extended length of time should therefore be deployed on a large scale in these versatile vehicles, guaranteeing electric functionality for day-to-day use and optimised hybrid operation for the rest of the time.

3.4 Utility vehicles (LCV)

For this study, only a diesel IC engine was considered for conventional and hybrid powertrains, in order to retain some continuity in relation to current trends in a segment where fuel consumption and cost of use are key. Due to the poor aerodynamic performance of utility vehicles, the energy consumption on the road increases very significantly with an increase in vehicle speed. For this reason, moving to an all-electric vehicle could be problematic. In fact, the electricity consumption, which is very high in highway cycle (over 60 kWh/100 km), reduces the range of the vehicle or its useful load (by about 300 kg) compared with a conventional vehicle, two crucial points for professionals using utility vehicles. Nevertheless, the substantial progress anticipated in batteries and electrical systems should make it possible to provide interesting solutions in 2030. A PHEV solution seems much more relevant from this point of view. An MHEV solution could also be very relevant to reduce the consumption of this type of vehicle in urban use (halved, compared with a conventional vehicle, in some congested conditions in 2030 with a high-power MHEV).

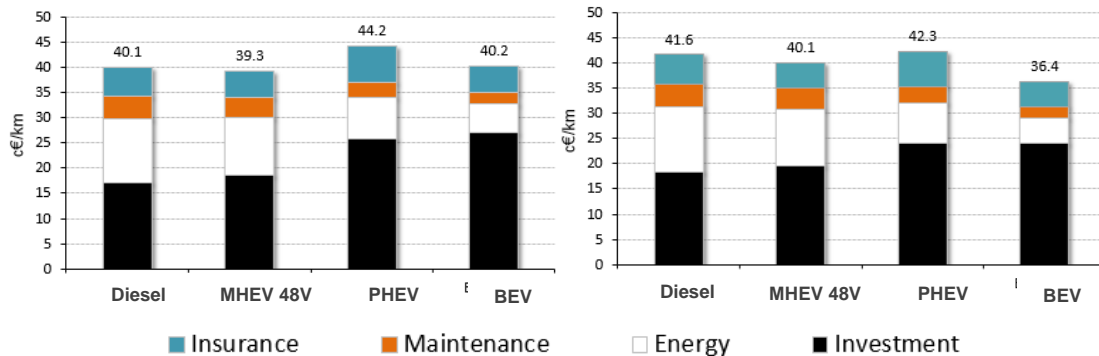


Figure 10: Comparison of TCOs of utility vehicles in 2015 (left) and 2030 (right) in the WLTP cycle

For an annual distance of 16,200 km travelled and in comparison with a reference diesel vehicle (see Figure 10), the electrification of LCVs seems a good solution from the economic point of view, firstly through an MHEV hybridisation that could be developed immediately (TCO below 0.8c€ per km compared with the reference diesel vehicle) then through a PHEV-type hybridisation in 2030 to open the city centres up (probably prohibited to diesel vehicles in the future) by providing an all-electric functionality for a limited usage and distance travelled. It should be noted that the PHEV solution could prove to be more economical if the IC engine is changed to a petrol engine, for example. This solution, which has not been covered in this study, would also be worth considering in the future.

The reduction in the cost of batteries will mean that the all-electric solution will gradually become very interesting economically, if it makes it possible to cover the whole of the range of activity of the professional concerned. This solution is also the most promising from the point of view of the impact on GHG emissions, halving emissions compared with a conventional diesel version in WLTC cycle.

3.5 Buses (12m)

As for LCVs, only a diesel IC engine was considered for the conventional and hybrid powertrains fitted in buses. The two hybrid architectures classically used in this type of segment (parallel and series) were analysed in several usage cycles. Given the application profiles (numerous stops and starts), hybridisation delivers substantial savings in consumption compared with a conventional engine, of the order of 40%. The two hybrid architectures currently comparable will become increasingly differentiated in the coming years due to progress in electrical systems that will give an advantage to series hybrid architecture. Series hybrid architecture is also an interesting transition towards all-electric, which seems to be the solution preferred by large cities and public authorities, when it becomes economically viable.

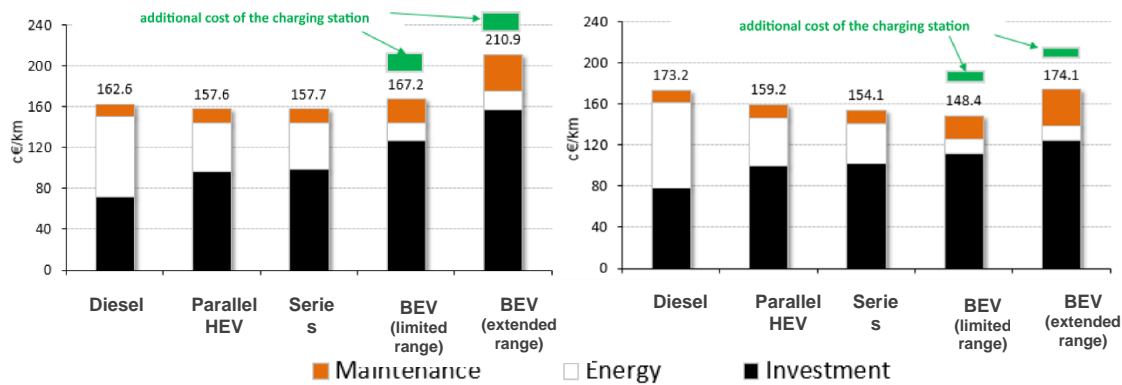


Figure 11: Comparison of bus TCO in 2015 (left) and 2030 (right) in the Parisian cycle

In fact, as shown in Figure 11 and for an annual distance travelled of the order of 40,000 km with a 12-year period of ownership¹, the all-electric bus is not currently an economically interesting solution, all the more so if one considers the associated charging infrastructure². Specifically, its TCO is disadvantaged by the cost of investment (linked to the current cost of the battery) and the cost of maintaining the bus. The all-electric bus is all the more cumbersome if one considers a battery enabling a whole day's travel without an intermediate recharge (case of an electric bus with extended range). The TCO of hybrid solutions is currently more interesting than that of the conventional reference vehicle, with an eco-friendly image that currently enables this solution to be deployed on a large scale.

Conversely, in 2030 the all-electric bus should approach, or even exceed, the levels of profitability of hybrid solutions, all the more so if the size of the battery can be limited by using intermediate recharges.

The impact on GHG emissions of electric solutions is particularly interesting (Figure 12). In fact, the impact of the battery is very quickly offset by the sizeable distance travelled by this type of vehicle. Also, the rolling cycle is particularly favourable to this type of engine. Given that this type of engine produces no pollutants, all-electric seems an interesting solution for the future.

¹ There is also a specific cost corresponding with the changing of the battery, inevitable over a period of 12 years and/or a distance of 480,000 km travelled.

² An additional cost corresponding with the price of the charging station (one is needed for every electric bus) is incorporated in the TCO. The bibliographic analysis shows that this type of charging station currently costs about €50. Our hypothesis is that this price will halve by 2030.

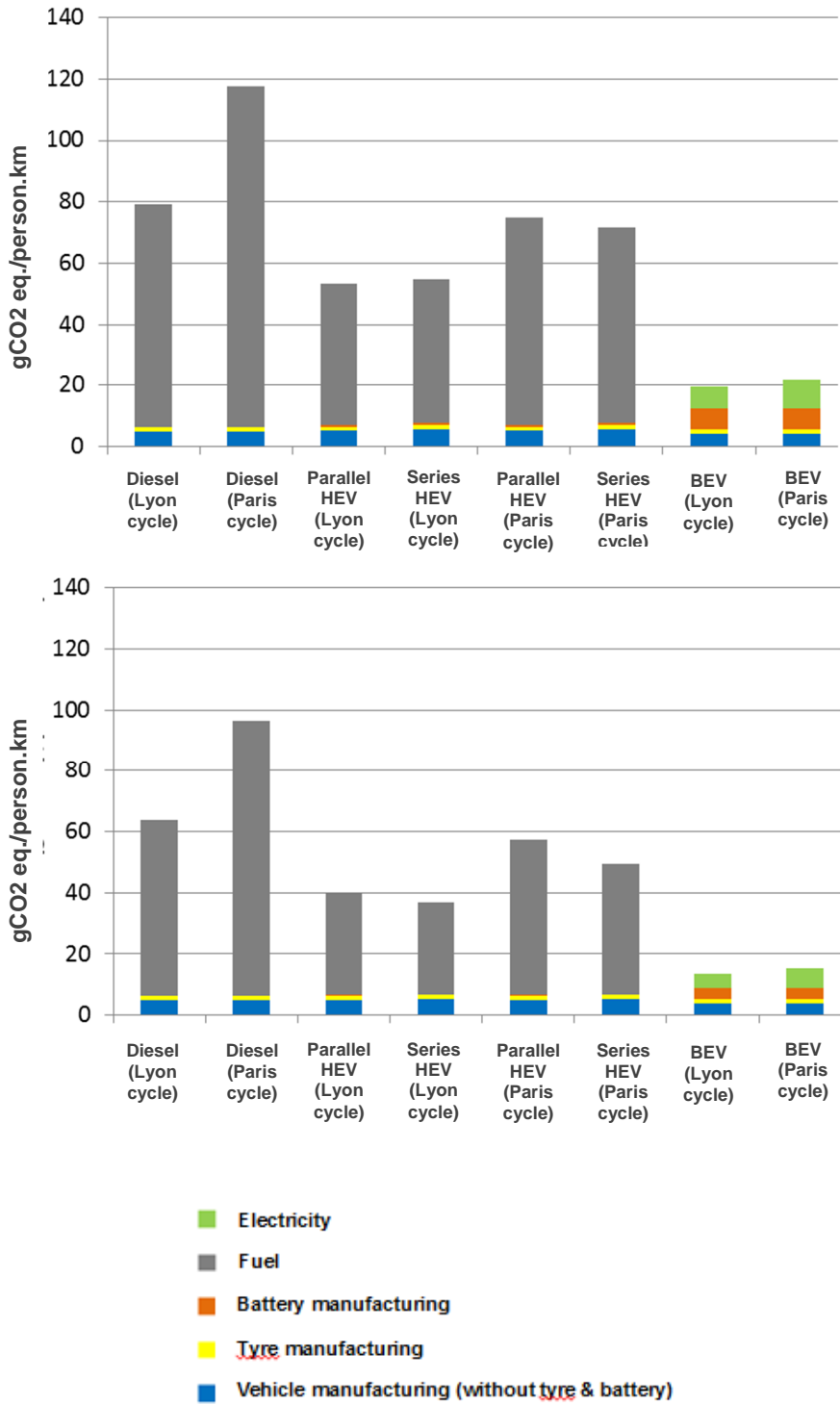


Figure 12: Impact on climate change of a person taking the bus with different technologies and different cycles. Time horizons: 2015 (top) and 2030 (bottom)

In conclusion, the strategy in the bus segment seems fairly simple for operators and the public authorities: deploying the most highly electrified solutions as quickly as possible, whilst guaranteeing profitability comparable to the current conventional and hybrid versions. Initially, the deployment of hybrid buses (preferably series hybrid architecture) seems a good transition in moving towards the all-electric vehicle for which the deployment of charging infrastructure and the financing thereof remain two crucial points to be dealt with. Gains in the range of all-electric vehicles could be substantial in the future, of the order of 30% due to progress in vehicle and motor design.

3.6 Urban delivery trucks

The conclusions for this vehicle segment are very close to those arrived at for buses, all the more so as the engines are generally the same in both segments. As urban delivery trucks tend to travel at higher speeds than buses, both the series and parallel hybrid architectures deliver very similar savings in consumption (of the order of 20 to 30% compared with equivalent IC vehicles). The choice of hybrid architecture could therefore be determined by the choices made for buses and the need to have extended electric functionality in this type of segment to allow access to city centres. For these two reasons, series hybrid architecture seems to be the most relevant, even for this segment. As for buses, the savings in electricity consumption of BEVs should be substantial by 2030 (of the order of 30%).

Nevertheless, for an annual distance travelled of 31,000 km and a period of ownership of the order of 12 years (including a battery change), the analysis of the TCO shows that hybrid and electric solutions are not currently profitable when compared with a conventional solution (Figure 13). This is the reason why truck manufacturers (such as Volvo) have stopped offering this type of engine in their range. It is particularly notable that all-electric vehicles make no economic sense in light of the fact that their useful load is strongly limited by the size of their battery.

By 2030, it seems that the hybrid and electric solutions will catch up in this segment, all the more so due to the probable banning of diesel engines in city centres. All-electric solutions are the most relevant from the point of view of reducing GHG emissions as they produce half the emissions of a series hybrid version and one third of those of a conventional version. A PHEV solution would be worth investigating once the cost of batteries has decreased sufficiently, with the aim of promoting electrification and progressively electrifying this segment.

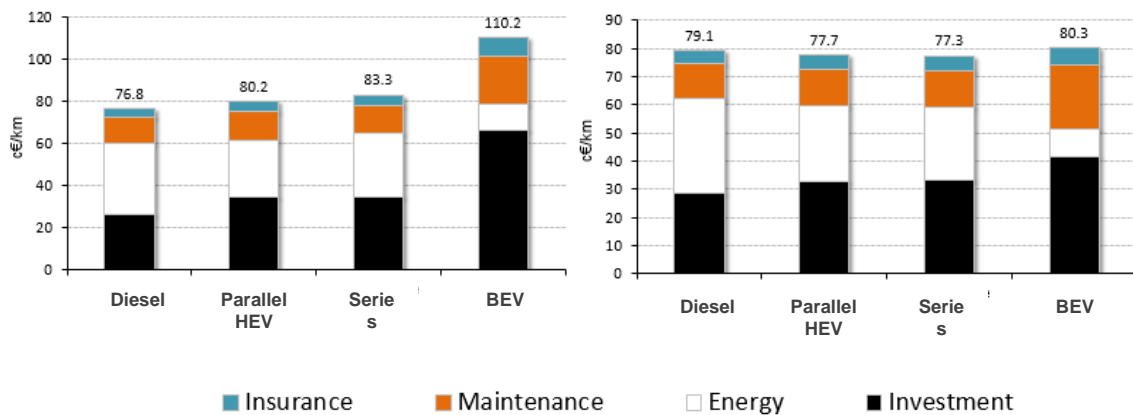


Figure 13: Comparison of delivery truck (12t) TCOs in 2015 (left) and 2030 (right)

3.7 Long-haul trucks

For this segment, the study related solely to the electrification of vehicles and did not consider other alternative fuels, only diesel engines were considered. The consumption of these vehicles could be decreased by as much as 30% between now and 2030 through substantial work on vehicle design (reducing mass by over 15% and tyre friction by 20%, and improving aerodynamics by up to 30%) and engine design (efficiency up by 7 points to exceed 50% through energy recovery).

For an annual distance travelled of 62,500 km, the total cost of ownership should decrease by more than 2c€/km between now and 2030, despite increases in the fuel price. Long-haul vehicles could be electrified only if the savings delivered reduced the cost of usage enough to make them competitive. All the more so as other technologies not covered in this study - such as NGV - have significant potential for development.

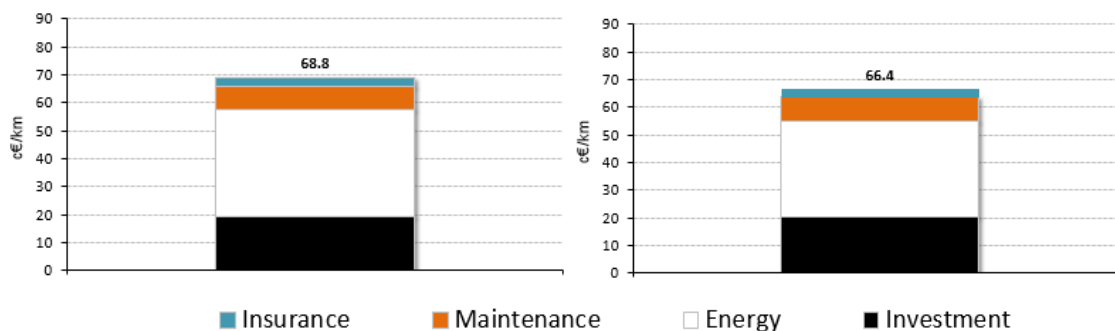


Figure 14: Comparison of TCO of long-haul trucks (40t) in 2015 (left) and 2030 (right)

4 Conclusion / Outlook

This document delivers a summary of the main results of the E4T project³, segment by segment, and provides an analysis of the main trends, either current or expected to emerge in the coming years (by 2030). Overall, the following are the main points to be borne in mind:

- Apart from the long-haul truck segment, conventional non-hybrid engines will meet strong competition from the electrified technologies, either from the point of view of their TCO or their environmental impact. Given this fact and the announcements by professionals in the sector and public authorities, the outlook for these conventional engines by 2030 looks bleak.
- MHEV architecture using components working to the limits of the operating voltage of 48V and using a parallel hybrid architecture enabling the IC engine to be disengaged, could be a very interesting solution competing with current HEV power-split solutions from the point of view of the compromise between TCO and GHG emissions.
- For light vehicles, the PHEV solutions seem the most relevant from the point of view of the impact on GHG emissions due to their limited-size battery that is perfectly suited to the most widespread use of the vehicles. Their economic profitability, without 'help-to-buy', nevertheless remains a barrier that is currently hindering their deployment.
- All-electric solutions are relevant from an ecological point of view and to reduce local pollution, all the more so if they are widely and frequently used (like buses) in such a way as to offset the impact of the production of the batteries (on GHG) through their use. The economic profitability of these solutions currently remains limited (or is becoming so due to the reduction in the 'help-to-buy' subsidy) but should increase by 2030 with the announced reduction in the cost of batteries. Attention should be paid to the race to increase range in light of the GHG emissions generated and the potential non-profitability of the solution, which might eventually cause it to stall.

When it comes to the movement of people, the most relevant solution for reducing GHG emissions remains public transport fitted with electric or hybrid powertrains. PHEV light vehicle solutions rank slightly below this, ahead of individual all-electric and diesel-engine public transport solutions. These different solutions should make it possible to limit individual transport to 50 gCO₂ per km by 2030. This represents about one quarter of the emissions of a current core range individual petrol vehicle.

For goods transport (and excluding NGV/BioNGV, not evaluated in this study), the solutions with the least impact on the environment remain long-haul transport with diesel engines followed by all-electric vehicles for urban transport, provided these latter solutions can be made profitable.

In conclusion, the E4T project has put in place a number of evaluation tools and has helped to reveal some significant trends. Taking these facts and results into account, it would appear important to continue with this structural approach, evaluating other hydrogen-based, biofuel and NGV energy systems (not covered in this study), whether in the current or other segments such as two- to three-wheeled vehicles for example. The cost of infrastructure (electric charging stations, hydrogen supply stations) should also be incorporated, particularly for these new sectors.

³The study also includes a prospective analysis of the criticality of the lithium supply in 2050 caused by the electrification of the world's motor cars. The results of this study are published independently.

Lastly, and given the impact of usage on the results, particularly for PHEVs, the usage characteristics of fleets should be defined even more precisely, together with annual usage, in order to arrive at the most solid conclusions and recommendations possible.

Index of tables and figures

Figures⁽ⁱ⁾

Figure 1 : objectifs d'émissions de CO₂ (en g/km) pour une flotte de véhicule d'un constructeurs. Objectif fixé sur cycle NEDC (avec équivalence pour le cycle WLTP à partir de 2025) - Sources : COM(2017) 676 final, European Commission, 08/11/17 ; Annexes 5

Figure 2 : Segmentation du secteur transport étudiée dans le projet E4T..... 6

Figure 3 : Scénarios de l'évolution du prix des batteries (cellules + pack) entre 2015 et 2030 (source : BNEF) 7

Figure 4 : architecture hybride parallèle utilisée sur les véhicules MHEV fonctionnant en 48V 8

Figure 5 : Représentation de l'approche bottom-up utilisée pour déterminer les prix de vente des véhicules..... 9

Figure 6 : TCO de véhicules de segment A en 2015 (à gauche) et 2030 (à droite) sur le cycle urbain10

Figure 7 : Impact sur le changement climatique d'une personne utilisant son véhicule de segment A en 2030 en usage urbain..... 11

Figure 8 : Comparaison des TCO de véhicules de segment C en 2030 sur le cycle WLTC 13

Figure 9 : Impact sur le changement climatique d'une personne utilisant son véhicule de segment C en 2015 (en haut) et 2030 (en bas) sur le cycle WLTC 14

Figure 10 : Comparaison des TCO de véhicule utilitaires en 2015 (à gauche) et 2030 (à droite) sur le cycle WLTP..... 15

Figure 11 : Comparaison des TCO de bus en 2015 (à gauche) et 2030 (à droite) sur le cycle parisien 16

Figure 12 : Impacts sur le changement climatique d'une personne prenant le bus pour différentes technologies et différents cycles. Horizons temporels 2015(en haut) et 2030 (en bas) 17

Figure 13 : Comparaison des TCO de poids lourds de livraison (12t) en 2015 (à gauche) et 2030 (à droite)..... 18

Figure 14 : Comparaison des TCO de poids lourds routier (40t) en 2015 (à gauche) et 2030 (à droite) 19

Abbreviations and acronyms

ADEME	French Environment & Energy Management Agency
--------------	---

ADEME IN BRIEF

ADEME (French Environment & Energy Management Agency) is active in the implementation of public policy in the areas of the environment, energy and sustainable development. ADEME provides expertise and advisory services to businesses, local authorities and communities, government bodies and the public at large to enable them to establish and consolidate their environmental action. The agency also helps to finance projects from research to implementation in the following fields: waste management, soil conservation, energy efficiency and renewable energy, savings in raw materials, air quality, combating noise, the transition to the circular economy and combating food waste.

ADEME is a public establishment under the joint supervision of the Ministry for the Ecological and Solidarity Transition and the Ministry for Higher Education, Research and Innovation.

ADEME'S COLLECTIONS



THEY'VE DONE IT

ADEME the catalyst: The players testify to their experiences and share their knowledge.



EXPERTISE

ADEME the expert: ADEME reports on the results of research, studies and collective accomplishments achieved under its supervision.



FACTS AND FIGURES

ADEME the go-to reference: ADEME provides objective analyses using regularly updated enumerated indicators.



KEYS FOR ACTION

ADEME the facilitator: ADEME draws up practical guides to help players implement their projects methodically and/or in accordance with regulations.



HORIZONS

ADEME focused on the future: ADEME provides realistic prospective views of energy transition- and ecology-related issues to build a desirable future together.



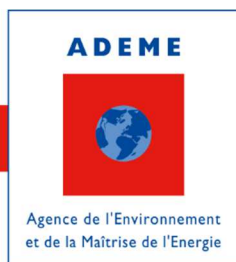
Cross-sector review of the impact of electrification by segment: E4T PROJECT

Summary:

This document delivers a summary of the main results of the “Economic, Energy and Environmental Study of French Road Transport Technologies” (E4T) project, segment by segment, and provides an analysis of the main trends in electrification currently being implemented or developed.

The bottom line

This summary shows that, except for the long-haul truck segment, conventional engines (petrol or diesel) will meet with strong competition in 2030, either from the point of view of their total cost of ownership (TCO) or their environmental impact (greenhouse gas (GHG) emissions and pollutants).



www.ademe.fr

