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1 **Life cycle assessment of mid-range passenger cars powered by liquid and gaseous**  
2 **biofuels: comparison with greenhouse gas emissions of electric vehicles and forecast to**  
3 **2030**

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9

10 **Abstract**

11 Current and future forecast comparative analysis of the greenhouse gas emissions of mid-range  
12 passenger cars, obtained using life cycle assessment (LCA) methodology, are presented. Two  
13 important factors are addressed by assessing the use of biofuels suitable for internal combustion  
14 engines (including bio natural gas vehicles) and forecasting the LCA results in 2030 with  
15 updated vehicle weight, battery technology, and CO<sub>2</sub> electricity content. The synthesis shows  
16 that conventional engines powered with biofuels complement electrified powertrains. Plug-in  
17 hybrid electric vehicles seem to be the ideal solution owing to the limited size of their batteries.  
18 The current trend of expanding the battery size to improve the range of electric vehicles is  
19 detrimental to greenhouse gas (GHG) impacts. Biofuels can provide significant GHG emission  
20 benefits in a short time as vehicle powertrains can already accommodate up to 85% ethanol or  
21 100% biodiesel without engine changes.

22 **Keywords**

23 Life cycle assessment, road transportation, passenger car, energy mix, electrified vehicles,  
24 WLTP (World harmonized Light vehicles Test Procedures), 2030, biofuels.

## 25 **1 Introduction**

26

27 Historically, there are close links between transport and oil; 93% of the energy used for  
28 transport comes from oil-based products. These links are challenged by energy transition  
29 scenarios because globally, the transportation sector is the second-largest contributor to  
30 anthropogenic greenhouse gas (GHG) emissions. In 2015, the transport sector accounted for  
31 23% of Europe's GHG emissions (European Commission 2017), and road transportation was  
32 responsible for more than 70% of these emissions (European Environment Agency 2019). To  
33 satisfy its new climate objectives, the European Union (EU) raised the CO<sub>2</sub> emissions standards  
34 of passenger cars by setting their upper limit at 95 g of CO<sub>2</sub> per kilometer (The European  
35 Parliament and the Council 2014). Considering these new thresholds, manufacturers must  
36 develop more innovations for their powertrains in their roadmap. Moreover, due to growing  
37 demand, GHG emissions from transport continue to rise in the EU (EEA 2015, Meyer et al.  
38 2012), even with the technological improvements in internal combustion engine (ICE)  
39 efficiency in recent years. However, in this harsh regulatory context, improving combustion  
40 engine performance alone will be insufficient, strongly encouraging manufacturers to develop  
41 and use low-carbon technologies.

42

43 Previous studies have shown that electric vehicles (EVs) can provide climate benefits, although  
44 the results depend considerably on several elements such as battery size or the CO<sub>2</sub> content of  
45 the electricity (Bauer et al. 2015, Wu et al. 2019). Ambrose et al. (2020) performed a life cycle  
46 assessment (LCA) study of passenger cars equipped with high battery capacity for the year  
47 2025. They determined that a larger battery system combined with low utilization did not reduce  
48 GHG emissions. Lombardi et al. (2017) and Elgowainy et al. (2018) presented a well-to-wheel  
49 assessment of CO<sub>2</sub> emissions and costs for current light-duty vehicles. They found that,

50 currently, plug-in hybrid electric vehicles (PHEVs) offer attractive carbon emissions abatement  
51 costs under certain hypotheses. Bouter et al. (2018) found that electric vehicles with large  
52 battery capacities are too expensive and the carbon emissions from battery manufacture are  
53 never counterbalanced by the use phase. Fortunately, the work of Miotti et al. (2016) has shown  
54 that the battery costs may decrease in the near future, allowing more consumers to buy low-  
55 carbon emitting vehicles. Similarly, Qiao et al. (2020) demonstrated that the life cycle cost of  
56 an electric car in China is still higher than that of a conventional car, but will be approximately  
57 equal in the near future. Finally, battery recycling represents a promising way to improve the  
58 global battery electric vehicle (BEV) LCA results (Silvestri et al. 2020); however, this industry  
59 appears to be in the early stages and has yet to enter the BEV value chain.

60 Another valuable solution would be to use more liquid (biodiesel, ethanol) or gaseous (biogas)  
61 biofuels by increasing their incorporation rate in petroleum liquid fuels (Doumax-Tagliavini et  
62 al. 2018).

63 Natural gas vehicles (NGVs) already exist in the market; they can be easily decarbonized by  
64 switching from natural gas to biogas, without any constraint on the engine or vehicle.  
65 Worldwide, there are more than 28 million NGVs running worldwide, with 15,000 in France,  
66 mainly buses, heavy goods vehicles, and light commercial vehicles (NGV Global 2020).  
67 Biomethane produced from organic sources (livestock effluents, crop residues, organic waste,  
68 etc.) can be used as a renewable and sustainable fuel (bioNGV) and energy source (Murphy et  
69 al. 2013, Prussy et al. 2019). The injection of biomethane into networks is currently under  
70 development (Kapoor et al. 2020). The potential of biomethane in reducing GHG emissions has  
71 already been established in LCA studies, an effective method that can reveal the technology  
72 potential (Huttunen et al 2014, Lamnatou et al. 2019). Ravigné and Da Costa (2020) have  
73 recently shown that bioNGVs can also be cost-effective for the freight transport sector.

74 Three main factors drive the development of liquid biofuels: the reduction of GHG emissions  
75 from the transportation sector (Larson 2006), the creation or maintenance of forestry and  
76 agricultural activities (Paris et al. 2018), and energy security (European Council 2014). First-  
77 generation (“conventional”) biofuels have been produced on an industrial scale. However, their  
78 development remains controversial as they compete with land use for food supply (Di Lucia et  
79 al. 2012).

80 Second-generation (“advanced”) biofuels depend on processes that, despite being  
81 technologically more complex, present multiple advantages, such as potential resource  
82 availability (Searle et al. 2016), greater environmental benefits, and the absence of food  
83 competition. Noh et al. (2016) showed that the biofuel share in the aviation sector energy will  
84 increase in the near future, supported by EU incentives. Advanced biofuels can also become an  
85 alternative for the road transportation sector, such as being used for freight transport (Meyer  
86 2020).

87 To LCA methodology is used to supply relevant and robust environmental findings to analyze  
88 the potential of low-carbon fuels for the road transportation sector. A tank to wheel (TTW)  
89 assessment, which concerns energy use and emissions only associated with vehicle use, of  
90 passenger car electrification found it to be a zero GHG emission technology (Nemry 2010,  
91 Sadek 2012). TTW excludes the emissions and energy use associated with fuel production  
92 (well-to-tank; WTT), and the vehicle’s life cycle. A complete approach is required to calculate  
93 the potential transfer of impacts from one life cycle stage to another (Chan 2007, Tran et al.  
94 2012). Therefore, only LCA by its intrinsic definition (ISO 2006a, 2006b) can address the entire  
95 system: WTT, TTW, and vehicle’s life cycle.

96 The objective of this study is to assess the environmental impacts of passenger cars assembled  
97 and used in France, targeting two time-horizons (2019 and 2030), and considering both the  
98 vehicle and the fuel life cycle. This study focuses on GHG emissions. In this paper, we address

99 two main factors, which have this far only partially been discussed in the literature, by reflecting  
100 the diversity of biofuels suitable for the internal combustion engine (including bioNGV) and  
101 their GHG emissions reduction potential, and forecasting the LCA results in 2030 by which  
102 time vehicle weight, battery technology, and electricity CO<sub>2</sub> content will have changed. More  
103 precisely, a more comprehensive LCA study including vehicle life cycles has yet to be carried  
104 out to assess the value of bioNGV fuel for road transport. A collaboration between the Joint  
105 Research Center, EUCAR, and CONCAWE produced a well-to-wheel report which evaluated  
106 relevant technologies to decarbonize the transport sector (JEC 2020). Elgowainy et al. (2018)  
107 presented a cradle-to-grave assessment of GHG emissions for current and future (2030) light-  
108 duty vehicles. However, neither of these studies considered biofuel as a method of reducing  
109 emissions.

110 The LCA of the vehicles (mid-range cars), coupled with propulsion technologies (combustion  
111 engine, hybrid, electric) and their associated energy vectors (fossil fuels, biofuels, and  
112 electricity mix) make it possible to compare the envisaged technology options and to identify  
113 those best suited to the various environmental contexts, namely, for combating climate change.  
114 Different levels of powertrain electrification were used based on the new world harmonized  
115 light vehicles test Procedures (WLTP) cycle.

116

## 117 **2. Method**

### 118 **2.1 General Methodology**

119 The first stage of this study was to conduct a systematic assessment of vehicle energy  
120 consumption for the “C segment,” defined as mid-range cars.

121 Each vehicle was classified according to its engine system characteristics, considering a variety  
122 of electrification ratio options, ranging from internal combustion vehicles, hybrid vehicles,

123 rechargeable hybrid vehicles, and all-electric vehicles. Each powertrain (combustion engine,  
124 electric engine, battery) was modeled from an energy perspective, considering major trends and  
125 predicted improvements by 2030. Similarly, each vehicle was modeled considering a  
126 prospective vision of its main characteristics (aerodynamics and tire friction) and weight (body  
127 and chassis lightening, impact of improved power, and energy density of electrified devices).  
128 These models made it possible to evaluate the current and future energy consumption (fuel and  
129 electricity) using these powertrain systems.

130 The CO<sub>2</sub> emissions of each vehicle (with its powertrain) were then evaluated using the LCA  
131 methodology to estimate the carbon footprint from energy production and use, and the carbon  
132 footprint from manufacturing the vehicle.

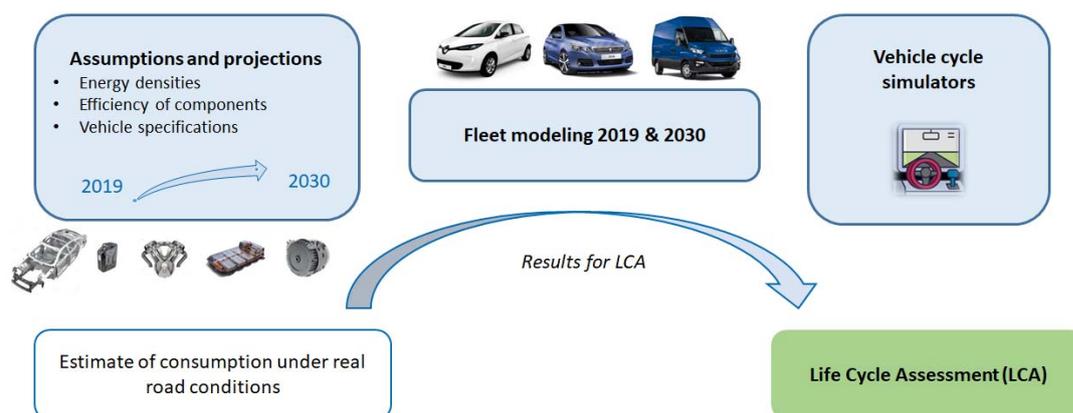
## 133 **2.2 Vehicle Simulation Platform**

### 134 **2.2.1 Principle**

135 Vehicle simulators have been developed and validated using measurements performed on  
136 components and vehicle tests (Badin et al. 2015, Da Costa et al. 2012). This step aims to assess  
137 the fuel or electricity consumption based on the WLTP cycle for passenger cars. Hybrid electric  
138 vehicles (HEVs) were simulated considering a sustainable battery mode. We considered that  
139 the battery of a PHEV can provide the driver with a sufficient range (approximately 50 km) if  
140 the battery is loaded (Loisel et al. 2014). Consequently, PHEV was simulated both at 100%  
141 electric mode and at 100% gasoline mode (and considered as an HEV in sustaining mode).

142  
143 To measure the energy consumption of various vehicles defined by their architecture and  
144 segmentation, simulations were performed using the Simcenter Amesim software package. This  
145 vehicle simulator was developed and validated through component and vehicle tests (Badin et  
146 al. 2013). The simulation platforms were based on the "IFP-Drive" library of components

147 developed jointly by IFP Energies Nouvelles and Siemens PLM Software (Figure 1). Several  
 148 simulation tools dedicated to vehicle energy consumption calculations exist, such as  
 149 Autonomie, developed by Argone National laboratory. The vehicle modeling approach in the  
 150 IFP-Drive library was similar. It was based on ‘forward modeling’, which computes the vehicle  
 151 speed from the driver’s demand by integrating transient behavior. The IFPEN-Siemens  
 152 collaboration developed embedded tools that help users to input characteristics for vehicle  
 153 components (such as energy conversion efficiency maps for electric machines, batteries, and  
 154 internal combustion engines) and to define optimal energy management strategies for hybrid  
 155 vehicles. Thus, the use of the Simcenter IFP-drive library was well suited for the purpose of the  
 156 study, which addresses the evaluation of multiple vehicle architectures and energy carriers.  
 157 These models considered the physics of all the devices present in conventional vehicles  
 158 (combustion engine, transmission, etc.) and electric vehicles (battery, traction engine, power  
 159 electronics, etc.). A component dedicated to hybrid architectures was used to determine the  
 160 optimal management strategy for internal combustion and electrical energy to minimize fuel  
 161 consumption. Further details can be obtained by consulting the Society of Automotive  
 162 Engineers (SAE) publication (Dabadie et al. 2017).



163

164

**Figure 1: Methodology used for the sizing and the energy analysis of vehicles**

165

166 These vehicle simulation platforms were validated against IFP Energies Nouvelles' laboratory  
167 equipment, namely laboratory bench facilities for combustion engines, electric engines, and  
168 batteries, as well as roller test benches. Thus, these resources provide data that accurately reflect  
169 the technological choices made by vehicle manufacturers.

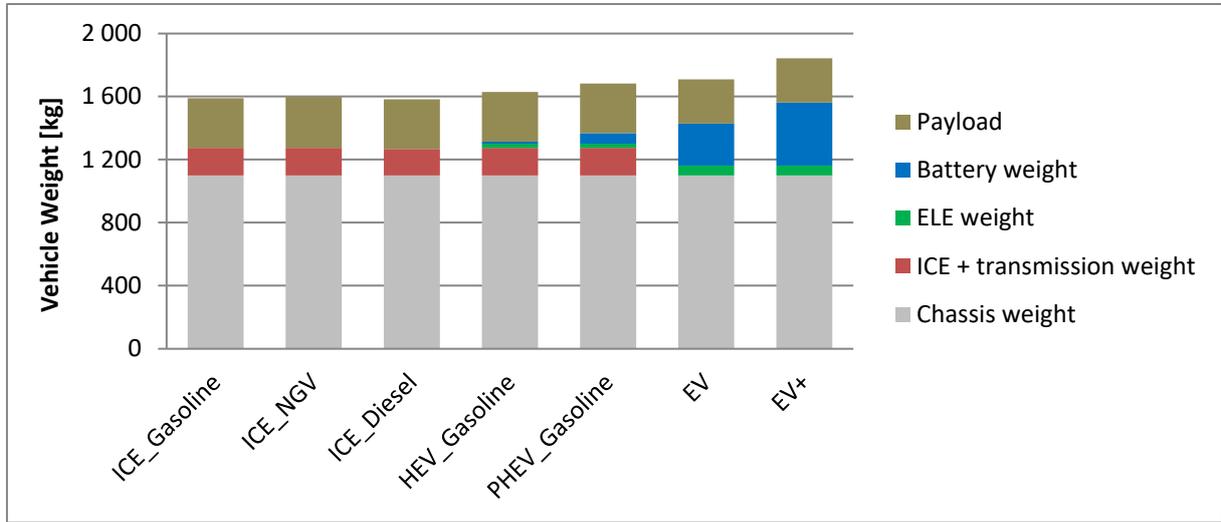
### 170 **2.2.2 Determination of weight**

171 Of all the input parameters for the vehicle simulations, the driving weight was paramount. For  
172 any given powertrain, the weight varies as a function of its architecture. A "shell" weight was  
173 identified for the segment, to which the weights of the components present in the vehicle were  
174 added according to their design. Battery electric vehicles are represented in two designs: EV  
175 (standard battery capacity) and EV+ (for BEVs with a larger battery). For electric vehicles, the  
176 calculation of component weights was based on assumptions for energy densities and power  
177 densities determined for the current horizon and the horizon projected for 2030. Batteries are a  
178 major component of the weight of EVs. The density of the total pack, including battery cooling,  
179 battery structure, and control, is currently estimated at 150 Wh/kg, predicted to rise to  
180 200 Wh/kg by 2030 (Baltac S. et al 2019).

181 For NGV and bioNGV vehicles, the weight of the gas tanks was defined using state-of-the-art  
182 principles. These tanks contain gas at 200 bars, and are made of steel, which makes NGV  
183 vehicles heavier than those equipped with plastic liquid fuel tanks: excess weight for NGV  
184 vehicles is around 30–40 kg. This relatively small surplus can be reduced by 50% by using  
185 composite carbon fiber tanks (type III and type IV), which are expected to become cheaper  
186 owing to the emergence of hydrogen powertrains.

187 Figure 2 shows a breakdown of the vehicles selected for the current horizon of segment C.  
188 "ELE" refers to electric engine and "ICE" to internal combustion engine. The payload is  
189 determined according to the European WLTP test protocol and the tank is considered. We note

190 the absence of hybrid NGV vehicles, as this type of vehicle is not marketed to date; however,  
 191 they will be part of the 2030 fleet considered in the study.

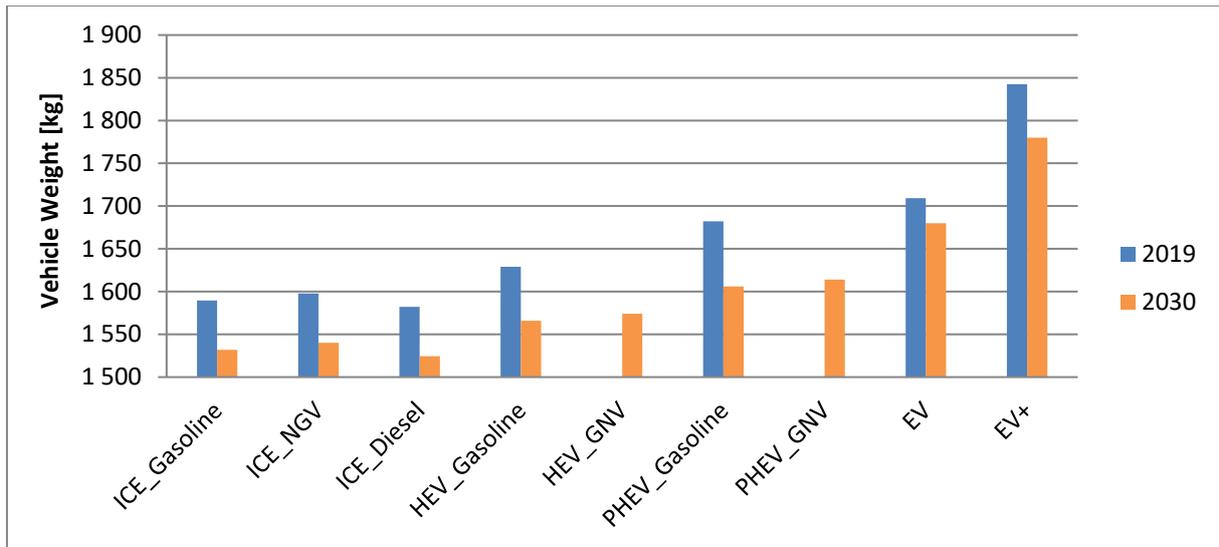


192

193 **Figure 2: Weight breakdown of C segment vehicles 2019**

194

195 Accounting for changes in the vehicle components through to 2030 allows us to estimate vehicle  
 196 driving weights for that year; Figure 3 shows the planned changes in vehicle road weight for  
 197 the C segment. The estimated weight reduction for conventional and hybrid vehicles by 2030  
 198 is approximately 4%. For electric vehicles, the estimated weight reduction is 3%, based on a  
 199 50% increase in battery capacity as extending the battery range remains a priority for  
 200 manufacturers (with an unchanged battery capacity in 2030, the weight reduction would be  
 201 8%). Details on assumptions regarding vehicle raw material composition and evolution are  
 202 presented in the following section (see Section 2.3.2).



203

204 **Figure 3: Change in simulated on-road weights between the 2019 and 2030 fleets of the C segment**

205

206 In addition to the weight reduction of components, several vehicle improvements are assumed,  
 207 among which the most significant are:

- 208 - 10% reduction of aerodynamic drag
- 209 - 20% reduction of rolling resistance force
- 210 - 3 points gain on engine peak efficiency
- 211 - 5 points gain on electric powertrain efficiency

212 The reference values for the 2019 C-segment vehicle on which the improvements were applied  
 213 are summarized in Table 1 .

214 **Table 1: Reference values for 2019 C segment vehicle parameters**

Aerodynamic drag (S: vehicle active area [m <sup>2</sup> ] - Cx: air penetration coefficient [null])	S x Cx = 0.67
Rolling resistance (C0: constant friction coefficient [null] - C1: proportional friction coefficient [1/(m/s)])	C0 = 7.80E-3 C1 = 1.40E-4
Engine peak efficiency	39%
Electrical Inverter efficiency	90%

215

216 These improvement assumptions match the ranges found in Argonne (2018) and Bauer (2015)  
217 and were validated by the French Environment and Energy Management Agency (ADEME)  
218 and through collaborations with French original equipment manufacturers (OEMs).

219

## 220 **2.3 Life Cycle Assessment**

### 221 **2.3.1 System definition**

222 The LCA was carried out in accordance with ISO 2006a and ISO 2006b standards using the  
223 SimaPro<sup>®</sup> commercial software (Siemens 2021). The database used was Ecoinvent v.3.5  
224 (Frischknecht. et al. 2005). The model selected “*allocation, cut-off by classification*” as default,  
225 meaning that producers are environmentally responsible regarding their waste, and so do not  
226 receive any credits for recycling. One consequence is that recyclable materials are burden-free.  
227 This system model allows the LCA practitioner to independently model the end-of-life scenario  
228 that they want to study. We considered the use of other LCA transportation databases: the GaBi  
229 database<sup>1</sup> developed by Sphera and the US GREET model<sup>2</sup> developed by Argonne National  
230 Laboratory (A. Elgowainy, M. Wang 2019). Because of the software choice, the use of the GaBi  
231 database was not an option. Considering the US GREET database, we preferred a European  
232 database as the geographical scope of the study was France by default and the conclusions can  
233 be extended to Europe. Another reason is that Ecoinvent was implemented in the SimaPro<sup>®</sup>  
234 software we used.

235 Two time-horizons were considered in the context of this study: current (2019) and prospective  
236 (2030). One cycle was examined, that is, the WLTP cycle. The low heating values (LHVs) in  
237 this study use the JRC values (JRC 2012), along with the quantities of CO<sub>2</sub> emitted during the

---

<sup>1</sup> <http://www.gabi-software.com/international/index/>

<sup>2</sup> <https://greet.es.anl.gov/>

238 combustion of gasoline and diesel fuels. Regarding NGV combustion, CO<sub>2</sub> emissions were  
239 based on a carbon open-source French database developed by the French Environment and  
240 Energy Management Agency (ADEME). For Biofuels, we followed the specifications of the  
241 renewable energy directive (RED) II (Directive EU 2018/2001). The consumption of vehicles  
242 per use cycle was established in the first phase of this study (see Section 2.2). The detailed LCA  
243 methodology used in this study is explained in a study by Bouter et. al. (2020).

### 244 **2.3.2 Description of the vehicles**

245 All vehicles were assembled and used in France. All vehicles were modeled according to  
246 previously mentioned data:

- 247 - bare vehicle body with gearbox
- 248 - combustion engine
- 249 - electric engine and generator
- 250 - battery

251 Table 2 summarizes the vehicle characteristics. The main assumptions for the model came from  
252 an ICE gasoline vehicle and were then customized using other models and expert opinion.  
253 Finally, we obtained virtual vehicles, not commercial, that were representative of the average  
254 vehicles existing on the market. For example, the HEV gasoline vehicle was derived from a  
255 baseline vehicle glider with a hybrid powertrain.

256 **Table 2:** Powertrain specifications

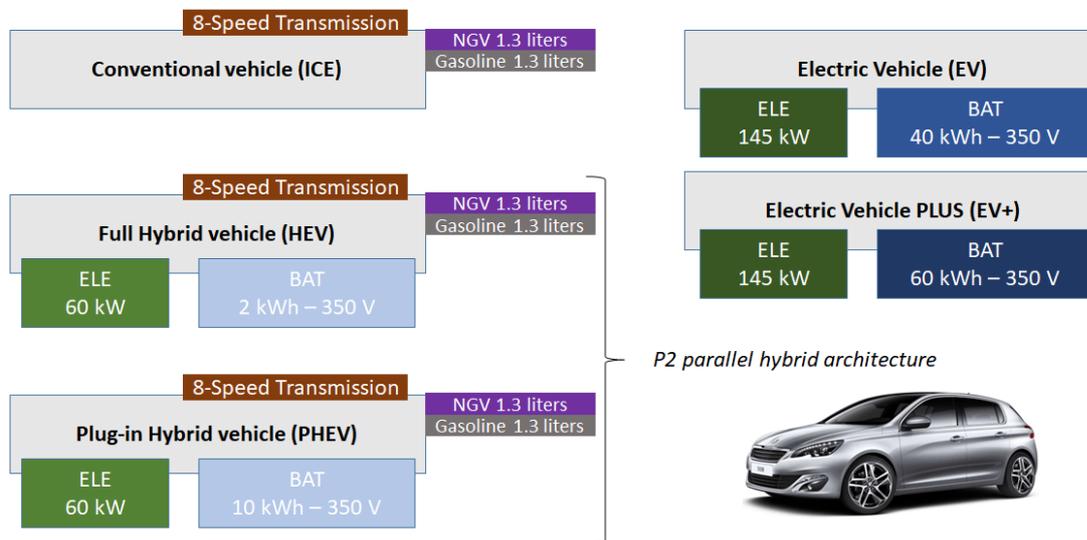
Type of Technology	ICE gasoline	ICE diesel	HEV gasoline	PHEV gasoline	EV	EV +
<i>ICE</i>						
Max power	96 kW	88 kW	72 kW	72 kW		
<i>Electric motor</i>						
Max power			70 kW	70 kW	80 kW	80 kW
<i>Generator</i>						
Max power			30 kW	30 kW		
<i>Battery Capacity</i>						
2019			2 kWh	10 kWh	40 kWh	60 kWh
2030			2 kWh	10 kWh	60 kWh	80 kWh

257

258

259 Figure 4 illustrates the design and choice details of the vehicle components representing

260 segment C.



261

262 **Figure 4: Design of C segment architecture for 2019 (ELE: electric engine, BAT: Battery)**

263

264 For the bodies of the 2030 horizon vehicles, 30% of the vehicle's steel was assumed to be

265 replaced by aluminum, a material which weighs only 65% that of steel per volume (ADEME et

266 al. 2013). The vehicle specifications were built from manufacturers' data and according to

267 IFPEN experts. The split of the raw material components of the gliders came from the IMPRO

268 Car II report (Nemry et al. 2009). The lifetime mileage of these mid-range vehicles was assumed

269 to be 10 years at a rate of 15,000 km/year, that is, 150,000 km over their entire life cycle.

## 270 *Batteries*

271 In this study, the battery model was informed with confidential data provided by ADEME  
272 (Bouter et. al 2019) based on data from two battery manufacturers. The battery type was  
273 lithium-ion, and the cathode chemistry was nickel manganese cobalt (NMC), resulting in an  
274 LiNMC battery. It results from a 50:50 combination of the two manufacturers' life cycle  
275 inventory datasets. The GHG emissions associated with the manufacturing of such batteries  
276 were approximately 102.7 kg CO<sub>2</sub> eq./kWh in 2019 and 77.0 kg CO<sub>2</sub> eq./kWh in 2030. These  
277 results are in accordance with those of other studies (Ciez et al. 2019, Jiang et al. 2020).  
278 Improvements refer to differences in technical specifications (Table 2) and energy density: 150  
279 Wh/kg in 2019 and 200 Wh/kg in 2030. These values are in line with the orders of magnitude  
280 reported in the literature (Peters et al. 2017, Dai et al. 2019). The expected battery lifespans  
281 were 10 years for passenger cars. Therefore, only one battery was considered during the vehicle  
282 life cycle.

## 283 *Liquid fossil fuels*

284 Gasoline and diesel fuels were modeled using Ecoinvent data for the upstream part, or WTT, at  
285 17.5 and 12.2 g CO<sub>2</sub> eq./MJ, respectively. Ecoinvent data were preferred over JEC data because  
286 the modeling used SimaPro<sup>®</sup> software. We also preferred to use a physical allocation for  
287 refinery products given the scope of our study, which is clearly attributional oriented (Sphera  
288 and IFPEN 2020). This is the methodology used for Ecoinvent processes, whereas JEC data  
289 base their calculations on incremental allocations, which more accurately reflects a  
290 consequential assessment. The emissions associated with gasoline and diesel combustion were  
291 based on JEC values (JEC 2014): TTW, namely 73.4 and 73.2 g CO<sub>2</sub> eq./MJ for gasoline and  
292 diesel, respectively. Reduction in fuel consumption modeled in 2030 in comparison with 2019  
293 are only triggered by improvements in engine performance.

294 *Liquid biofuels*

295 The introduction of biofuels in France is ruled by legislative measures to ensure the  
 296 sustainability of biofuels incorporated into gasoline and diesel pools. Thus, the quantity and  
 297 quality of incorporated or imported biofuels into French territory must be recorded (DGEC  
 298 2018). This allows a split between the bio-products incorporated into the diesel pool: fatty acid  
 299 methyl ester (FAME) biodiesel and hydrotreated vegetable oil (HVO) biodiesel, and into the  
 300 gasoline pool: ethanol. The resources (agricultural products, residues, or wastes) used for the  
 301 different biofuels are also known, and this leads to an assumed average biofuel for both  
 302 biodiesel and ethanol. We used the default GHG emissions proposed in Directive 2018 of the  
 303 European Parliament and the Council: REDII Directive. This has a twofold purpose: the aim of  
 304 the study is not focused on biofuel GHG emissions and their calculation, and the REDII values  
 305 have the advantage of being commonly used, representing a scientific consensus. REDII GHG  
 306 emissions values for biofuels also reflect the geographical perimeter of the study, which is  
 307 French-and European-oriented. Using these default GHG emissions proposed in Directive 2018  
 308 of the European Parliament and the Council led to an average value of 50.9 g CO<sub>2</sub> eq. g/MJ for  
 309 the French biodiesel (Table 3) and 44.2 g CO<sub>2</sub> eq./MJ for the French ethanol in 2017 (Table 4).

310 **Table 3:** Average composition of French biodiesel delivered at the pump in 2017

Biodiesel type		Agricultural resource	REDII GHG emissions, default value, without iLUC (in g CO <sub>2</sub> eq./MJ)	REDII provisional estimated iLUC mean value	
<b>FAME</b>	89.0%	Rapeseed	63.3%	50.1	
		Palm oil	12.4%	63.65 <sup>3</sup>	
		Soybean	4.7%	47	
		Sunflower	3.1%	44.7	
		Waste cooking oil	4.3%	14.9	
		Animal fats	1.2%	20.8	
<b>HVO</b>	11.0%	Palm oil	11.0%	60.65 <sup>4</sup>	55
<b>French average 2017 biodiesel</b>	100%		100%	<b>50.9</b>	<b>52</b>

<sup>3</sup> Mean of the two proposed technologies in REDII: open effluent pond and process with methane capture at oil mill.

<sup>4</sup> Mean of the two proposed technologies in REDII: open effluent pond and process with methane capture at oil mill.

311

312

**Table 4:** Average composition of French ethanol delivered at the pump in 2017

		<b>Agricultural resource</b>	<b>REDII GHG emissions, default value, without iLUC (in g CO<sub>2</sub> eq./MJ)</b>	<b>REDII provisional estimated iLUC mean value</b>	
<b>Ethanol</b>		Wheat straw	0.9%	15.7	
		Wood	4.1%	15.2 <sup>5</sup>	
		Sugar cane	1.3%	28.6	13
		Maize	27.6%	50.85 <sup>6</sup>	12
		Sugar beet	27.2%	33.45 <sup>7</sup>	13
		Wheat	38.7%	51.55	12
<b>French average 2017 ethanol</b>	100%	100%	<b>44.2</b>	<b>11.6</b>	

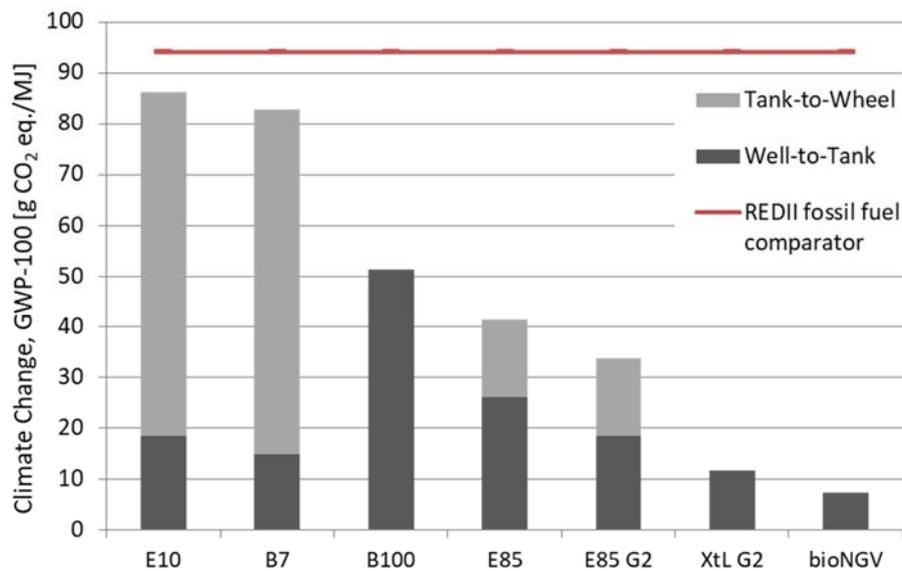
313

314 Thus, the fuels delivered at the pumps used in this study were: unleaded 98 fuel, 95-E10 fuel  
315 containing up to 10% ethanol, super-ethanol E85 (gasoline containing up to 85% ethanol), or  
316 biodiesel B7 (containing up to 7% biodiesel in volume), and B100 (100% biodiesel), the  
317 emission factors for the selected products were calculated as presented in Figure 5. Expected  
318 future advanced biofuels have also been simulated as they are close to being industrially  
319 produced and are compatible with current vehicles, these were: advanced E85, called E85 G2,  
320 and advanced biodiesel, named XtL G2. The same resources were modeled for advanced  
321 biofuels, accounting for the energy required for the conversion of waste wood.

<sup>5</sup> Mean of the two wood resources in REDII: waste wood and farmed wood.

<sup>6</sup> Mean of the four proposed processes for ethanol production from maize

<sup>7</sup> Mean of the six proposed processes for ethanol production from sugar beet



322

323 **Figure 5 : Well-to-wheel CO<sub>2</sub> emissions according to biofuel incorporation as energy pathway**

324 Vehicle consumptions were adapted for biofuels, especially E85, E85 G2, B100, and XtL G2,  
 325 from their equivalent fossil consumptions. Indeed, LHVs of these products are significantly  
 326 lower than their fossil counterparts (European Commission 2014), leading to an increase in fuel  
 327 consumption.

328 For liquid fossil fuels, no differences in the biofuel production processes were considered  
 329 between 2019 and 2030; only vehicle engine improvements were modeled through a decrease  
 330 in consumption.

### 331 *Gas and biogas*

332 Emissions relative to NGV production and combustion were based on the emission factors of  
 333 the Ecoinvent database and the ADEME carbon database (13.2 and 56.7 g CO<sub>2</sub> eq./MJ,  
 334 respectively). The two databases use the same emission factor for NGV production: 12.9 g CO<sub>2</sub>  
 335 eq./MJ. The Ecoinvent data were preferred, given its implementation in the software used.

336 GHG emissions for bioNGVs were based on the GHG emission default values of REDII. As  
 337 four default values were proposed for biomethane from wet manure production, we decided to  
 338 model the upper value range: 22 g CO<sub>2</sub> eq./MJ, representing the technological option of open

339 digestate and no off-gas combustion, and the lower value range of -100 g CO<sub>2</sub> eq./MJ (negative  
340 value, European Union 2018), representing the technological option of closed digestate with  
341 off-gas combustion. In both cases, manure credits were considered, but an important difference  
342 remains in terms of the process stage contribution. For open storage of digestate, additional  
343 emissions of CH<sub>4</sub> and N<sub>2</sub>O occur. For close storage, no GHG emissions were included in the  
344 process. The CO<sub>2</sub> emitted during the combustion of biomethane is fully offset upstream by the  
345 CO<sub>2</sub> captured from the atmosphere (by photosynthesis) during plant growth, as for liquid  
346 biofuels (IPCC 2013): carbon neutrality principle.

347 Consumption improvements for liquid fuels, fossil fuels, and bio-based fuels, between 2019  
348 and 2030 were considered for the future predictions.

### 349 *Electricity*

350 Electricity was modeled in accordance with the Ecoinvent v.3.5 process for French production  
351 in 2017 (IEA 2017). For France, this model provided an average emission factor of  
352 55.4 g CO<sub>2</sub> eq./kWh, using the global warming potential methodology from the IPCC over a  
353 100-year period. This value was used in the 2019 scenario. For the 2030 value, the objectives  
354 of both RED II (The European Parliament and the Council 2018/2001) and French forecast  
355 energy multi-annual programming (Ministère de la Transition Ecologique et Solidaire 2018)  
356 were considered, as presented in Table 5. A 40% renewable energy incorporation rate for  
357 French electricity in 2030 was assumed: 11% hydraulic, 14% onshore, 9% photovoltaic, 4%  
358 offshore wind, and 2% biomass. These values are in line with the projections of the French  
359 government for 2028. Meanwhile, the share of nuclear energy in the electricity mix in France  
360 will decrease from 78.8% in 2019 to 53.9% for 2030, in line with the goal of 40% renewables  
361 by 2030 and the forecasted scenario proposed by the French government for 2028. Meanwhile,  
362 the contribution of gas to the French electricity mix will increase from 0.6% in 2019 to 4.6% in

363 2030. These changes combined will mean that by 2030, electricity emissions in France will  
 364 average at 69.6 g CO<sub>2</sub> eq./kWh, compared to the current 55.4 g CO<sub>2</sub> eq. / kWh.

365 **Table 5:** French electricity mix by sources for 2019 and 2030 (projected)

		2019	2030
Fossil	Coal	1.6%	0.0%
	Nuclear	78.8%	53.9%
	Gas	1.5%	5.5%
	Oil	0.1%	0.0%
Renewable	Hydro	12.9%	10.7%
	Wind, onshore	3.0%	13.9%
	Wind, offshore	0.0%	3.6%
	Photovoltaic	0.0%	9.1%
	Biomass	0.2%	1.7%
	Imports (BE, CH, DE, ES, GB, IT)	1.5%	1.5%

366  
 367 The same methodology was used for the European electricity mix based on the JRC report  
 368 (Banja and Jégard, 2017). The renewable energy rate for electricity production is projected to  
 369 be 54.5%, according to EU targets. To assign the average carbon intensity for each electricity  
 370 production source in Europe, representative countries were chosen to represent each pathway.  
 371 These were French nuclear electricity, German wind, Italian gas, German solids, French  
 372 hydropower, German solar, biomass and waste, and French oil and other renewables. The 2030  
 373 European electricity mix is predicted to be 233.3 g CO<sub>2</sub> eq./kWh, compared to the current 439.7  
 374 g CO<sub>2</sub> eq./kWh. Even if European electricity may appear high, it is not compared with the  
 375 values for other countries or other primary energies. For example, the current electricity mix  
 376 productions for Japan and the US are at 714 and 563 g CO<sub>2</sub> eq./kWh, based on Ecoinvent data  
 377 assessed using the IPCC 2013 methodology (Frischknecht et Rebitzer 2005; IPCC 2013).  
 378 Regarding 100% coal-powered electricity, the carbon intensity would be 1060 g CO<sub>2</sub> eq./kWh.

379 ***End of life***

380 The stage “end of life” was simulated in accordance with the avoided burden allocation  
 381 methodology (Allacker et al. 2017), meaning that the product is given credit for the potential

382 recycled material included. The end of lives of vehicles were based on manufacturers' data and  
383 European directives. The end of lives of wheels and tires were modeled based on data from the  
384 ADEME report (ADEME 2017). The end of lives of batteries follow the European directive  
385 2006/66/CE. It considers two different technologies in equal proportions: hydrometallurgical  
386 treatment and pyrometallurgical treatment, from the Ecoinvent database.

387

### 388 **2.3.3 Functional Unit**

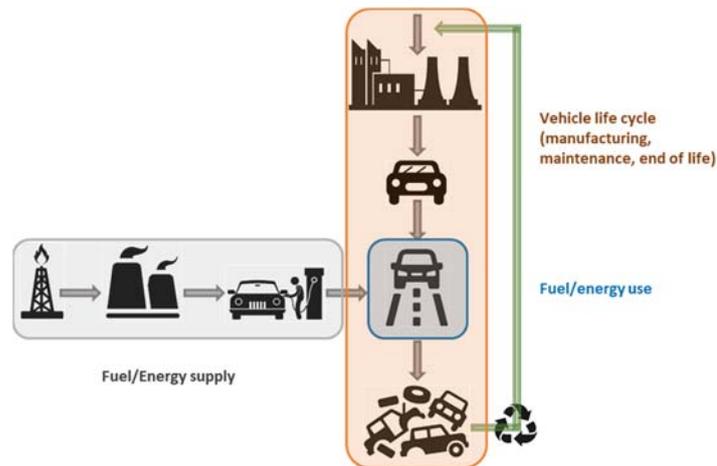
389 The functional unit adopted for the comparative assessment of passenger transportation is  
390 represented by one assumed average kilometer within a given traffic context, here the WLTP  
391 cycle is "one kilometer driven".

392

### 393 **2.3.4 System boundaries**

394 The steps considered are those shown in Figure 6. On the horizontal axis, all stages of the fuel  
395 production cycle are considered, from raw material extraction to the vehicle's fuel tank (WTT)  
396 to the use of the fuel (TTW). On the vehicle-specific vertical axis, there are two components:  
397 the life cycle of the vehicle and vehicle operation using fuel. Therefore, the present study is  
398 well-to-wheel as the vehicle life cycle is also taken into account.

399 Infrastructure was not included in the scope of this study (roads and charging stations).



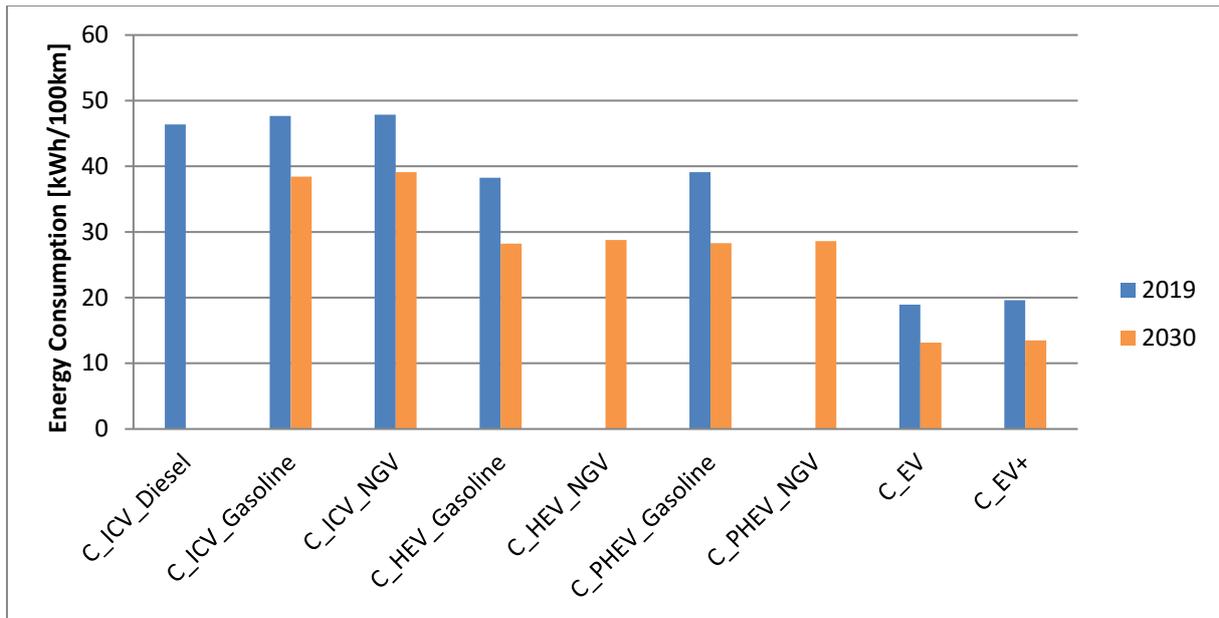
400  
 401 **Figure 6: Life cycle stages considered in the study: Well-to-Wheel assessment and vehicle life**  
 402 **cycle**

403  
 404 The impact assessment methodology used to estimate the potential impact on climate change is  
 405 the one recommended by the European Commission, Global Warming Potential, which  
 406 calculates radiative forcing over a time period of 100 years using the IPCC 2013 methodology  
 407 (IPCC 2013).

### 408 **3 Results**

#### 409 **3.1 Energy consumption simulation**

410 The vehicles were simulated over the WLTP cycle, which replaced the NEDC cycle in 2018 to  
 411 better represent the overall usage of a given vehicle. The energy results for the C-segment  
 412 vehicles are shown in Figure 7. Fuel consumption corresponding to biofuels was the same as  
 413 the results of the equivalent 100% fossil fuel, because they are expressed in kWh/100 km and  
 414 not in liter/100 km (same vehicle and powertrain efficiency).



415

416

**Figure 7: Energy consumption [kWh/100 km] of C segment vehicles – 2019 & 2030**

417

418

### 3.1.1 Analysis for 2019

419

The energy consumptions of conventional internal combustion gasoline and NGV vehicles are similar because of the similarity of the engine mappings used in the study. Manufacturers use a "gasoline" engine baseline to develop NGV technological solutions.

422

Figure 7 also shows the gains made through electrification: the components detailed in Figure 2 reduce fuel consumption by up to 20% for standard hybrids (HEVs).

423

424

The PHEV shows higher consumption than the HEV owing 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.

425

426

This finding alone shows that the electric mode for a PHEV, and thus regular recharging, is the preferred option. In this mode, the PHEV behaves like an electric vehicle with an energy

427

428

consumption of less than 20 kWh/100 km for both battery capacity assumptions envisaged: EV and EV+. This low energy consumption is achieved by the high efficiency of the components

429

430

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.

431

432

433

### 3.1.2 Projected energy consumption by 2030

434 The planned changes for 2030, in terms of reducing the component weights, reducing the forces  
435 exerted on the vehicle, and increasing device performance, would lead, according to the  
436 simulations, to a lower consumption by 20% for conventional vehicles and up to 30% for  
437 electric vehicles benefiting from increases in battery energy densities, despite their capacity  
438 increase.

439 Analysis of the mid-range car results do not reveal an energy benefit from using natural-gas  
440 engines versus liquid fossil-fuel engines because the converter performance is of the same order  
441 of magnitude. To see any differences, the entire energy chain must be looked at: from well to  
442 wheel. This is the purpose of the next part: the life cycle analysis, which uses the component  
443 characteristics and the energy results of the cars modeled via the simulation platform as input  
444 data.

445

446

## 3.2 GHG Emissions results

447 A large sample of vehicle technologies and energy pathways were assessed, but some  
448 combinations are not shown in this paper, as we decided to represent the most common and  
449 representative combinations of vehicle technology and energy carrier. This leads to  
450 supplementary combinations for 2030, as we considered HEVs and PHEVs that run using gas.

451 Figure 8 and Figure 9 present the results of the potential impacts of the various vehicles on  
452 climate change in terms of GHG emissions in grams of CO<sub>2</sub> equivalent per kilometer in 2019  
453 and 2030.

454 The distribution of global emissions from each life-cycle stage is represented. The dark blue  
455 portion represents emissions related to the vehicle shell and powertrain type (engine, gearbox,  
456 etc.), also known as the glider. This portion is relatively similar for the various engines;  
457 however, it has a slight disadvantage for hybrid powertrains that integrate two engines: thermal  
458 and electric. Thermal gas powertrains are also emit slightly more because of the heavier gas  
459 tank.

460 The life cycle stage with the highest GHG emissions for combustion vehicles is fuel (in gray),  
461 including WTT and TTW emissions. TTW emissions represent the combustion of fuel by the  
462 vehicle during its 150,000 km of use, which constitutes a major part of the impact on global  
463 warming.

464 NGVs produce less CO<sub>2</sub> than their fossil combustion-based equivalents, gasoline and diesel,  
465 owing to a lower emission factor (favorable H/C ratio for CH<sub>4</sub> compared to the longer carbon  
466 chains of liquid hydrocarbons).

467 BioNGV, produced with open digestate and no off-gas combustion process, has an emission  
468 factor approximately 75% lower than its fossil GNV counterparts and produces very favorable  
469 results: 71.2 g CO<sub>2</sub> eq./ km, which is approximately 60% less than that of the equivalent diesel  
470 vehicle. The results were almost identical to those of EVs running in France.

471

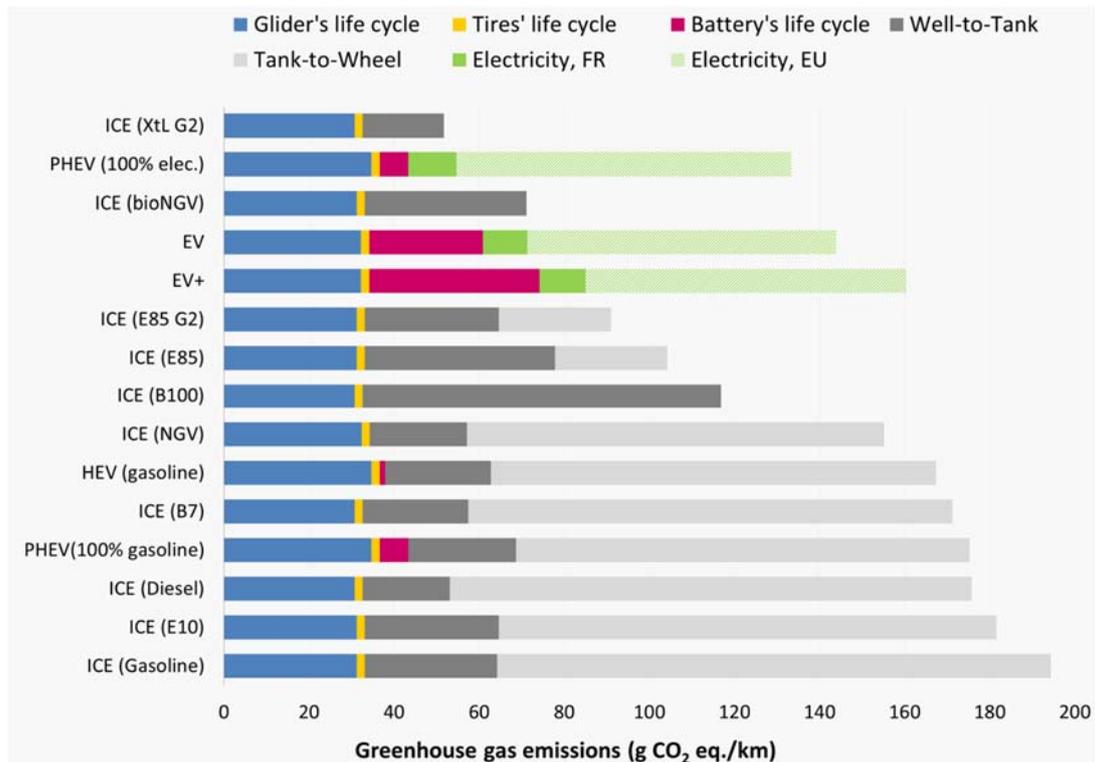


Figure 8: Potential impact on climate change for C-segment vehicles in 2019

472

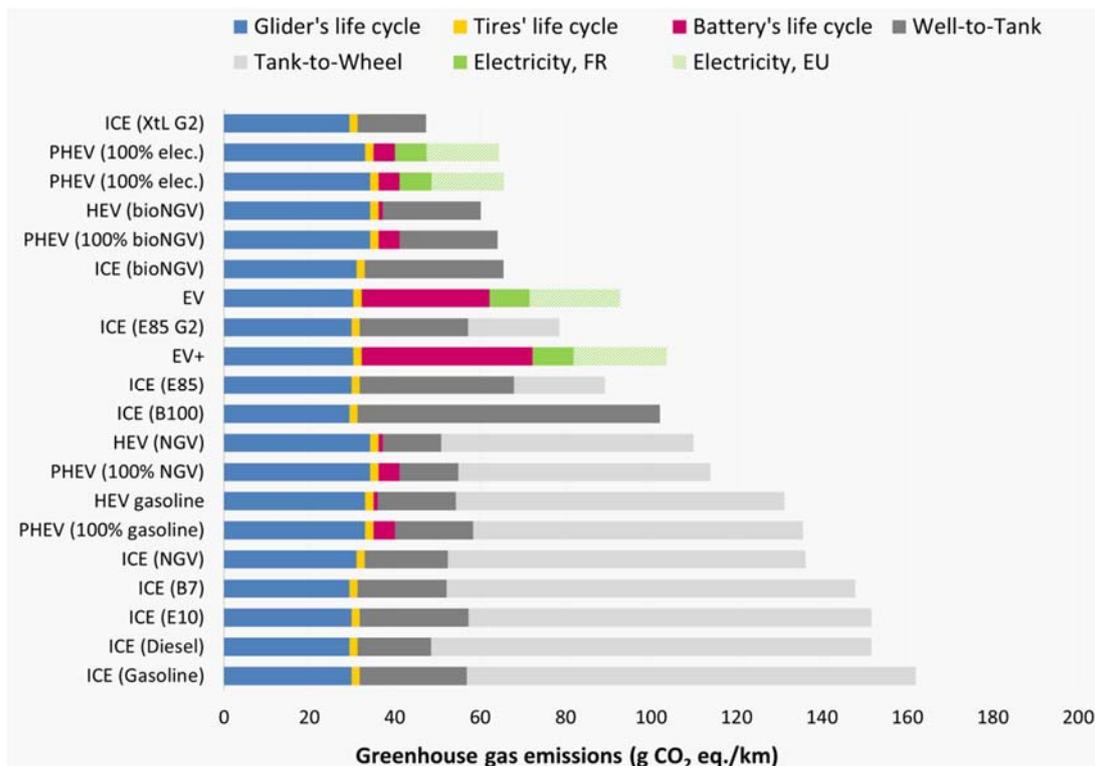
473

474

475 The results for electrified vehicles, including PHEVs and BEVs, show that the battery  
 476 manufacturing emissions are significant (red part). These are directly proportional to the  
 477 capacity of the onboard battery (kWh). Technical advances (increase in energy density mostly)  
 478 explain why the projected emission factor for batteries in 2030 is lower than in 2019.

479 Very different results can be observed for rechargeable hybrids when comparing all-electric use  
 480 versus all-combustion use, that is, without ever recharging the battery (100% gasoline or 100%  
 481 gas). With the 100% electric mode, the result was 54.7 g CO<sub>2</sub> eq./km in 2019, in line with  
 482 combustion vehicles running on bioNGVs. With the 100% combustion mode, the PHEV results  
 483 were worse as emissions from battery manufacturing were added to those from fossil fuel  
 484 combustion. The way PHEVs are used by their owners, and their willingness to recharge their  
 485 vehicles, are still relatively unknown, however the introduction of on-board fuel consumption  
 486 meters (OBFCM) in January 2020 will probably improve this. The two contrasting results

487 presented here make it possible to establish the lower and upper limits of use of this type of  
 488 vehicle. This shows that PHEVs can achieve their full potential only if their owners are willing  
 489 to do so.



490  
 491 **Figure 9: Potential impact on climate change for C-segment vehicles in 2030**

492  
 493 Hybridization (HEV) reduces the fuel consumption of vehicles and, therefore, their CO<sub>2</sub>  
 494 emissions. For a gasoline HEV, emissions are lower than those of an NGV combustion vehicle  
 495 (approx. 154 and 167 g CO<sub>2</sub> eq./km, respectively). A non-rechargeable NGV hybrid in 2030  
 496 (Figure 9), according to our assumptions, will perform even better, at 110 g CO<sub>2</sub> eq./km.  
 497 Finally, non-rechargeable bioNGV hybrids combine the advantages of hybridization and  
 498 biomethane, with emissions of 60.1 g CO<sub>2</sub> eq./km by 2030. For each powertrain running with  
 499 bioNGV, another result is possible considering the lower range value of the REDII GHG  
 500 emissions value for biomethane. Indeed, when close digestate with off-gas combustion is  
 501 considered as the technological option, the total net results are -115, -63, and -67 g CO<sub>2</sub> eq./km  
 502 for the ICE, PHEV, and HEV, respectively.

503 BEVs (EV and EV+ for those with a larger battery) emit much less CO<sub>2</sub> than internal  
504 combustion vehicles, and even hybrids, depending on how and where the electricity is  
505 produced. While French electricity mix carbon intensity is very low as electricity is mainly of  
506 nuclear origin, European electricity is more CO<sub>2</sub> emitting as some European countries still  
507 produce electricity using coal. While emissions from battery manufacturing (in China) are  
508 largely offset by the low emissions of French electricity production during the 150,000 km of  
509 use, the same cannot be said for European electricity production, which is approximately eight  
510 times higher than the French electricity mix, even if they are more sustainable compared to  
511 vehicles running using fossil fuels. For an electric vehicle carrying a 40-kWh battery in 2019,  
512 approximately 71.3 g CO<sub>2</sub> eq./km are produced. An EV+ carrying a 60-kWh battery, will  
513 produce approximately 85 g CO<sub>2</sub> eq./km. However, these results are higher than those of  
514 bioNGV or XtL G2 combustion vehicles. The results demonstrate that the location where  
515 electric vehicles are deployed is highly important regarding GHG emissions (Bouter et al.,  
516 2020).

## 517 **4 Discussion**

518 As expected, the results for CO<sub>2</sub> emissions depend strongly on vehicle powertrains.  
519 Electrification brings interesting benefits in comparison with engines that use liquid fossil fuels.  
520 Gas vehicles also have a slightly higher contribution owing to a heavier gas tank. The  
521 manufacturing stage for both the battery and glider accounts for between 77% and 83% of the  
522 total impact of BEVs. The decrease between the current and future technology vehicles mostly  
523 reflects improvements in future technologies, such as vehicle manufacturing, tailpipe  
524 emissions, and battery efficiency. The impact of replacing steel glider production with  
525 aluminum between 2019 and 2030 is an increase in the relative end-of-life, as steel is less  
526 recyclable.

527 The use stage is significant for combustion engine powertrains and HEV vehicles due to fossil  
528 liquid fuel use: between 67% and 85% of the total GHG emissions. For PHEV and BEV, the  
529 use stages for vehicles and batteries are small contributors to GHG emissions due to the low  
530 carbon electricity available in France.

531 Another important result is that BEVs are not the smallest contributors to GHG emissions, and  
532 PHEVs seem to be more competitive if they are mostly used in electric mode. This is mostly  
533 due to adequate sizing of the battery for daily use and thus the capability of the PHEVs to rely  
534 on their battery during their daily cycles of use (battery charges were considered to be every  
535 night). Some manufacturers have configured their PHEV vehicles in order to switch  
536 automatically to electric mode when they enter a low emission zone.

537 It is also noteworthy that the electricity mix used for the study is that produced in France, which  
538 corresponds to an average of 55.4 g CO<sub>2</sub> eq./kWh, currently. In the European context, the  
539 electricity mix is approximately 439.7 g CO<sub>2</sub> eq./kWh. Thus, the use stage for both the PHEV  
540 and BEV would be approximately eight times higher for the European average. This would lead  
541 to fewer differences between electrified and thermic vehicles. This highlights the importance  
542 of location and electricity production for the use of electrified vehicles. The same trend is  
543 observed for midsize cars both for 2019 and 2030, since an “electric +” vehicle with an extended  
544 range emits CO<sub>2</sub> emissions as an HEV. The location of the electricity production is  
545 consequently a very important parameter to be aware of, and sensitivity analysis must be  
546 performed. The improvement of the impact on the climate change of electrified vehicles  
547 requires low-carbon electricity sources. These LCA results demonstrate the importance of  
548 considering the vehicle’s life cycle when considering electrified vehicles. The smart use of  
549 PHEVs presents a high potential for climate change mitigation.

550 For biofuels (liquid or gas), the results depend strongly on the incorporation rate and the  
551 pathway (conventional or advanced biofuels). Figures 8 and 9 show a low incorporation rate  
552 (E10 and B7, that is, gasoline with 10% ethanol and diesel with 7% biodiesel) led to small  
553 benefits, as expected. However, this solution is available today, and has been widely adopted.  
554 This method brings interesting benefits without any powertrain change. Regarding the E85 and  
555 B100 fuels, the gains in CO<sub>2</sub> emissions are impressive, even if E85 is produced from  
556 conventional biofuels (ethanol). The results using biofuels are close to BEVs with extended  
557 range (“EV +”) in 2019: 103 vs 85 g CO<sub>2</sub> eq/km. In 2030, this is predicted to be 91 vs 83 g CO<sub>2</sub>  
558 eq/km. These improvements can be obtained at a lower cost and without the need to adapt  
559 engine hardware; only a few setups must be implemented inside the engine control unit.

560 The last alternative low carbon fuels investigated in this paper were bioNGV and liquid biofuels  
561 exclusively produced from advanced pathways (XtL). E85 produced from advanced biofuels  
562 reduces GHG emissions by 15% compared with standard E85. Consequently, this pathway is a  
563 realistic option. The gap with electric vehicles equipped with an extended range “EV+” (in  
564 order to compare similar range) is very small: 91 vs 85 g CO<sub>2</sub> eq/km in 2019, and the results  
565 are even closer in 2030: 80 vs. 83 g CO<sub>2</sub> eq/km. In addition, when considering European  
566 electricity production, E85 with advanced biofuels is clearly a better option. Advanced biodiesel  
567 represents a very good opportunity to reduce GHG emissions from the global fleet. Indeed,  
568 vehicles using this type of low-carbon fuel represent the lowest GHG emissions value in 2019,  
569 considering the LCA approach, although no CO<sub>2</sub> emissions at the exhaust pipe are taken into  
570 account. Finally, bioNGVs produced exclusively from agricultural waste constitute another  
571 interesting pathway with immediate environmental benefits. Combined with a hybrid  
572 powertrain, this solution has the best results in 2030, and consequently has to be considered as  
573 a credible alternative option.

574 Finally, it is important to underline that the global trend towards electrification is not in  
575 competition with low-carbon fuels, and biofuels in particular. Clearly, in order to achieve the  
576 objectives of the European Green Deal in 2050, electrification represents a very efficient  
577 solution. However, it will require significant investments, including improvements in European  
578 renewable electricity production and the development of new infrastructure across Europe  
579 (charging stations). Moreover, beyond the indicators stated in this paper, the constraint from  
580 battery manufacturing is a substantial concern. Hache et al. (2019) detailed a bottom-up study  
581 on raw material supply and showed that the cumulated lithium demand will be 53% of the  
582 current resources in a 2 °C scenario by 2050. Nevertheless, the absence of geological criticality  
583 does not hide certain forms of vulnerability, whether economic, industrial, geopolitical, or  
584 environmental. A study by Hao (2019) considered heavy-duty electrification growth. The large  
585 single-vehicle battery capacity required by heavy-duty vehicles and the expected battery  
586 replacement would substantially increase lithium demand in the future. A study by Seck (2020)  
587 showed that raw material production will be deeply impacted by the penetration of low-carbon  
588 technologies in transport, such as copper. The cumulative primary copper demand between  
589 2010 and 2050 is expected to be 89% of known copper resources in 2010.

590 Low-carbon fuels and biofuels represent an alternative to rapidly reducing global GHG  
591 emissions from an LCA perspective. By increasing the incorporation rate of standard biofuels  
592 and advanced biofuels in the short term, it is possible to reduce CO<sub>2</sub> emissions with very little  
593 adjustments for powertrains and for manufacturers. Of course, investments are also necessary,  
594 particularly for the development of biorefineries.

595

## 596 **5 Conclusions**

597

598 The transportation sector must reduce its greenhouse gas emissions over the next few decades,  
599 starting with the passenger transportation sector. Consumers have a wide range of vehicle  
600 powertrains and fuel choices today and in the near future, most of which offer effective  
601 solutions to reduce greenhouse gas emissions.

602 This study examines the carbon intensities of mid-sized cars (from cradle to grave) in the French  
603 and European markets today and in 2030. The synthesis shows that conventional engines  
604 (gasoline or diesel) struggle with low-carbon technologies. The full-hybrid architecture could  
605 be an interesting solution to compete with current engine solutions. Plug-in Hybrid Vehicles (if  
606 driven in electric mode all the time) seem to be the most relevant solution owing to their limited  
607 battery size perfectly adapted to the everyday use of the majority of vehicles. Battery electric  
608 vehicles are effective solutions for reducing greenhouse gas emissions, especially with low-  
609 carbon electricity as produced in France.

610 Nevertheless, without attractive costs for customers, these technologies will not enter the  
611 market, and the objective of strong CO<sub>2</sub> reduction will be unreachable. Consumer behavior  
612 should be considered when designing government policies. Consequently, another alternative  
613 pathway could also be a part of the energy transition applied to the transportation sector over  
614 the short term. Concerted efforts are needed to avoid global climate change until the hurdles  
615 preventing massive fleet electrification deployment are overcome. The study shows that  
616 standard and advanced biofuels (liquid and gas) represent a very efficient way to quickly reduce  
617 the greenhouse gas emissions of the global fleet, without important adjustments of powertrains  
618 and service stations across Europe. Increasing the incorporation rate of biofuels would yield  
619 immediate results, and advanced biofuels or bioNGVs can avoid the biofuel controversy  
620 regarding competing with food production for land. Of course, large investments are necessary  
621 to develop advanced biofuel production (all the value chains have to be taken into account) but  
622 the global electrification in Europe will also require large financial support, with mid-term

623 return of investment. Both approaches (electrification and biofuel development) are  
624 complementary and would represent the best way to reach the objectives of the European Green  
625 Deal.

626

## 627 **Acknowledgments**

628 We are very grateful to the French Environment and Energy Management Agency (ADEME),  
629 who supported a part of this study. It also received financial support from the Association  
630 Française du Gaz (AFG).

## 631 **Acronyms**

632 B7: Diesel fuel with 7% vol. of biodiesel

633 BAT: Battery

634 BEV: Battery Electric Vehicle

635 E10: Gasoline with 10% vol. of ethanol

636 ELE: Electric Engine

637 EV: Electric Vehicle

638 FAME: Fatty Acid Methyl Ester

639 GHG: Greenhouse Gas Emission

640 HEV: Hybrid Electric Vehicle

641 HVO: Hydrotreated Vegetable Oil

642 ICE: Internal Combustion Engine

643 iLUC: Indirect Land Use Change

644 LCA: Life Cycle Assessment

645 LHV: Low Heating Value

646 NGV: Natural Gas Vehicle

647 PHEV: Plug-in Hybrid Electric Vehicle  
648 TTW: Tank-To-Wheel  
649 WLTP: Worldwide harmonized Light vehicles Test Procedure  
650 WTT: Well-To-Tank  
651 XtL: Synthetic Liquid Fuel

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