
# ENERGY, ECONOMIC AND ENVIRONMENTAL ANALYSIS

## FOR FRENCH ROAD TRANSPORT TECHNOLOGIES BY 2040

An analysis

# ORGANIZATION AND OBJECTIVES

Cutting $CO_2$ emissions from road vehicles is essential and necessary in order to reduce long-term greenhouse gas emissions in France. In addition to reducing the climate impact, the development of new powertrains makes it possible to mitigate the impact of traffic on air quality (particularly true for electric vehicles were traffic-related emissions are concerned), lower the cost of fuel for users and cut oil imports.

To analyze the available technologies for propulsion systems in both existing vehicles and those of tomorrow, working within the framework of the E4T 2040 project co-financed by ADEME, IFPEN has access to methods and tools that make it possible to conduct prospective analyses concerning the transport sector. For the purposes of this project, these methods and tools have been used to evaluate the economic, energy and environmental performances of vehicle technologies as a function of operating conditions.

The diversity of road transport segments (light vehicle, light commercial vehicle, heavy truck, bus and motorcycle) and the incorporation of medium-term (out to 2040) technological and economic evolutions have been taken into account in the analysis. Thus, using the modeling tools described in this report, new technologies and their future evolutions have been evaluated with a view to anticipating future needs and the sector's strategic directions.

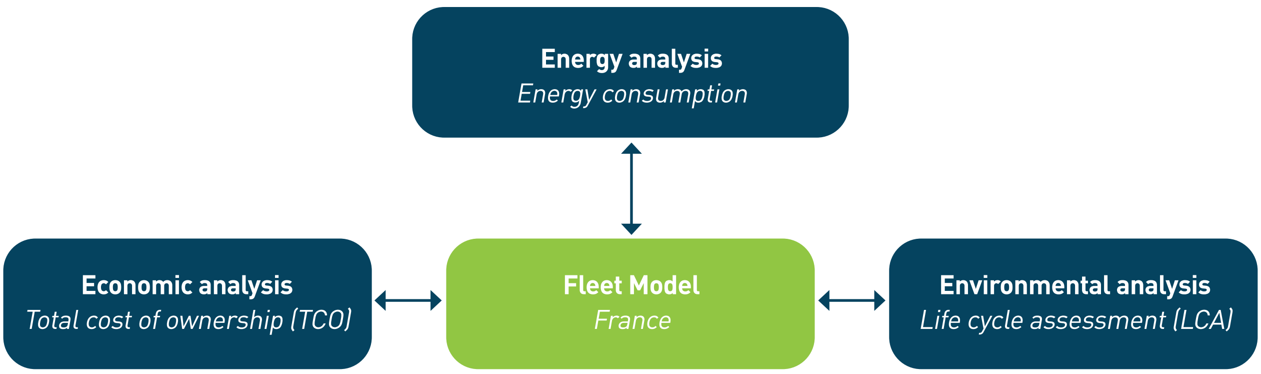
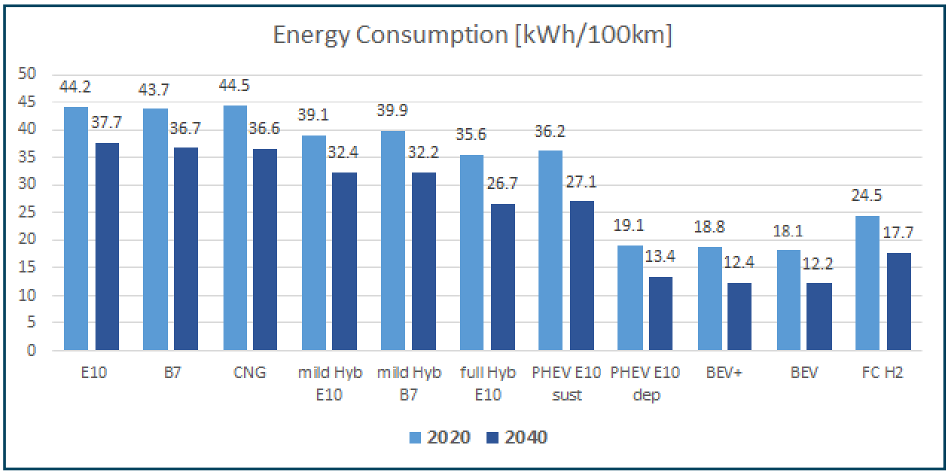



***Diagram illustrating the work packages of the E4T 2040 project***

# ENERGY WORK PACKAGE

The first phase of the holistic analysis that the E4T 2040 study aims to achieve consists in establishing the energy consumption of these different propulsion technology solutions, based on "system" simulation. Simulation makes it possible to model the entire vehicle fleet, to simulate vehicles under realistic operating conditions and to forecast long-term evolutions (technical improvements, change of mass, etc.).

The graph below presents the energy consumption (tank-to-wheel) results for different C-segment architectures over the WLTC (worldwide harmonized light vehicle test cycle) up to 2020 and 2040. The evolution of energy performances, energy densities and vehicle characteristics projected in this study lead to average energy consumption reductions compared to 2020 of 16% for conventional vehicles, 22% for hybrids, 33% for electric vehicles and 29% for fuel-cell vehicles. These observed reductions depend on the usage cycle. Energy expenditure for an "urban" operating cycle is significantly impacted by a vehicle's mass: expected progress in terms of the increase in battery energy density, coupled with improvements in the energy efficiency of components, herald the possibility of significant consumption reductions for electric vehicles (39% reduction compared to 2020 for the same battery capacity, but only 11% for conventional vehicles over the urban cycle).



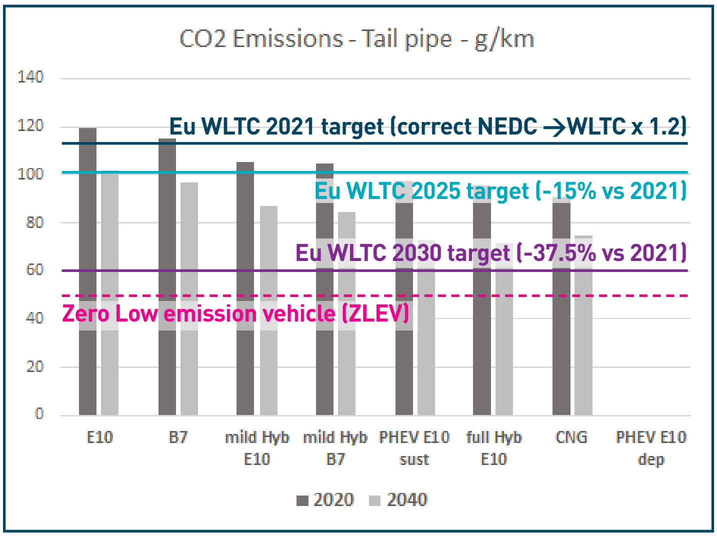

***C-segment vehicle energy consumptions over the WLTC [kWh/100km]***

Generally speaking, simulation results established all-electric architectures as being the most energy efficient, due to the higher average efficiency of the components and the possibility of recovering a significant proportion of kinetic energy during the deceleration phases.

The energy analysis also highlighted the benefit of powertrain electrification, particularly for urban cycles during which mild hybrid vehicles (or hybrid 48V) present consumption figures that are 20% below those of the equivalent IC powertrain, and at least 40% lower than those of the full hybrid versions. This benefit diminishes for high-speed cycles, particularly for heavy applications.

The hypotheses retained for 2040 reveal energy consumption reductions of at least 30% in electric vehicles for all applications. This improvement can primarily be explained by the two-fold-reduction in battery mass for an identical onboard capacity.

These evolutions also improve hybrid vehicle consumption, but **associated $CO_2$ emissions demonstrate that these gains are not enough to meet the $CO_2$ emission reduction objectives fixed by the European Union for 2030**, which explains the shift to "electric" of vehicle manufacturers. This is illustrated in the figure below.



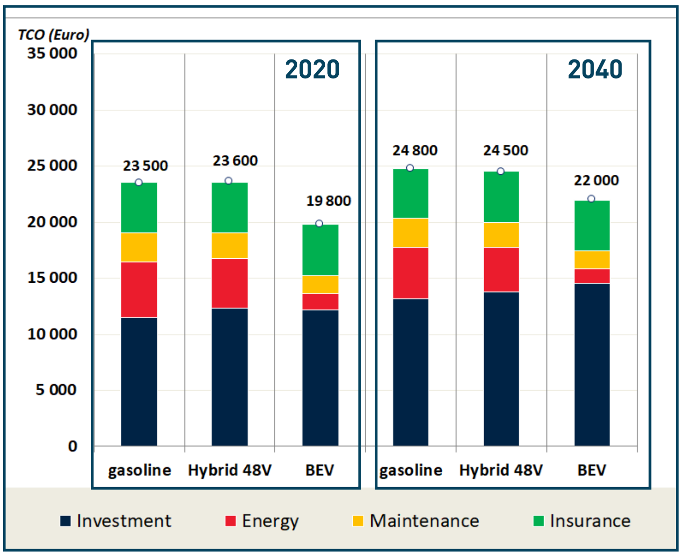

***Exhaust $CO_2$ emissions for C-segment vehicles over the WLTC***

# ECONOMIC WORK PACKAGE

A major and gradual change in land mobility is already underway. It concerns light vehicles, utility vehicles, heavy trucks, buses and even motorcycles. It therefore seems important to investigate whether or not this technological revolution is likely to go hand in hand with a significant increase in the costs of ownership.
That is because the energy transition within the transport sector will need to be led by vehicle users, who, via their future purchases, will slowly but surely change the composition of the French vehicle fleet.
This part of the study concerns the Total Cost of Ownership (TCO) analysis for all these vehicles for the period up to 2040.

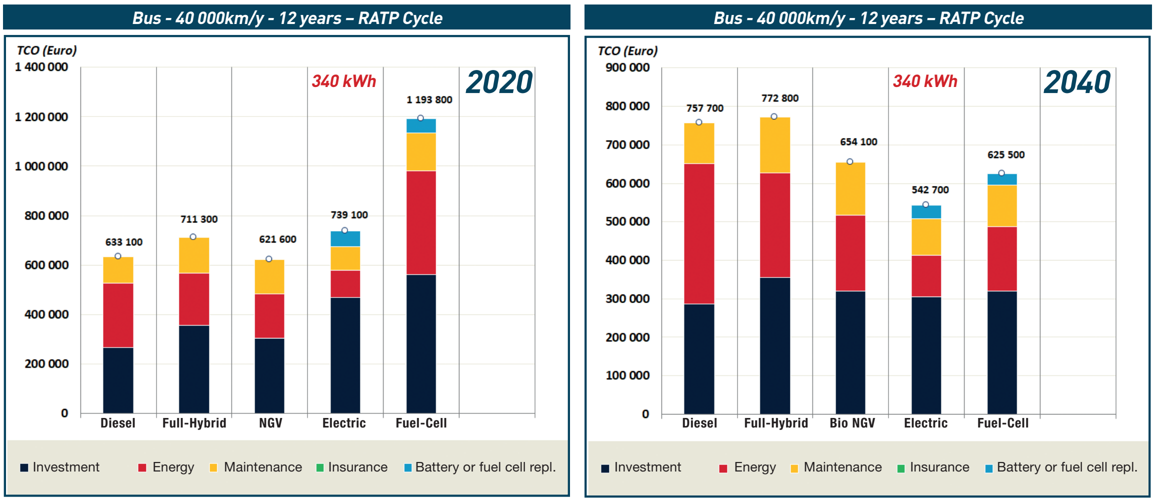
A TCO analysis is extremely dependent on how the vehicle is used. However, it is possible to try to use annual mileages and average lengths of ownership to deduce trends (i.e., comparison between technologies) and, above all, project forward to 2040.

To summarize this economic package, **battery electric vehicles are already cost-competitive for light or compact vehicles, if the battery capacity remains reasonable (typically < 50 kWh)**. This is shown in the graphs below. Electric vehicles benefit from a purchase subsidy and a low running cost, which allows them to pay back the initial investment.



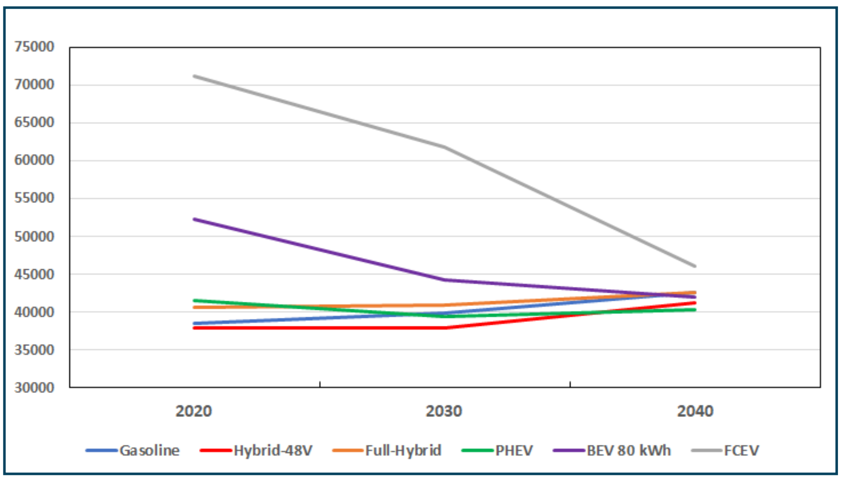

*TCO of a small car in 2020 and 2040 – Cycle WLTC – 10 years of ownership – 8 000km/year*

The results for buses, for example, show that in 2020 a battery electric or even more hydrogen fuel cell bus works out to be more expensive than an IC (diesel or NGV) or diesel hybrid bus (figure below). In 2040, the electric bus becomes the better choice, and the fuel cell is a solution to be considered, especially if the price at the pump of green hydrogen falls below €6/kg. The reduction in the "energy" cost component could then have a very favorable impact on the TCO.




***TCO of a bus in 2020 and 2040 – RATP Cycle – 12 years of ownership – 40,000 km/year***

Conversely, where light vehicles are concerned, the fuel cell solution will probably not be profitable in 2040. It can be seen that even with a lower price "at the pump" of hydrogen (-20%, i.e., €4.8/kg in 2040 compared to €6/kg – basic hypothesis) the Segment-C fuel-cell electric vehicle (FCEV) struggles to be competitive in 2040. A breakdown of the TCO shows that, in the end, the "energy" component is not the most important one. It is the investment (vehicle purchase price less the resale price) that has the greatest impact on TCO. With our hypotheses, the price of purchasing a C-segment vehicle with fuel cell technology is €37,000 in 2040 (constant-euro price). In order to be competitive, the purchase price needs to be lower still and be similar to that of a battery electric vehicle. For that to be the case and using these hypotheses, that would mean a fuel cell cost of below €60/kW in 2040.

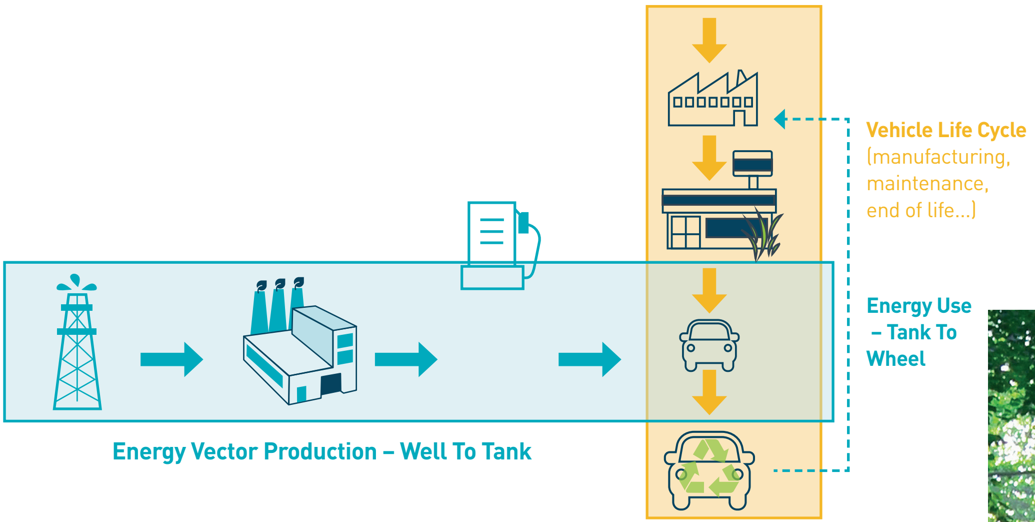



***Evolution over time of TCO [€] for C-segment vehicles – 12,500 km/year – 10 years***

Where heavy trucks are concerned, the equilibrium between the TCO of an IC powertrain and a battery electric powertrain will be reached between 2025 and 2035, once again depending on the target range and battery capacity. The hydrogen electric solution (fuel cell) is likely to become more attractive a little further down the line, but it will benefit from an increased range and be less dependent on charging stations. In 2040, electric solutions (battery or hydrogen) will be competitive across all segments in the study. The ban on the sale of IC solutions at some point during the period in 2035 is thus likely to occur without any major increase in the TCO for users, according to the price and tax change hypotheses used for the purposes of this study (particularly the significant fall in the price of hydrogen at the pump).

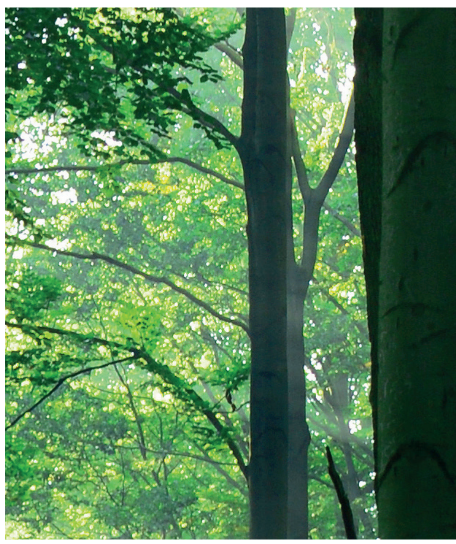
# ENVIRONMENTAL WORK PACKAGE

A Life Cycle Analysis of the different vehicle segments coupled with propulsion technologies and their associated energy vectors (fossil fuels, electric and hydrogen mix) makes it possible to compare the various technological options envisaged as a function of use and to identify the most appropriate among them from an environmental point of view. The life cycle analysis also makes it possible to take into account the environmental impacts more broadly than is the case within the regulatory framework, as illustrated below.

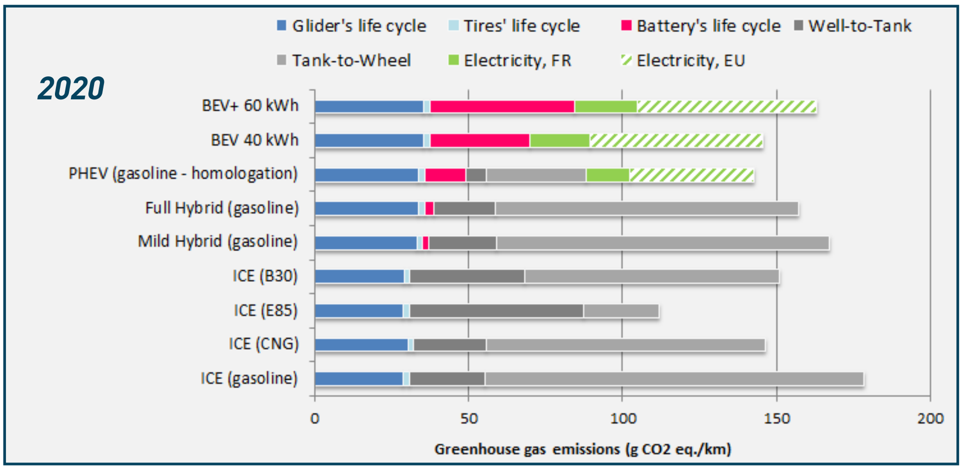


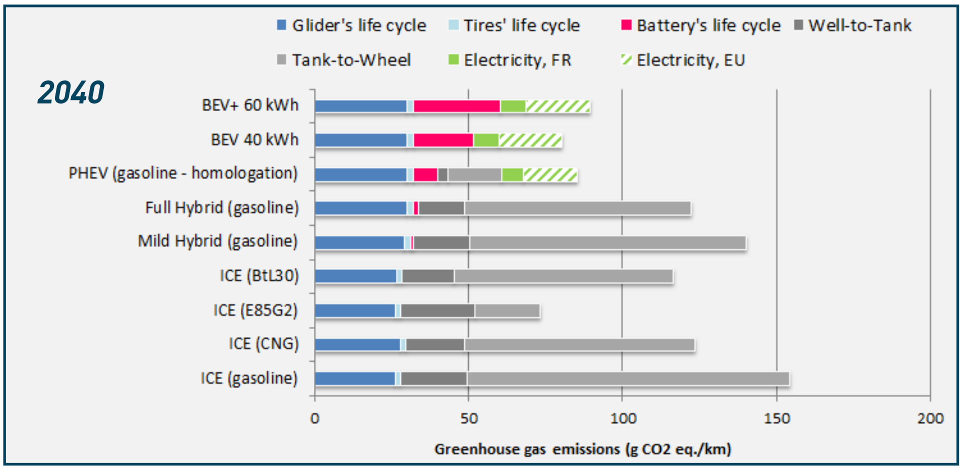

***Steps considered within the scope: WtW including vehicle life cycle***

For the global warming indicator (expressed in g $CO_{2eq}$/km), the results demonstrate the potential of electrification (battery or hydrogen fuel cell) combined with a French electric mix irrespective of vehicle and driving cycle. Apart from electric vehicles, plug-in hybrid vehicles emerge as excellent candidates for reducing greenhouse gas emissions, subject to systematic recharging behavior on the part of users: any journey below the electric range must be made in «zero emission» mode.




Similarly, the contribution of biofuels in fuel pools may offer a genuine solution for reducing greenhouse gas emissions in France in the short and medium terms, under the assumptions of the study (biofuels excluding ethanol lignite by 2020, and 100% gen2 by 2040). For example, E85, which uses a large proportion of bioethanol, has very good results in terms of GHG reduction. It has a very advantageous emission factor from a life cycle point of view (46% reduction in emissions in 2020 and 77% in 2040 compared to the fossil reference at 88.3 $gCO_{2eq}$/MJ). In order to fully highlight this potential, the regulation will have to take into account the biogenic nature of a fraction of the $CO_2$ emissions from the combustion of biofuels, or establish a specific display.

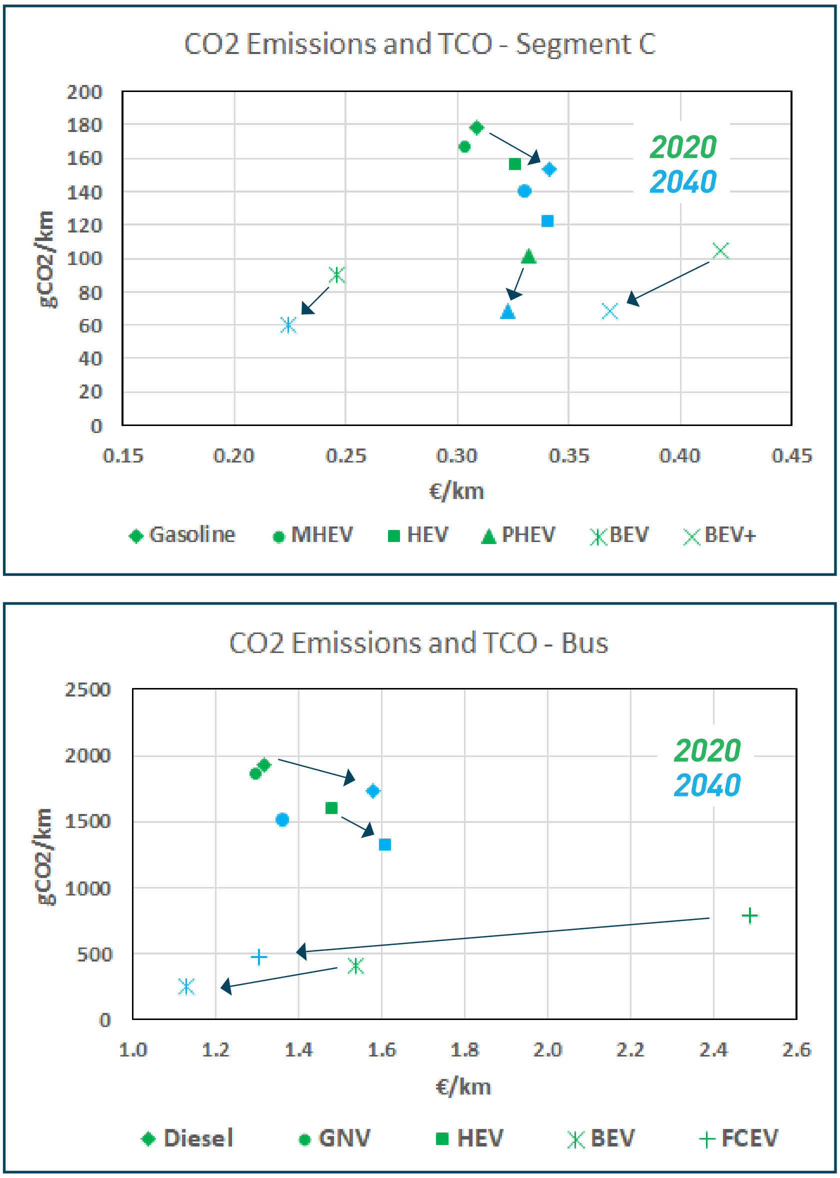



***Potential impacts on climate change for C-segment vehicles. WLTC driving cycles. For the years 2020 and 2040 (12,500 km/year)***

For this to be the case, regulations should take into account the biogenic nature $CO_2$ emissions resulting from biofuel combustion. In terms of the other environmental indicators (particles, acidification, etc.), the electric vehicle and hydrogen fuel cell vehicle do not present the same footprint and, for the majority of indicators, have a greater impact than IC vehicles, using biofuels in particular.

This research also makes it possible to relate the environmental aspects studied via this work package, with the cost aspects covered in the Economic work package. An approach combining the two research avenues can be used to propose economically and environmentally optimized solutions. The combined analysis is illustrated below. The main effects to be retained can be seen on the two diagrams (C-segment vehicles and buses). Primarily IC powertrains (ICE, MHEV and HEV) will see their costs rise over the period to 2040, alongside a moderate reduction in $CO_2$ emissions. Conversely, electric solutions (battery or hydrogen) will see a significant fall in their costs, while bringing about $CO_2$ emission reductions.

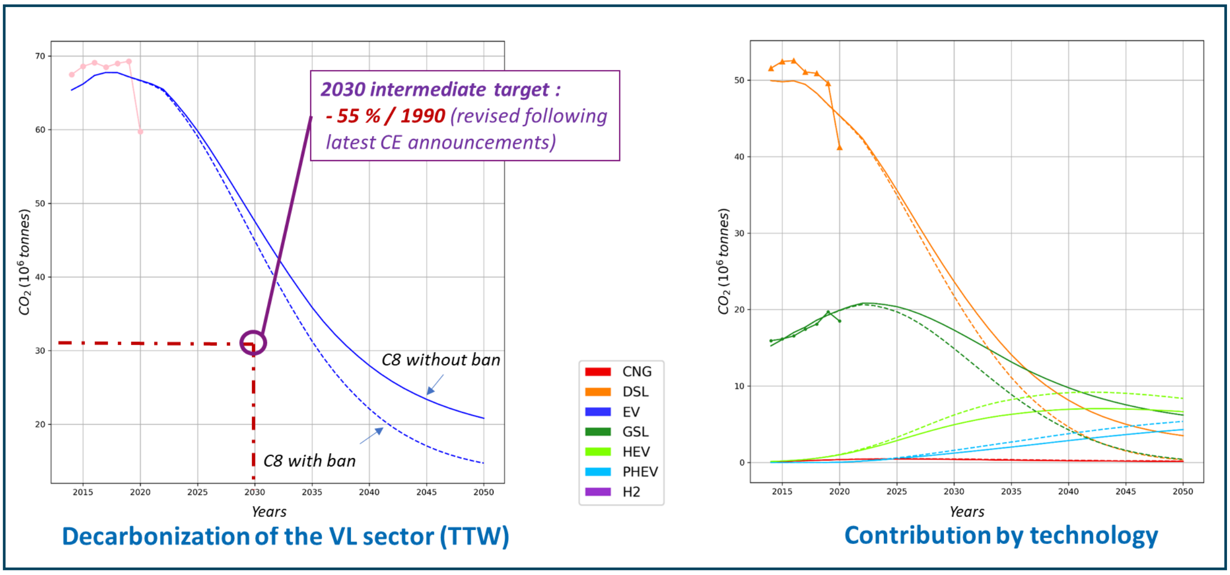



***Combined analysis of TCO and $CO_2$ emissions (WTW) for C-segment vehicles (top) and buses (at the bottom)***

# FLEET PROJECTION FOR 2050

Finally, the last part of the study was aimed at integrating the results of the first three work packages into the fleet model. In order to analyze different public policies targeting the decarbonization of the transport sector and to study the scenarios making it possible to achieve the $CO_2$ emissions objectives contained in the French national low-carbon strategy (SNBC), IFPEN developed an integrated transport demand simulation model: the DRIVE[RS] (*DiscRete cholce modeling for low-carbon VEhicles fleet scenaRioS*) vehicle fleet model.

The consumptions (Energy work package), TCO (Economic work package) and LCA (Environmental work package) results were integrated into the model. Several hypotheses in terms of context (oil price changes, increase in the number of rapid charging stations across the country, etc.) and public policy (evolution of the TICPE - domestic consumption tax on energy products -, carbon tax, purchase incentives) were used to establish scenarios for 2050.




***Evolution over time of TTW $CO_2$ emissions of the fleet (left) and by technology (right) for C8 scenarios with and without a ban on the sale of IC vehicles after 2035***

The results show that even in the most favorable scenario for the sale of the electric vehicle, the Green Deal objectives (90% cut in transport sector $CO_2$ emissions in 2050 compared to 1990) are not met. In 2050, $CO_2$ emissions will amount to 21 Mt. It should be recalled that they amounted to 70 Mt in 1990. The ban on the sale of IC vehicles in 2035 has to be added to this scenario in order to get close to the objective. In such a scenario, $CO_2$ emissions will amount to 11.4 Mt in 2050. With policies aimed at supporting car-sharing, and/or the increased use of advanced biofuels, the Green Deal objective could thus be met.

The study also shows that a reduction in the demand for vehicles associated with a change in behavior (–10% passenger car mobility in 2040) only has a slight impact on the sector's decarbonization. That is because the drop in the demand for mobility slows down fleet renewal (vehicles take longer to become obsolete) thereby slowing the penetration of low-carbon vehicles. Finally, the recent "Fit for 55" objective set by the European Commission, i.e., a 55% reduction in $CO_2$ emissions by 2030, is going to be difficult to achieve. It appears challenging to change the French fleet sufficiently to validate this objective in less than a decade. In the short term the incorporation of biofuels (that can be directly used by the majority of vehicles in the fleet) and a change in regulations (taking into account the biogenic origin of a part of the $CO_2$ emitted through biofuel combustion) may improve this observation.

The conclusions of this project will be used to draw up recommendations concerning the technological choices to be made in order to meet mobility needs through to 2040, based on economic, energy and environmental criteria as well as future French national (SNBC) and European regulations (Fit for 55 and Green deal).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