LCA Study of Vehicles Running on NGV and bioNGV

Authors:
Anne Bouter
Joris Melgar
Cyprien Ternel

Final version, September 19, 2019

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1 Study objectives

1.1 Background

Historically, there have been close links between transport and oil: 93% of the energy used comes from oil-based products. This is the link called into question in energy transition scenarios because, globally, the transport sector is the second-largest contributor to anthropogenic greenhouse gas (GHG) emissions, after electricity generation. However, efforts have been made to reduce the transport sector's dependence on oil by proposing innovative alternative energy solutions. For a manufacturer marketing light vehicles in Europe, existing regulations impose a CO_2 emission limit on the entire fleet, set at 130 g CO2 eq./km, with penalties incurred if the manufacturer breaches this ceiling. This celling will fall to 95 g CO_2 eq./km for a manufacturer's entire fleet (annual sales), starting from 2021.

In this harsh regulatory context, a performance improvement in combustion engines alone will be insufficient, strongly encouraging manufacturers to use other low-carbon technologies:

- electrification, provided that the electricity is low-carbon-footprint
- the incorporation of biofuels at the pump
- fuel cell technologies
- etc.

Another solution would be to use alternative fuels: NGV (natural gas for vehicles) or bioNGV. A market already exists, as more than 18 million vehicles already run on NGV worldwide, of which some 15,000 are in France, mainly buses, heavy goods vehicles (HGVs) and light commercial vehicles (LCVs).

Fossil-based NGV has the added benefit of an emission factor lower than that of gasoline or diesel. This means that for the same amount of energy burned in the engine, less CO_2 will be emitted as exhaust. However, it is produced from fossil resources and cannot be a sustainable solution in the energy transition of the transport sector.

Produced from organic sources (livestock effluents, crop residues, organic waste, etc.), biomethane, used here as a fuel (bioNGV), is a renewable, sustainable energy source. Biomethane injection into grids is currently a booming sector. This momentum also heralds a change in the waste treatment sector, which faces challenges in terms of management and recovery. The effectiveness of biomethane in reducing greenhouse gas emissions has already been established in studies using Life Cycle Analysis (LCA), which are often highlighted to show the promise of this sector. However, to date, a more comprehensive LCA study including vehicle life cycles has yet to be carried out to assess the value of BioNGV fuel for road transport.

1.2 Objectives

The aim of this study is to assess the potential environmental impacts of different means of road transport (people and goods), over different time horizons (current and 2030), taking into account both the vehicle life cycle and the fuel life cycle. The study focuses on only one global warming indicator: greenhouse gas (GHG) emissions.

The LCA of the various vehicle segments (passenger cars, buses, light commercial vehicles, heavy goods vehicles), coupled with propulsion technologies (combustion engine, hybrid, electric) and their associated energy types (fossil fuels, bioNGV and electricity mix) have made it possible to compare the envisaged technology options, and to identify those best suited to the various environmental contexts, focusing on climate change. However, the study is not fully comprehensive, and comparisons with other alternative fuels such as conventional or advanced liquid biofuels remain to be made.

1.3 General methodology

The first stage of the study was to conduct a systematic assessment of vehicle energy consumption for the various segments analyzed in the project (Figure 1), namely:

- The light vehicle segment, with two vehicle ranges: Core (C segment) and Luxury (D segment)
- The bus segment (12m)
- The light commercial vehicle segment (e.g., Renault Master)
- Urban heavy goods delivery vehicles (12 tons)

Figure 1: Segmentation of the Transport sector used in the study

Each segment was broken down by engine system, incorporating variable electrification ratios, ranging from internal combustion vehicles to hybrid vehicles, rechargeable hybrid vehicles, and all-electric vehicles. Each powertrain (combustion engine, electric engine, battery) was modeled from an energy perspective, taking into account major trends and future improvements by 2030. Similarly, each vehicle was modeled taking into account a prospective vision of its main characteristics (aerodynamics and tire friction) and its weight (body and chassis lightening, impact of improved power and energy density of electrified devices). These models enabled us to assess the energy consumption (of fuel and electricity) for different usage cycles, both current and future.

After this first Tank-to-Wheel energy approach, each type of vehicle and powertrain was then assessed using the LCA methodology, incorporating the carbon footprint from energy production and the carbon fooprint from manufacturing the vehicle. This study continues the approach of the E4T[1] study published in 2018. The architectures (in particular electrical) were updated, and the NGV and bioNGV engine data were added in full.

[1] Environmental, Economic and Energy Study of Transport (IFPEN-ADEME, 2018)

2 Simulations of real-world vehicle consumption

2.1 Vehicle simulation platform

To measure the energy consumption of the various vehicles defined by their architecture and segmentation, simulations were carried out using Simcenter Amesim™ software. The simulation platforms are based on "IFP-Drive" library components developed jointly by IFP Energies Nouvelles and Siemens PLM Software (Figure 2). These models transcribe the physics of all devices present in conventional vehicles (combustion engine, transmission, etc.) and electric vehicles (battery, traction engine, power electronics etc.). A component dedicated to hybrid architectures (*ECMS: Equivalent Consumption Minimization Strategy*) is used to determine the optimal management strategy for internal combustion and electrical energy in order to minimize fuel consumption. Further details can be obtained by consulting the SAE publication *[Automatic Generation of Online Optimal Energy Management Strategies for Hybrid Powertrain Simulation]*

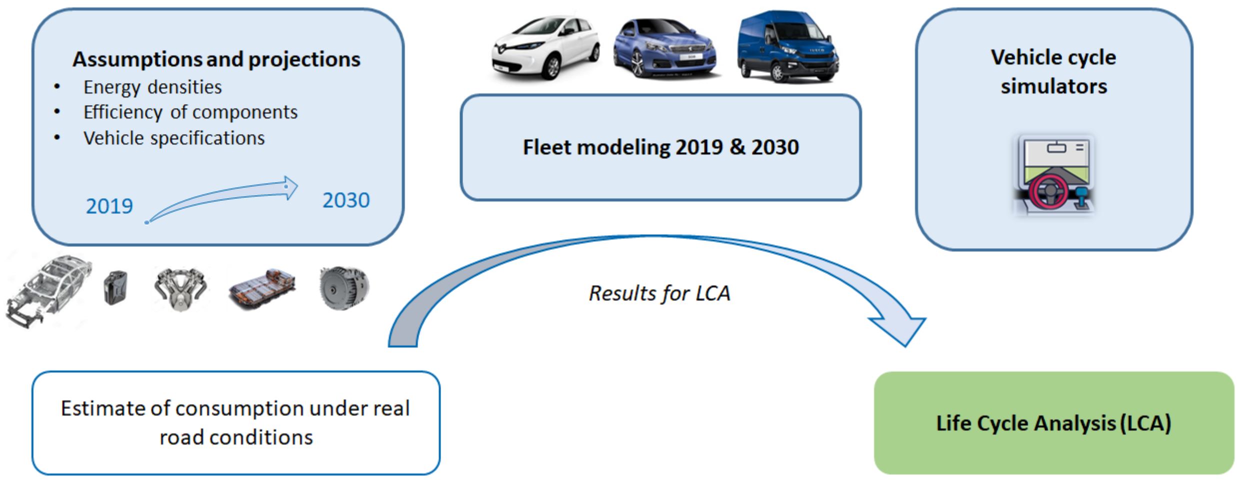

Figure2: Methodology used for the dimensioning and energy analysis of vehicles

These vehicle simulation platforms were validated on using IFP Energies Nouvelles' experimental resources, namely lab bench facilities for combustion engines, electric engines and batteries, as well as roller test benches on which the vehicles are tested. These resources also enable us to provide data that faithfully reflects the technological choices made by vehicle manufacturers.

2.2 Significant results of the energy simulation

2.2.1 Determination of weight

Of all the input parameters of the vehicle simulations, road weight is paramount. For any given segment, this weight differs according to the architecture. A "shell" weight was identified for each segment, to which the weights of the devices present in the vehicle were added according to their design. Figure 3 illustrates the design and choice of components for vehicles representing the C segment.

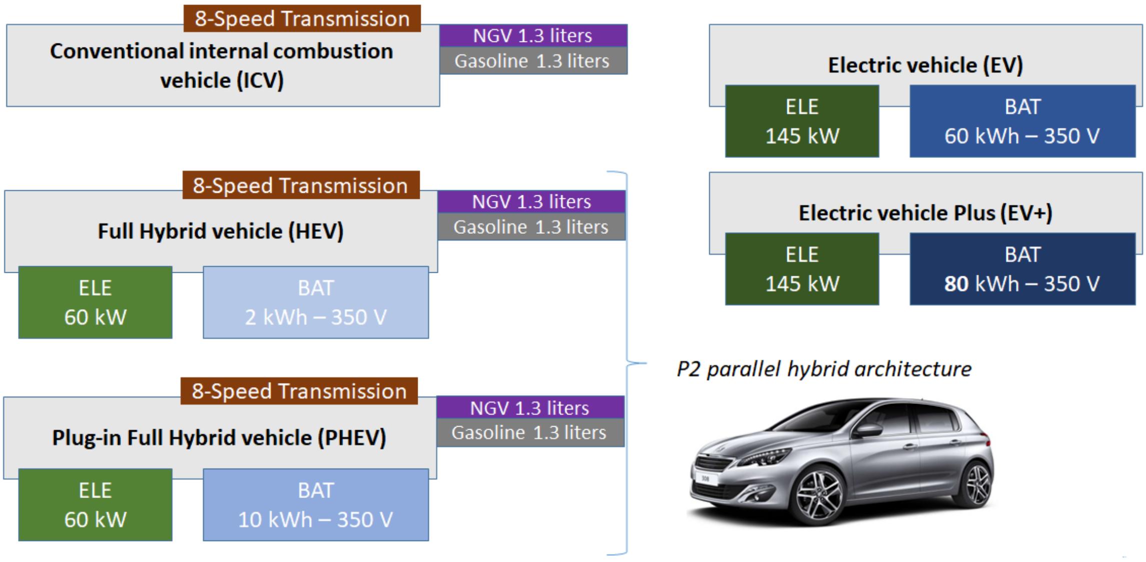

Figure 3: Design of C segment architecture (ELE: electric engine, BAT: Battery)

The calculation of components' weights is based on assumptions of energy densities and power densities determined for the current horizon and projected for 2030. The battery is a major component of the weight of electric vehicles; the density of the total pack including battery cooling, battery structure and control is currently estimated at 150 Wh/kg, rising to 200 Wh/kg by 2030.

For NGV and bioNGV vehicles, the weight of gas tanks was defined using state of the art principles. These tanks contain gas at 200 bar, and are made of steel, which makes NGV vehicles heavy, particularly when carrying large volumes of gas as is the case with heavy goods vehicles and buses that can carry up to eight 150-liter tanks. In these heavy applications, steel tanks may weigh up to 400 kg. For light vehicles, the excess weight is around 30 – 40 kg compared to plastic liquid fuel tanks.

Figure 4 shows a breakdown of the vehicles selected for the current horizon of the C segment. We note the absence of electric NGV vehicles, as this type of vehicle is not marketed to date – but they will be part of the 2030 fleet considered in the study.

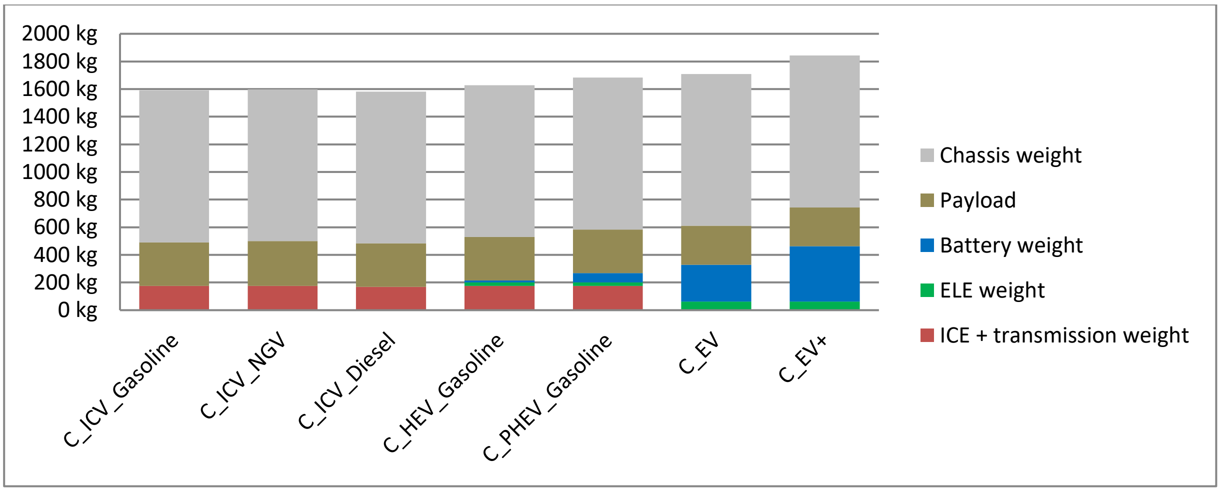

Figure 4: Weight breakdown of C segment vehicles 2019*(ELE: Electric engine - ICE: Internal combustion engine - the payload is determined by reference to the European WLTP test protocol plus the tank taken into account)*

Changes in the assumptions regarding components available by 2030 allow road weights to be estimated; Figure 5 shows the planned changes in vehicle road weight for C segment. The weight reduction of conventional and hybrid vehicles over the next 10 years is around 4%. For electric vehicles, weight reduction reached 3%, based on a 50% increase in battery capacity, as extending battery life remains a priority for manufacturers (at ISO-battery capacity in 2030, the weight reduction would be 8%).

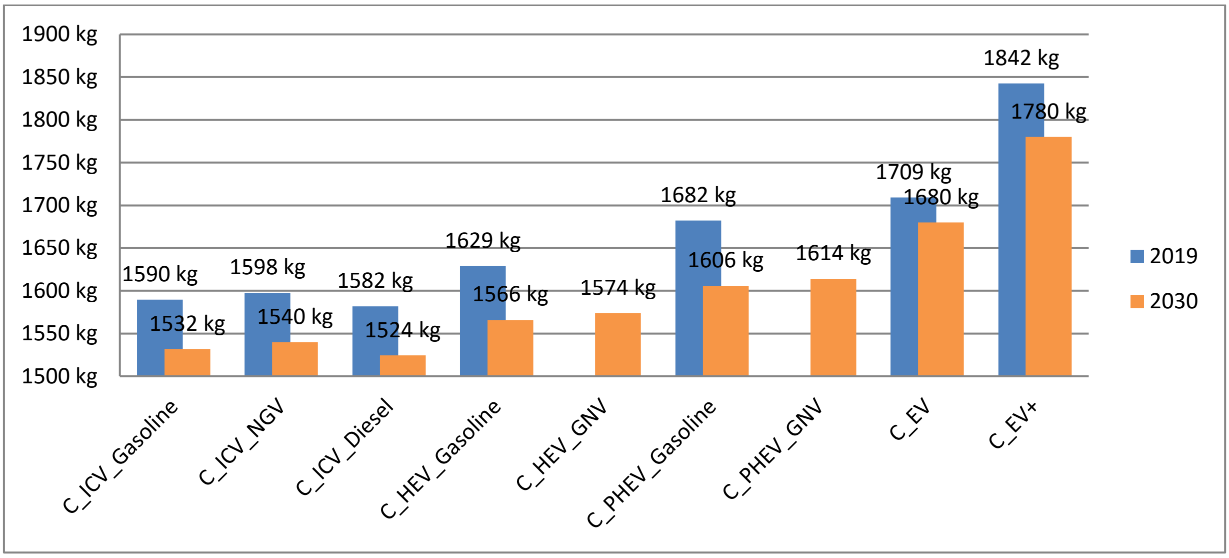

Figure 5: Change in simulated on-road weights [kg] between the 2019 and 2030 fleets of the C segment

2.2.2 Consumption over cycle

Light vehicles were simulated over the WLTC cycle, which replaced the NEDC cycle in 2018 in order to better represent the overall usage of a given vehicle. The bus cycle was assessed from recording by the RATP which is more dynamic (a lot of acceleration and braking) with a relatively low average speed (11 km/h). HGV was assessed from the recording of a suburban delivery cycle.

The energy results for C segment vehicles on the WLTC cycle are shown in Figure 6.

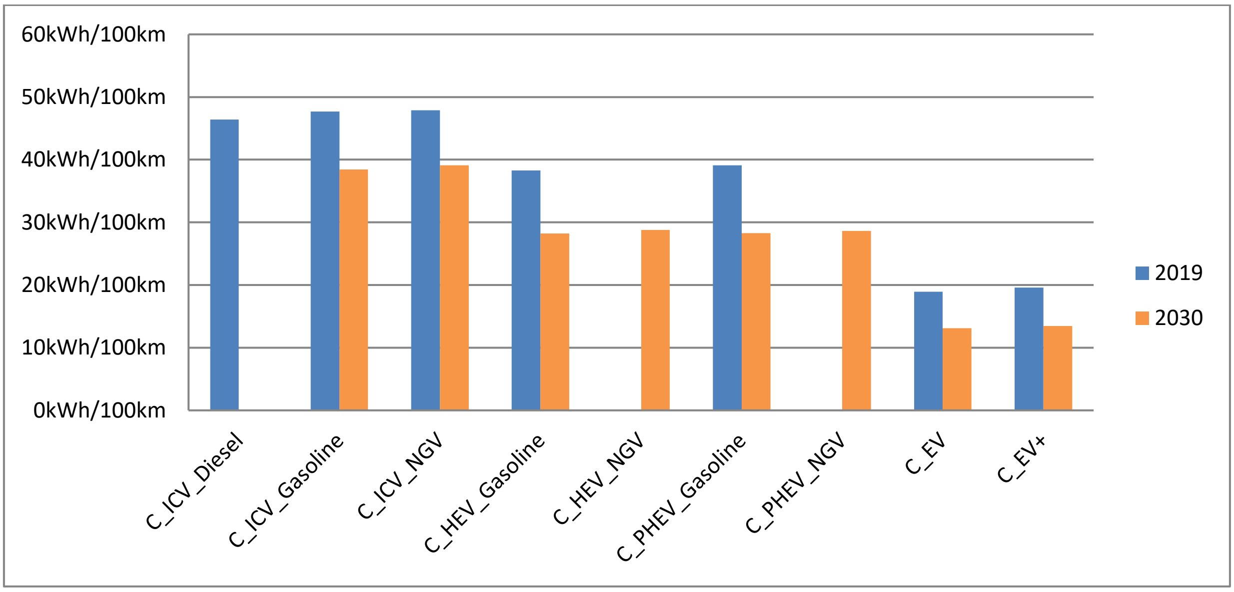

Figure 6: Energy consumption [kWh/100 km] of C segment vehicles – 2019

- **Analysis of results for 2019:**

We can see that the consumptions of conventional internal combustion gasoline and NGV vehicles are similar, due to the similarity of the engine mappings used in the study; in fact, manufacturers use a "gasoline" engine baseline to develop NGV technological solutions.

Figure 6 also shows the gains made by electrification: the design of the components detailed in Figure 3 produces reductions in consumption of up to 20% for standard hybrids (HEV).

For its part, the Plug-in Hybrid Electric Vehicle (PHEV) shows higher consumption than the hybrid HEV due to the weight of its on-board battery – with the cycle based on identical battery-charge levels at the start and end of the cycle. This finding alone shows that the electric mode for a PHEV – and thus regular recharging – is the preferred option. In this mode, the PHEV is therefore like an electric vehicle whose energy consumption results are below 20 kWh/100 km, for both the envisaged battery capacity assumptions: EV and EV+. This low energy consumption is achieved by the high efficiency of the components in the powertrain, specifically the electric engine, whose average cycle performance is 94% compared to 34% for the combustion engine of a conventional gasoline vehicle.

- **Projected energy consumption by 2030:**

The planned changes for 2030 - in terms of reducing component weight, reducing the forces exerted on the vehicle, and increasing device performance - would lead, according to the simulations, to reduced consumption for all architectures: 20% for conventional vehicles and up to 30% for electric vehicles benefiting from the increase in energy densities of batteries, despite the increase in capacity.

Analysis of the C segment results does not reveal an energy benefit from using natural-gas engines versus liquid fossil-fuel engines, as converter performance is of the same order of magnitude and will improve in the same way between now and 2030. To see any differences, the entire energy chain must be looked at: “from well to wheel". This is the purpose of the next part: the Life Cycle Analysis (LCA), which uses as input data the characteristics of the components and the energy results of the 80 vehicles modeled via the simulation platform.

3 Life Cycle Analysis

3.1 System definition

The LCA was carried out in accordance with standards ISO 14040:2006 and ISO 14044:2006 using the SimaPro® commercial software. The database used is Ecoinvent v. 3.5. The modeling selected is “*allocation, cut-off by classification*” by default.

Here we assume that the vehicles are both assembled and used in France.
Two time horizons were considered in the context of this study: current (2019), and prospective (2030). Several use cycles were examined: the WLTC-approved[2] cycle for light vehicles (C and D segments) and light commercial vehicles, the RATP cycle for buses, and the Carrefour City cycle for 12-ton heavy goods vehicles.

The NCVs[3] in this study use the JRC’s values,[4] along with the quantities of CO_2 emitted during the combustion of gasoline and diesel fuels.

Vehicle consumption per use cycle was established in the first phase of this study (see Chapter 2). A distinction was made between the transportation of people and transportation of goods as they do not perform the same function, and as such are not directly comparable. This methodological aspect will be clarified in the definition of the functional unit, section 3.2.

3.1.1 Description of the vehicles studied

All vehicles were modeled according to the data in the 2.2.1 section on weights, as follows:
- bare vehicle body with options and gearbox
- combustion engine
- electric engine and generator
- battery

Vehicles for the 2030 horizon are modeled on vehicles considered for the current horizon. Only a reduction in vehicle weight was taken into account (PE International AG and Gingko 21 2013): replacement of 30% of the vehicle's steel by an amount of aluminum weighing 65% of this 30% steel percentage. Vehicles were modeled according to two European reports from the IMPRO CAR (Nemry et al. 2008; Nemry et al. 2009) Project and the Ecoinvent database (Frischknecht et al. 2005).

3.1.1.1 Light vehicles (C and D segments)

The service life of these vehicles is assumed to be 10 years at a rate of 15,000 km/year, i.e., 150,000 km over their life cycle. This is consistent with the previous E4T study.

3.1.1.2 Light commercial vehicles (LCV)

The service life of these vehicles is assumed to be 12 years at a rate of 16.200 km/year, i.e., 194.400 km over their life cycle.

[2] World harmonized Light vehicles Test Cycles
[3] Net Calorific Value
[4] Well-to-Wheels analysis of future automotive fuels and powertrains in the European context. Appendix 4a

3.1.1.3 Buses

The material composition of buses is based on the physical sections used in the Iveco Irisbus presentation, detailed according to the architecture: combustion, hybrid, or electric. Assumptions and extrapolations were also made. The service life of buses is assumed to be 12 years at a rate of 40,000 km/year, i.e., 480,000 km over their life cycle.

3.1.1.4 Heavy goods delivery vehicles (12 tons)

The service life of heavy goods vehicles is assumed to be 12 years at a rate of 31,000 km/year, i.e., 372,000 km over their life cycle.

3.1.2 Tires

The determination of the weight and tire composition of passenger cars and LCVs is based on the Nemry et al. report. The weight of the tires on buses and heavy goods vehicles is based on the presentation by Iveco Irisbus. Their composition is based on the Nemry et al. report. Tire service life, regardless of vehicle type, is assumed to be 40,000 km.

The number of tires on a given vehicle is 4, as is the case for LCVs. The number of tires on buses and HGVs is taken as 6.

3.1.3 Batteries

The assumptions for battery modeling used in this study are taken from data provided by ADEME. They are Lithium-ion Nickel Manganese Cobalt (LiNMC) batteries. They are a 50:50 combination of two technologies. The GHG emissions associated with their manufacturing are around 101 kg CO_2 eq. /kWh of battery modeled for 2019, and 76 kg CO_2 eq. /kWh of battery modeled for 2030. These values are in line with the orders of magnitude found in the literature.
Expected battery lifespan is 10 years for passenger cars. It is assumed to be 6 years for buses, LCVs and HGVs. Thus two batteries are necessary for the life cycles of these vehicles.

3.1.4 Fuel types

Different types of fuel were used to model fleet vehicles for the current horizon and the 2030 horizon: liquid, gas and electric energy vector fuels.
Liquid biofuels do not fall within the scope of the study.

3.1.4.1 Liquid fuels

Fossil fuels: Gasoline and diesel are modeled using the Ecoinvent data for the upstream part, or “Well-to-Tank”, respectively 63 and 43.9 g CO_2 eq. / kWh.
The emissions associated with their combustion are based on JEC values: Tank-to-Wheel (TTW), namely 264 and 263 g CO_2 eq. / kWh.

3.1.4.2 Gas and biogas

Emissions relating to NGV production and combustion are based on the emission factor of the Ecoinvent database, and the ADEME carbon base (respectively 45.3 and 204.1 g CO_2eq. / kWh). The emission factor for NGV production is essentially the same between the two databases: 46.5 g CO_2eq. /kWh for the ADEME carbon base. Ecoinvent was preferred, given its implementation in the software used.
GHG emissions from bioNGV (biomethane) are based on the results of the study “Assessment of the GHG impact of biomethane injection into the natural gas network, ENEA Quantis, 2017” (Quantis 2017). GHG emissions from the production, injection and consumption of biomethane are valued at 23.4g CO_2 eq/kWh PCI, i.e., around 9 times lower than natural gas. In particular, the CO_2 emitted during the combustion of biomethane is fully offset upstream by the CO_2 captured from the atmosphere (by photosynthesis) during

plant growth. This results in a neutral CO_2 balance. This principle of carbon neutrality applies more generally to all short-lifespan products derived from plant biomass and degraded by combustion: biofuels in the broad sense, for example.

The low GHG emissions from the production of bioNGV (based on the results of the ENEA-Quantis study conducted for GRDF – see bibliography) and the non-inclusion of biogenic CO_2 emissions data from the combustion of BioNGV (as biofuel), lead to very low GHG emissions over the entire life cycle of the various vehicles.
In order to refine the study and to make it more conclusive, a sensitivity analysis should be carried out on the GHG emissions from the production of bioNGV. There is little harmonization in this area and the carbon database does not point to any useful recommendations either.

3.1.4.3 Electricity

Electricity is modeled in accordance with the Ecoinvent process for French production in 2017(IEA 2017). For France, this provides an average emission factor of 55.7g CO_2 eq. /kWh, used for 2019 and 2030.

3.2 Functional unit

The functional unit adopted for road vehicles used for passenger transport is the movement of one person over 1 km within a given traffic context expressed as person.km.

The functional unit adopted for road vehicles used for goods transport is the movement of one metric ton of goods transported over 1 km within a given traffic context expressed as ton.km.

The assumption of an average 1.3 persons per passenger car is comparable to 17.4 persons per bus (RATP data).
LCV load ratios are assumed to be 28% (according to a Ricardo study) and HGV ratios 60% based on IFPEN assumptions.

3.3 System limitations

The following factors were not included in the scope of the study: infrastructure, roads, charging stations, vehicle charging, consumption by auxiliary functions, emissions related to tire wear and braking. In the context of the future roll-out of electrification, they should be included in the scope. Consumption by auxiliary functions, emissions related to tire wear and braking may be assumed to be comparable between the different case studies and are not taken into account.

The steps considered are those set out in the Figure 7 below. On the horizontal axis, all stages of the fuel production cycle are taken into account: from raw materials extraction to the vehicle's fuel tank (Well-to-Tank) to the use of the fuel (Tank-to-Wheel or TTW). On the vehicle-specific vertical axis, there are two components: the life cycle of the vehicle (Cradle-to-Grave or C2G) and vehicle operation through the use of fuel. The study carried out therefore considers the Well-to-Wheel, with the vehicle life cycle also taken into account.

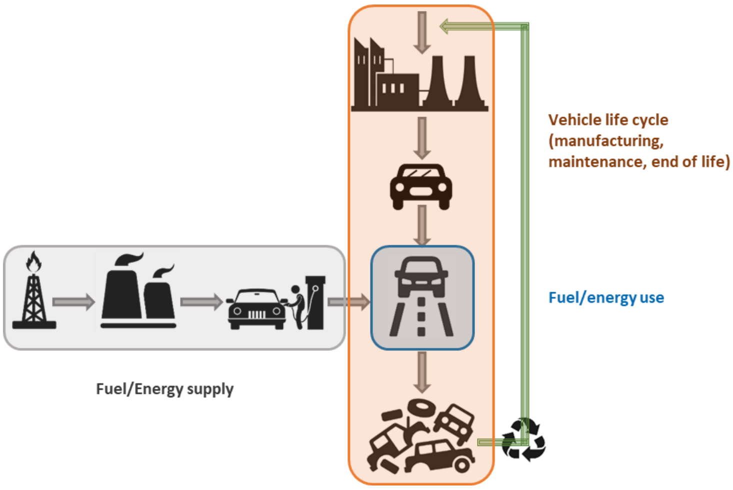

Figure 7: Life cycle stages considered in the study: Well-to-Wheel assessment and vehicle life cycle

3.4 Results

The method used to estimate the potential impact on climate change is the one recommended by the European Commission, Global Warming Potential, calculating radiative forcing over a time period of 100 years using IPCC 2007 methodology.

3.4.1 Light vehicles

3.4.1.1 C segment

Figure 8 and Figure 9 present the results for C segment (compact cars such as a Renault Megane, Peugeot 308 or Volkswagen Golf), of GHG emissions in grams of CO_2 equivalent per kilometer and per person transported in 2019 and 2030. The dark blue portion represents emissions related to the vehicle shell and powertrain type (engine, gearbox, etc.). It can be observed that this portion is relatively similar between the various engines, with a slight advantage for electric vehicles (no combustion engine and no gearbox).

The life cycle stage with the highest GHG emissions for combustion vehicles is related to the fuel portion (in grey), i.e., Well-to-Tank and Tank-to-Wheel emissions. It is mainly these Tank-to-Wheel emissions representing the combustion of fuel in the vehicle during its 150,000 km of use that constitute the major part of the impact on global warming.

NGV (in turquoise) emits less CO_2 than its combustion-based equivalents, gasoline and diesel, thanks to a lower emission factor (favorable H/C ratio for CH4 compared to the longer carbon chains of liquid hydrocarbons). A significant reduction in these emissions can also be seen between 2019 and 2030, thanks to improved performance.
BioNGV, which has an emission factor around 9 times lower, produces very favorable results: approximately 40g CO_2 eq. /person.km, i.e., 3.5 times less than the equivalent diesel vehicle.

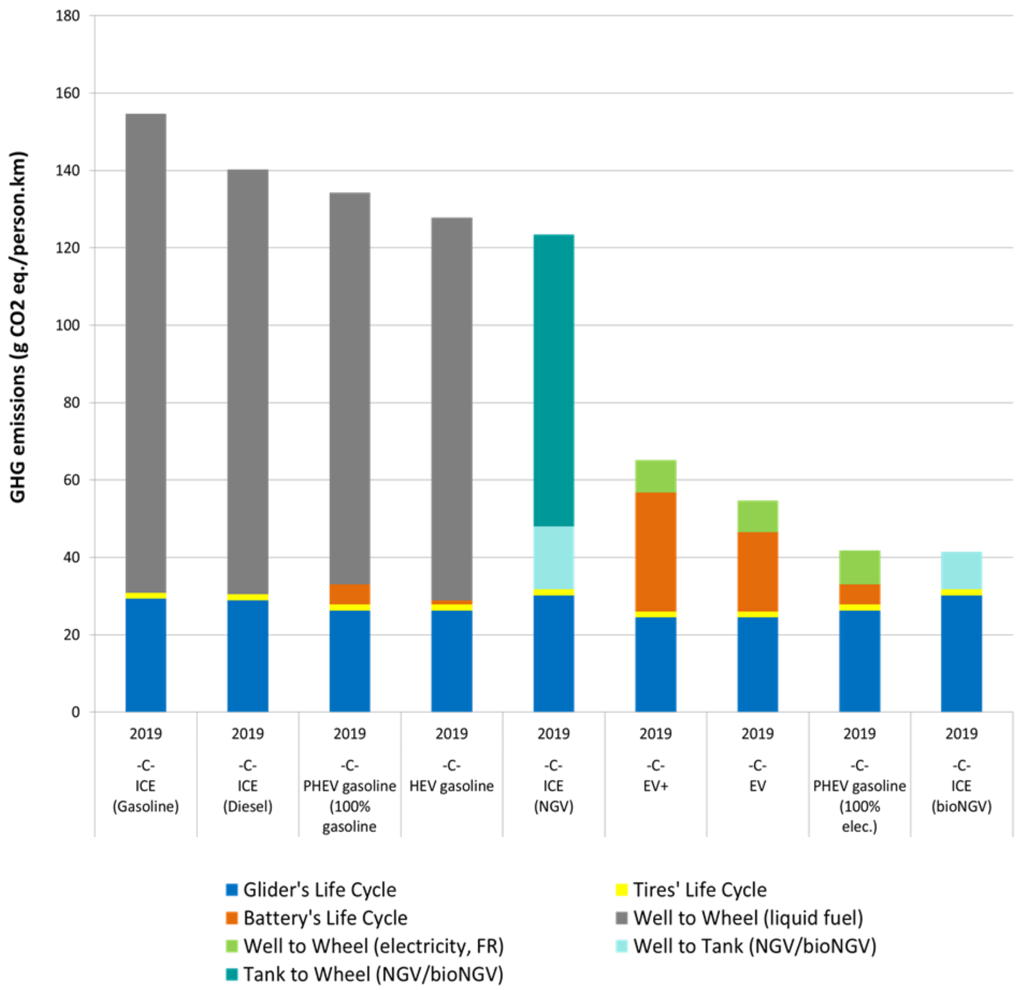

Figure 8: Potential impact on climate change for C-segment vehicles in 2019

If we look at existing electrified vehicles, including rechargeable hybrids (PHEV) and battery electric vehicles, we can see that battery manufacturing emissions (orange portion of the chart) are significant. These are of course directly proportional to the capacity of the onboard battery (in kWh). Technical advances and potential new Gigafactory facilities in Europe explain why the emission factor of the batteries in 2030 is lower than in 2019 in our projections.

Very different results can be observed for rechargeable hybrids, when comparing all-electric use (100% electric PHEV) versus all-combustion use, i.e., without ever recharging the battery (100% Gasoline or 100% NGV rechargeable hybrid). In 100% electric vehicles, the results are very good (41g CO_2 eq. /person.km in 2019), and are in line with combustion vehicles running on bioNGV. In 100% combustion vehicles the results are of course worse: emissions from battery manufacturing are added to those from fuel combustion.

The way in which PHEVs are used by their owners, and their willingness to recharge their vehicles, are still relatively unknown today. The two contrasting results presented here at least make it possible to establish the lower and upper limits of use of this type of vehicle.

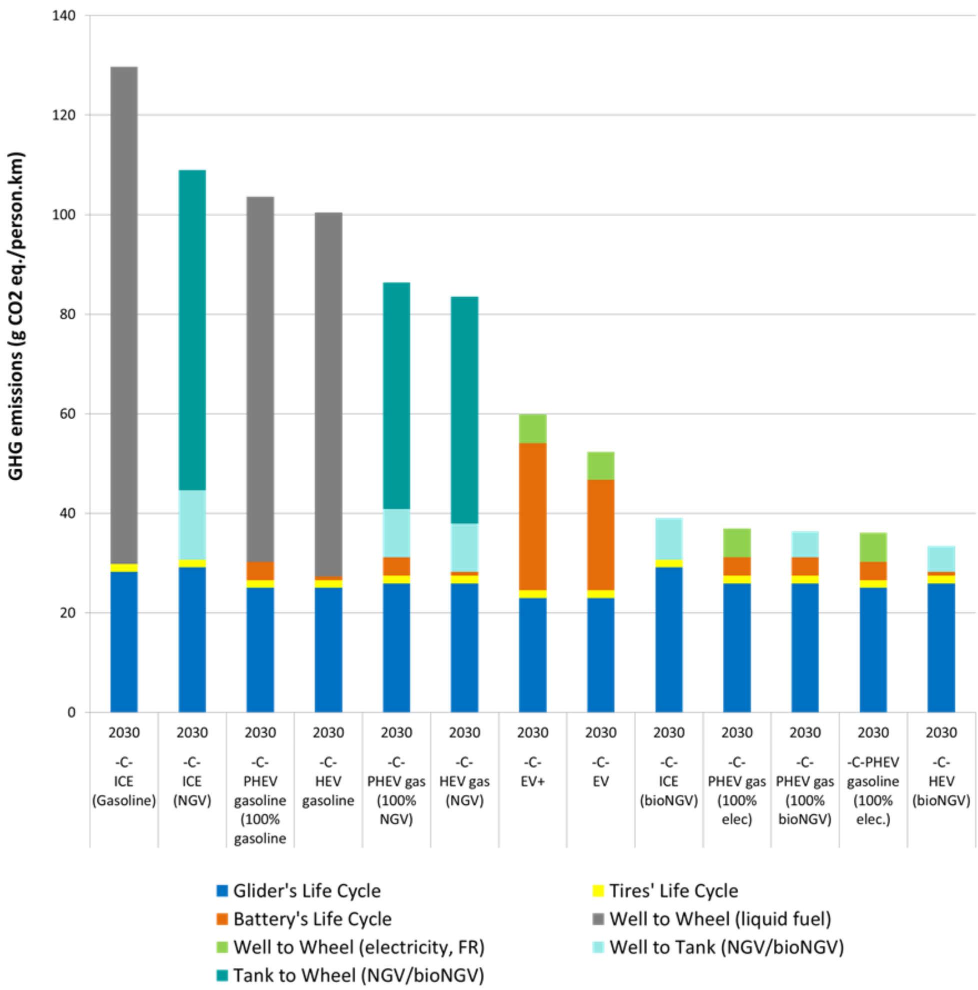

Figure 9: Potential impact on climate change for C-segment vehicles in 2030

The contribution of non-rechargeable hybrids (HEV) reduces vehicles' consumption and therefore their CO_2 emissions. For a gasoline HEV, the emissions are similar to those of an NGV combustion vehicle (i.e., approx. 123 g CO_2eq. /person.km). A non-rechargeable NGV hybrid, available in 2030 (Figure 9) according to our assumptions, performs even better with 82g CO_2 eq. /person.km. Finally, the non-rechargeable bioNGV hybrid combines the dual advantage of hybridization and biomethane, with total emissions of 33g CO_2eq. /person.km in 2030.

Battery electric vehicles (electric and electric+ for those with a bigger battery) emit much less CO_2 than internal combustion vehicles, even hybrids. Emissions from battery manufacturing are largely offset by the low emissions from electricity production during the 150,000km of use. It is French electricity production under consideration here and the emission factor is very low (55.7g CO_2 eq. /kWh), due to the predominant use of nuclear energy.
For an electric vehicle carrying a 40 kWh battery in 2019, approx. 52g CO_2eq. /person.km are produced. For an electric+ vehicle carrying a 60 kWh battery, this figures is approximately 63g CO_2 eq. /person.km. However, these results are higher than those of a bioNGV combustion vehicle.

3.4.1.2 D segment

Figure 10 and Figure 11 show the potential Impact on climate change for D-segment vehicles in 2019 and 2030.
The trends are the same as for C segment.

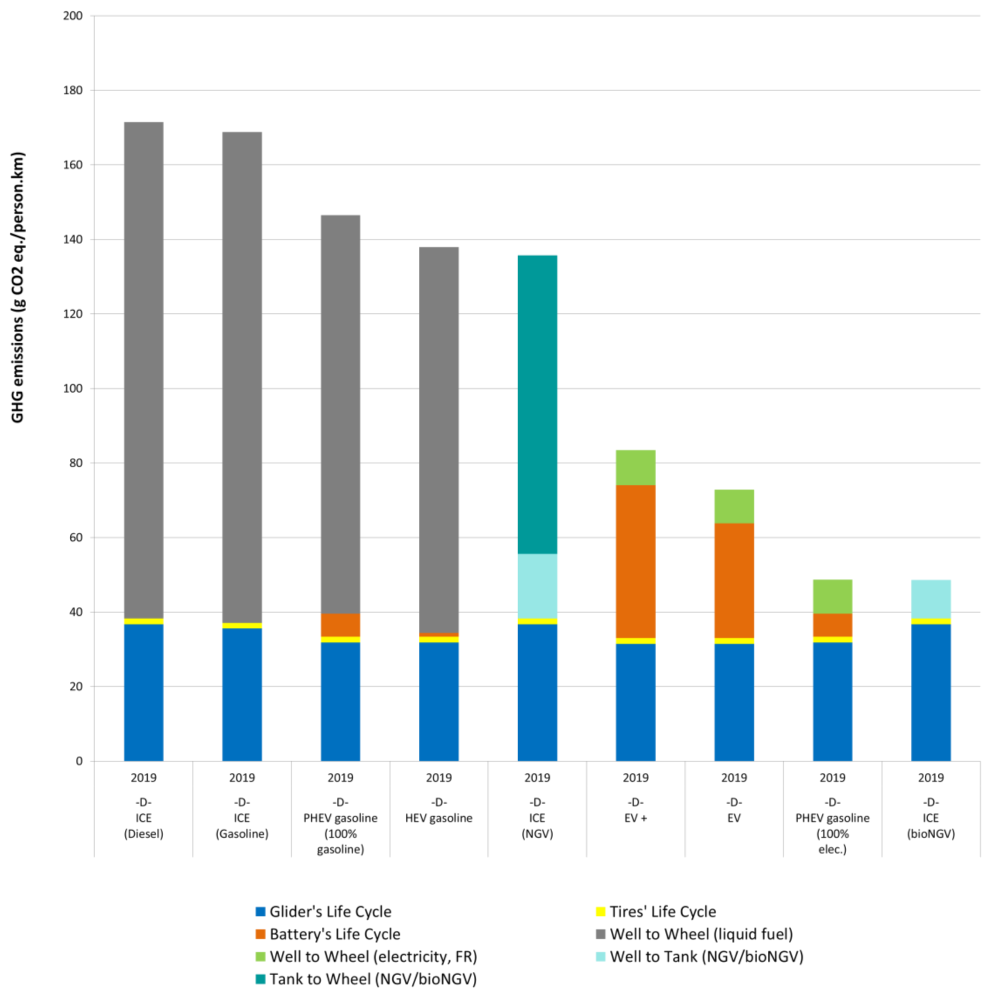

Figure 10: Potential impact on climate change for D-segment vehicles in 2019

The use of a bioNGV internal combustion vehicle is of particular interest as it is shows the best results in 2019 with 47g CO_2 eq. /person.km, equivalent to those obtained with the rechargeable hybrid operating in electric mode.

With high-capacity batteries in the D segment (60 and 80 kWh in 2019 for electric and electric+), electric vehicles are penalized by the emissions from battery manufacturing. Even the low emission factor for French electricity production (mainly nuclear) cannot bridge this gap.

In 2019 as in 2030, rechargeable hybrids running 100% of the time in electric mode show very good results, almost the same as from bioNGV-based internal combustion.

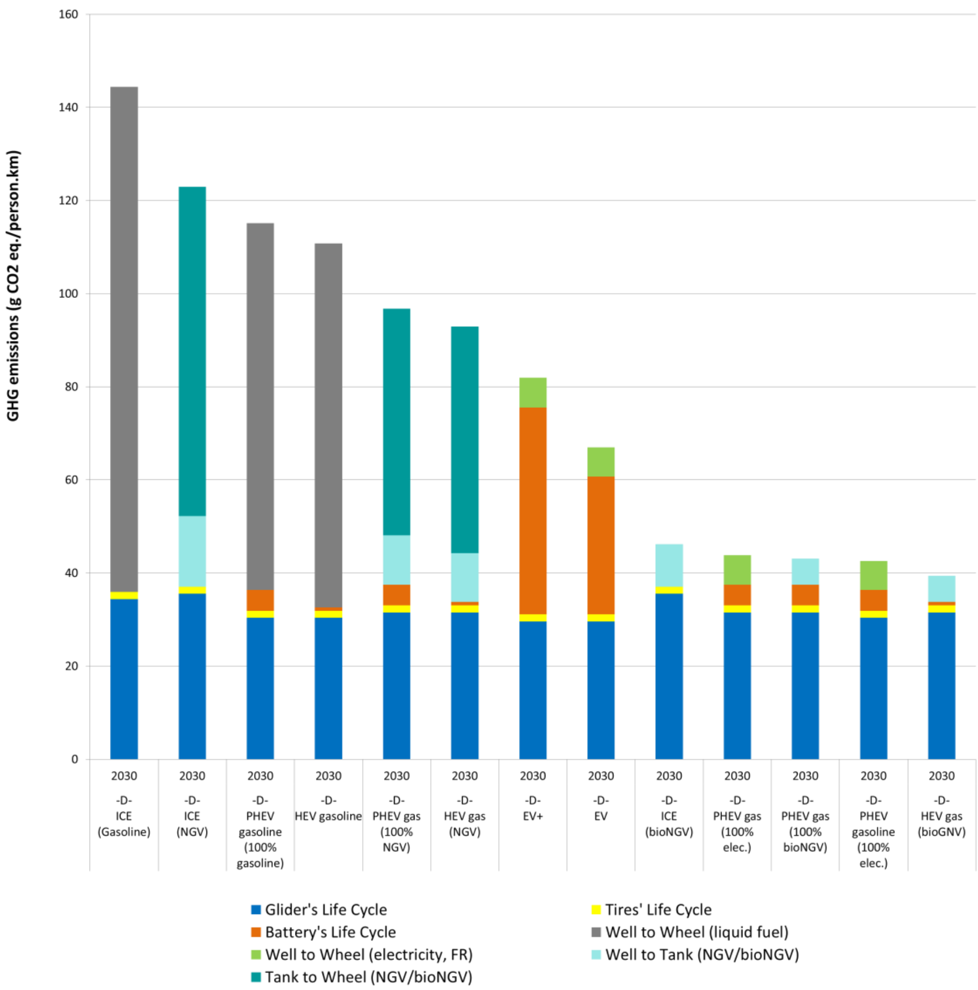

Figure 11: Potential impact on climate change for D-segment vehicles in 2030

3.4.2 Buses

The results for buses are presented in Figure 12 for 2019, and Figure 13 for 2030.
As buses travel many kilometers (40,000 km per year for 12 years), the contribution to GHG emissions of shell and powertrain manufacturing is proportionately less significant than for light vehicles. The same applies to battery manufacturing. As such, emissions from fuel production and combustion predominate. As a result, this levels out the results to a certain extent when compared to C- and D-segment light vehicles.

The results of 100% electric buses are slightly lower than internal combustion buses running on bioNGV.
Diesel and fossil NGV buses produce much higher GHG emissions than electric or bioNGV buses.
The contribution of hybridization decreases emissions, of course, but they remain 3 to 4 times higher than those of electric buses.

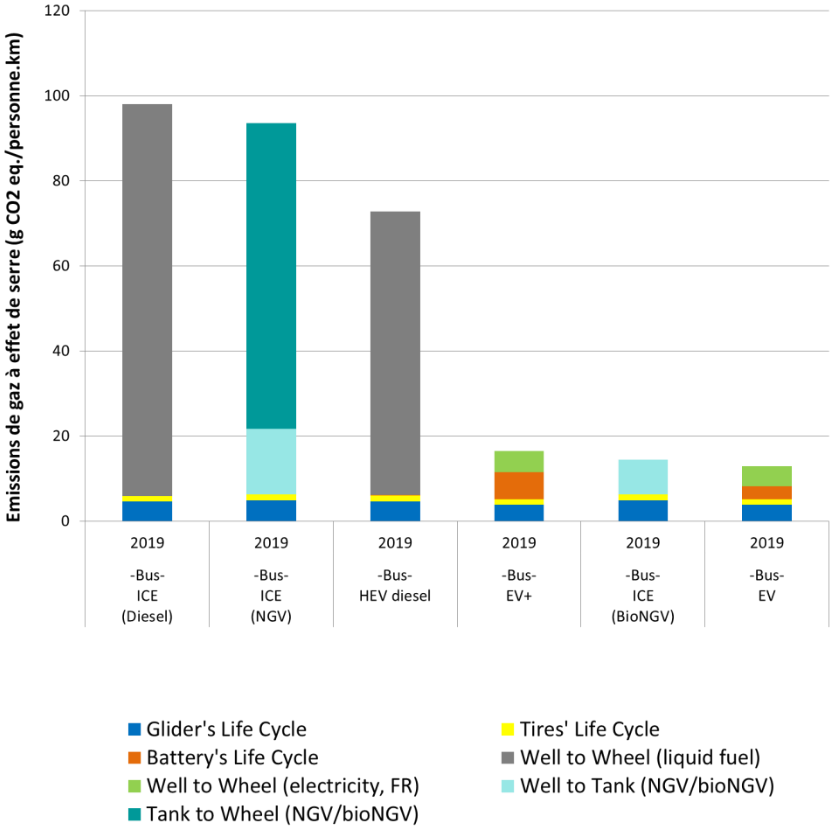

Figure 12: Potential impact on climate change for buses – 2019 time horizon

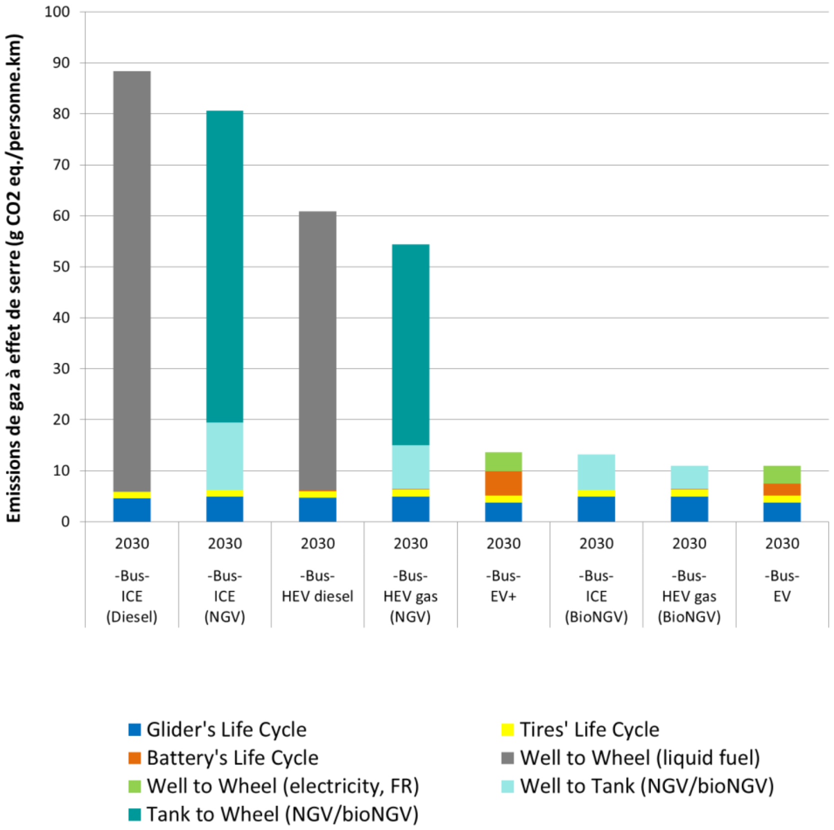

Figure 13: Potential impact on climate change for buses – 2030 time horizon

3.4.3 Light commercial vehicles (LCV)

The results of Figure 14 and Figure 15 show the GHG emissions of light commercial vehicles for the years 2019 and 2030. The analysis is consistent with that for D segment light vehicles: the large battery size (80 and 100 kWh in 2019 and 2030) results in significant emissions during manufacturing. Internal-combustion light commercial vehicles (Diesel or NGV) produce high volumes of emissions, unlike those running on bioNGV.

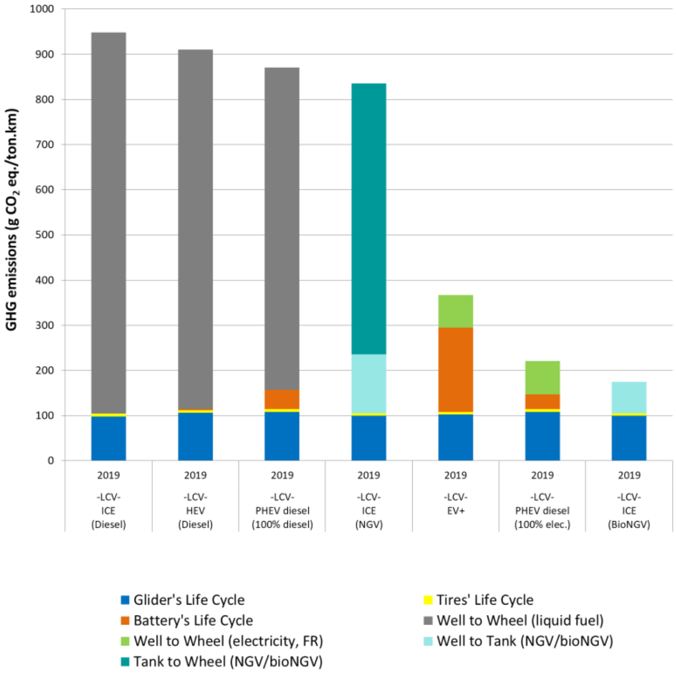

Figure 14: Potential impact on climate change for light commercial vehicles – 2019 time horizon

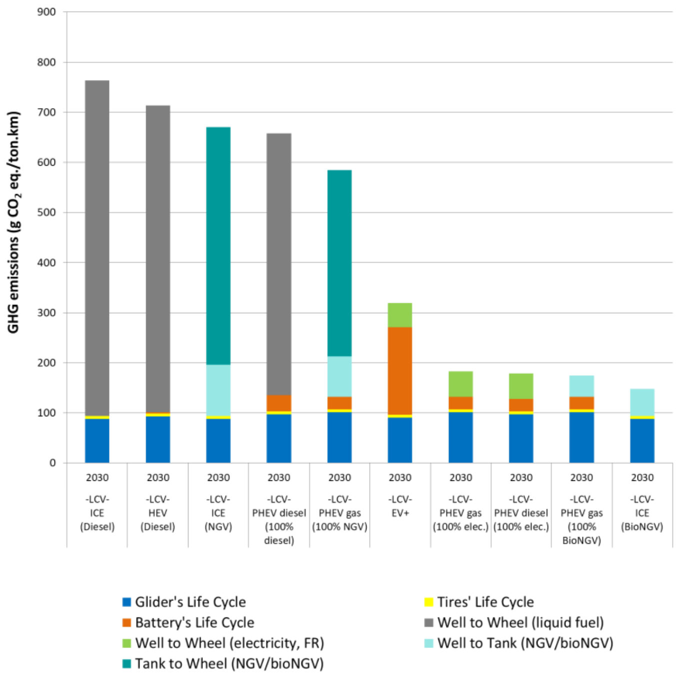

Figure 15: Potential impact on climate change for light commercial vehicles – 2030 time horizon

3.4.4 12-ton Heavy goods vehicles

The results for 12-ton heavy goods vehicles (HGV) are shown in Figure 16 and Figure 17. With 372,000 kilometers traveled over 12 years, the usage phase (with fuel consumption) predominates. The best results are provided by internal combustion engines running on bioNGV.

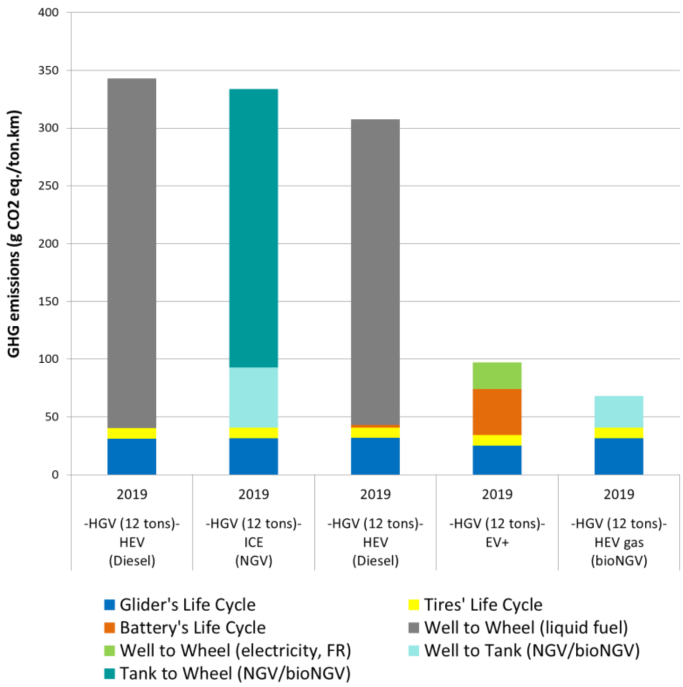

Figure 16: Potential impact on climate change for 12-ton heavy goods vehicles – 2019 time horizon

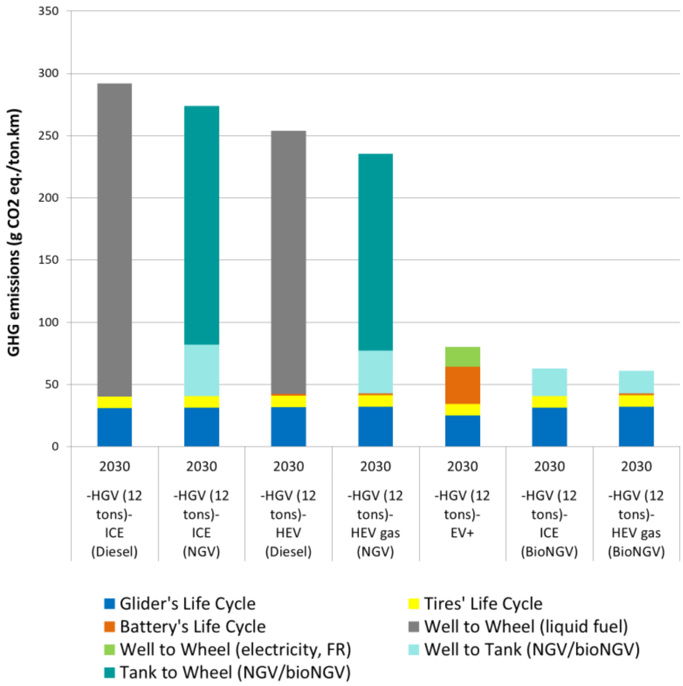

Figure 17: Potential impact on climate change for 12-ton heavy goods vehicles – 2030 time horizon

4 Conclusion and recommendations

In view of the results of this study, a number of conclusions or lessons should be highlighted:

- With regard to light vehicles, light commercial vehicles and 12-ton heavy goods vehicles, the use of a combustion engine powered exclusively by bioNGV (also referred to as “biomethane”) provides the best results in terms of GHG emissions, followed closely by rechargeable hybrids operating exclusively on electric power (a theoretical case given that it is difficult to apply under real conditions with only 50-70 km of battery life, particularly for long distances). Then come the electric vehicles.

- The hybridization of bioNGV engines further improves results, as it does for gasoline, diesel and NGV.

- Electric vehicles, which tend to have large-capacity batteries, are therefore penalized by the significant amount of CO_2 emitted during battery manufacturing, largely from the extraction and refining of the metals used (lithium, cobalt, nickel, etc.), and by the energy-intensive processes used in manufacturing and assembling the cells.

- (Fossil) NGV vehicles produce fewer GHG emissions than their diesel and gasoline equivalents, in both 2019 and 2030.

- BioNGV/biomethane production capacity in France (between 1 and 1.5 TWh) would allow approximately 100,000 to 150,000 vehicles to be supplied. Methanation plants should therefore be significantly expanded to be able to ensure a massive roll-out of bioNGV/biomethane vehicles.

- Finally, one solution for faster provision of bioNGV vehicles could be to use a fossil NGV and bioNGV/biomethane mix. This would allow a larger number of vehicles to be supplied, while maintaining a very favorable GHG balance, particularly in the case of engine hybridization.

5 Notes to the parent company financial statements

Data	Value	Source
NCV NGV	47.5 MJ/kg	IFPEN
Upstream NGV EF[5]	45.3g CO_2 eq./kWh	Ecoinvent v3.3
NGV combustion EF	204.1 g CO_2 eq./kWh	ADEME Carbon Base, p. 44
EF bioNGV	28.4 g CO_2 eq./kWh	ENEA Quantis Study
Diesel NCV	43.1 MJ/kg	JEC
Diesel upstream EF	43.9 g CO_2 eq./kWh	Ecoinvent v3.3
Diesel combustion FE	263.5 g CO_2 eq./kWh	JEC
Gasoline NCV	43.2 MJ/kg	JEC
Gasoline upstream EF	63 g CO_2 eq./kWh	Ecoinvent v3.3
Gasoline combustion EF	264.2 g CO_2 eq./kWh	JEC
FR Electricity EF, 2019	55.7g CO_2 eq./kWh	Ecoinvent v3.3 (IEA 2017, 2014 data)
FR Electricity EF, 2030 (for sensitivity analysis)	50.4 g CO_2 eq./kWh	IFPEN Projection according to RED II (target: 27% renewable energy) based on EI v3.3 data
Bus tank weight - NGV/bioNGV	433kg	GRDF
Bus tank composition - NGV/bioNGV	Aluminum	GRDF
HGV tank weight - NGV/bioNGV	558 kg	GRDF
HGV tank composition - NGV/bioNGV	Steel	GRDF
HGV and bus tank weight - diesel	100 kg	GRDF
HGV and bus tank composition - diesel	50% aluminum/50% Steel	GRDF
C-Segment tank weight - NGV/bioNGV	30 kg	http://isidoredd.documentation.developpement-durable.gouv.fr/documents/dri/RMT07-010.pdf
C-Segment tank composition - NGV/bioNGV	Epoxy	
D-Segment tank weight - NGV/bioNGV	39 kg	Extrapolated from http://isidoredd.documentation.developpement-durable.gouv.fr/documents/dri/RMT07-010.pdf
D-Segment tank composition - NGV/bioNGV	Epoxy	
LCV tank weight - NGV/bioNGV	47 kg	
LCV tank composition - NGV/bioNGV	Epoxy	
C, D, & LCV cycle segments	WLTC	IFPEN
Bus cycle	RATP	IFPEN
HGV cycle	Carrefour city	IFPEN
Passenger car exhaust emission standards, 2019	Euro6B standards, passenger cars	Delphi

[5] Emission Factor (EF)

Passenger car exhaust emission standards, 2030	Euro7 standards, passenger cars	Delphi
LCV and HGV exhaust emission standards, 2019	Euro6b/6c LCV standards	Delphi
LCV and HGV exhaust emission standards, 2030	IFPEN Assumptions	IFPEN
Bus exhaust emission standards, 2019		https://www.dieselnet.com/standards/eu/hd.php
Bus exhaust emission standards, 2030		
Steel reduction 2030	30 %	ADEME study, 30% less steel mass for 2030 vehicles
Aluminum reduction 2030	65 %	ADEME study, aluminum replaces steel with a ratio of 65% to 30%
C-Segment battery capacity – EV – 2019	40 kWh	IFPEN
C-Segment battery capacity – EV+ – 2019	60 kWh	IFPEN
C-Segment battery capacity – EV – 2030	60 kWh	IFPEN
C-Segment battery capacity – EV+ – 2030	80 kWh	IFPEN
D-Segment battery capacity – EV – 2019	60 kWh	IFPEN
D-Segment battery capacity – EV+ – 2019	80 kWh	IFPEN
D-Segment battery capacity – EV – 2030	80 kWh	IFPEN
D-Segment battery capacity – EV+ – 2030	100 kWh	IFPEN
LCV battery capacity – EV+ – 2019	80 kWh	IFPEN
LCV battery capacity – EV+ – 2030	100 kWh	IFPEN
Bus battery capacity – EV – 2019 and 2030	170 kWh	IFPEN
Bus battery capacity – EV+ – 2019 and 2030	340 kWh	IFPEN
HGV battery capacity – EV – 2019 and 2030	130 kWh	IFPEN
HGV battery capacity – EV+ – 2019 and 2030	240 kWh	IFPEN

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