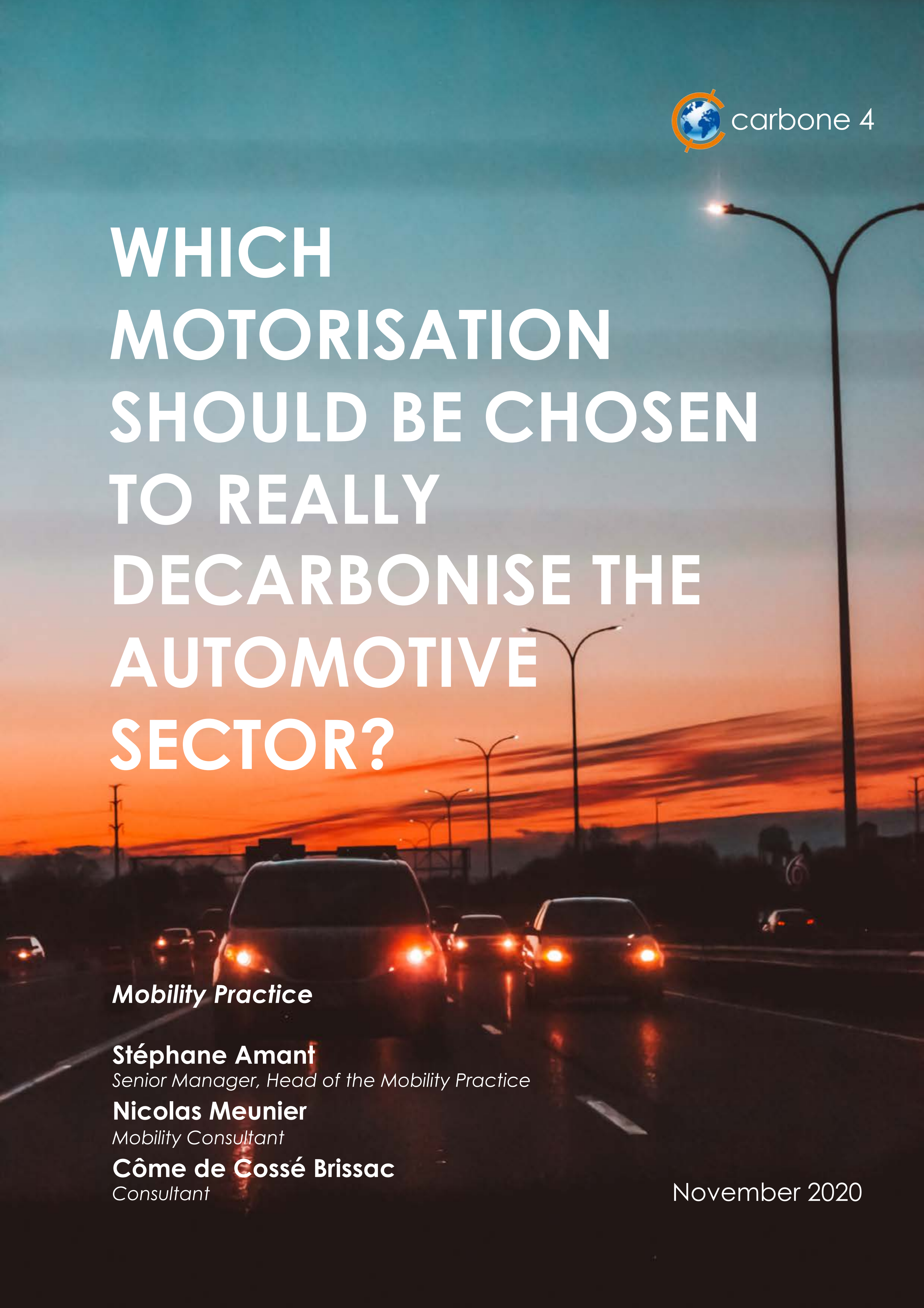

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WHICH MOTORISATION SHOULD BE CHOSEN TO REALLY DECARBONISE THE AUTOMOTIVE SECTOR?

Mobility Practice

Stéphane Amant
Senior Manager, Head of the Mobility Practice
Nicolas Meunier
Mobility Consultant
Côme de Cossé Brissac
Consultant

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Context and purpose of the study

In order to respond to the climate challenge, the mobility sector has no choice but to reinvent itself, particularly the automotive sector. Through new technologies, new uses and by acting on demand: the challenge is so great that all the levers will have to be activated.

Regarding the technological lever, despite government announcements and the positions taken by major industrial players, the path of the energy transition has not yet been clearly mapped out: it is difficult to affirm today with certainty which will be the most relevant alternatives to fossil fuels, between bioNGV, liquid biofuels, battery-electric, hydrogen or hybrid electric. In order to rank these different available energy options, one of the justices of the peace will be the **carbon footprint over its life cycle**, taking into account the manufacture, usage and end of life of the vehicles, as well as **the "well to wheel"[1] approach for the energy carriers.**

This summary for decision-makers presents the most recent results obtained by Carbone 4 on this subject, for cars. The aim is to enlighten the debate and help stakeholders to make the best decisions with full knowledge of the facts.

The assumptions used, detailed results and sensitivity analyses are available in <u>our detailed publication.</u> It should be noted that for combustion vehicles, the incorporation of biofuels in diesel or petrol and of biomethane in CNG (Compressed Natural Gas) is taken into account[2].

Glossary

GHG	Greenhouse Gas
ICEV	Internal Combustion Engine Vehicle
PHEV	Plug-In Hybrid Electric Vehicle
BEV	Battery Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
NGV	Natural Gas for Vehicle
CNG	Compressed Natural Gas

1. From production/extraction to final use in the vehicle.
2. E.g.: for PHEV Diesel, the calculations take into account an increasing percentage of biodiesel over time.

THE PRIZE GOES TO THE BATTERY ELECTRIC VEHICLE

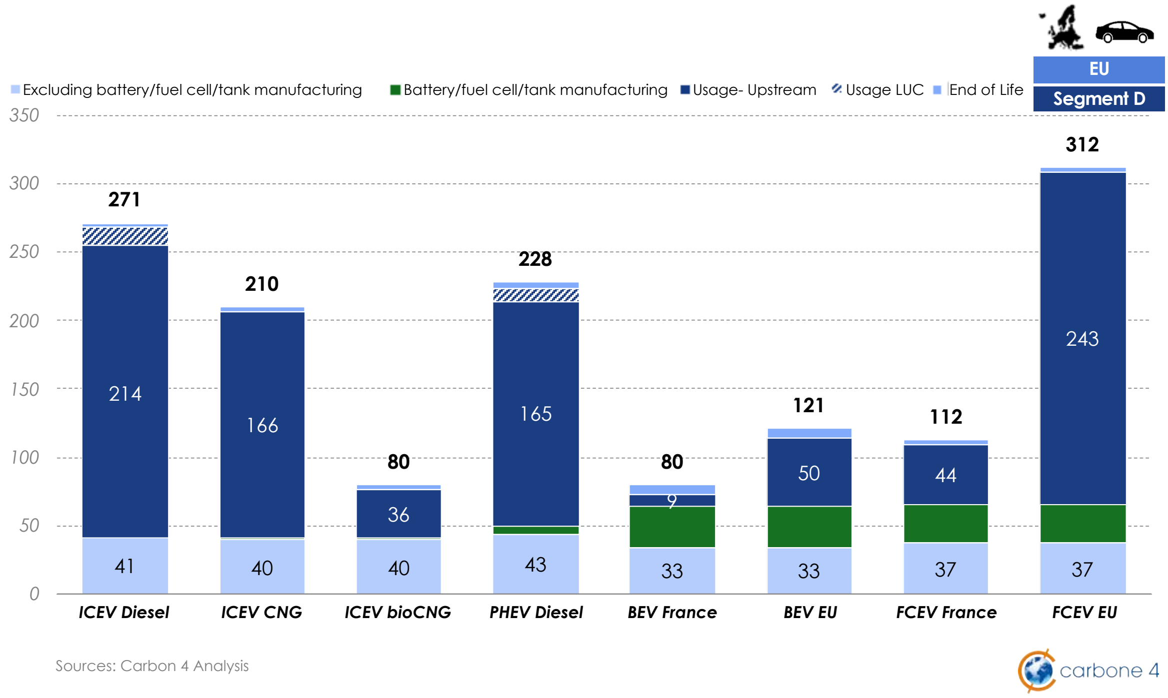

Figure 1 - Average carbon footprint over the lifetime of a car sold in 2020[3]
Europe - Segment D | gCO_2e/km

Considering the carbon footprint of a car sold today over its life cycle, e.g its manufacture in 2020, its use over 12 years and its end of life in 2031 (see **Figure 1**), **the least emitting passenger cars are:**

Battery electric vehicles (BEVs), whatever the electricity mix of the region under consideration

BEVs have a 50-70% reduction in their carbon footprint compared to a fossil-fuelled vehicle, despite the battery's manufacture and recycling. Although a decarbonised electricity mix (for example, France, renewable electricity) provides better performance, a BEV sold today in Germany, or even in Poland, remains less emissive than an equivalent ICEV. This relatively new finding is due to two effects: (i) the mass production of batteries for electromobility has made it possible to significantly reduce their carbon footprint per unit (scale effect), and (ii) the electricity mix of all European countries is gradually being decarbonised.

3. ICEV: Internal Combustion Engine Vehicle; PHEV: Plug-in Hybrid Electric Vehicle; BEV: Battery Electric Vehicle; FCEV: Fuel-Cell Electric Vehicle (electrolysis).

Vehicles using bioNGV (ICEV-BioNGV)

Vehicles running on bioNGV have the lowest carbon footprint, thanks to the very low emission factor of biomethane (44 gCO_2e/kWh[4]) and with the assumption that gas vehicles would be developed with mild hybridisation (as with conventional combustion vehicles). The emission factor of biomethane varies little according to the country of production, and this observation remains valid throughout Europe. However, **the biomethane resource is limited, and it is better to reserve it for other uses for which electricity has its limits, particularly for heavy mobility** (see detailed publication).

It should be noted that **the methanisation production chain has co-benefits that result in avoided emissions** at the level of the waste treatment system or the agricultural system. These co-benefits cannot be transferred to the emission factor of the biomethane produced but are fully recoverable as a contribution to the decarbonisation of the other sectors (see insert in the detailed publication).

Electric vehicles powered by hydrogen (FCEV) produced by electrolysis or biomethane steam reforming, with decarbonised electricity (French grid or renewables)

FCEV has very good results provided that the hydrogen itself is low carbon! If the hydrogen is produced by electrolysis, the electricity must be decarbonised (as in France or with renewable energies). Conversely, production by electrolysis with grid electricity leads to very unfavourable results in countries such as Germany or the Benelux countries. Similarly, if hydrogen is produced by steam reforming, it must be produced with biomethane, which then raises the question of the proper allocation of a limited resource.

The potential for low-carbon hydrogen production will remain low for many years to come, in order to cover a wide range of needs (particularly industrial needs). In the transport sector, this should encourage **giving priority to hydrogen for heavy mobility** (trucks, buses, coaches) where batteries are reaching their limits (required volume, payload, vehicle autonomy and recharging speed), or for special cases of very intensive use with high availability rates, such as some taxis.

In contrast, **ICEV running on NGVs (excluding bioNGV), PHEVs, or even liquid biofuels[5] bring few gains by 2040**; these solutions are not up to the task in terms of the decarbonisation expected for the sector.

4. ENEA-Quantis study for GRDF - Evaluation of the GHG impacts of biomethane injection - March 2020.
5. Direct and indirect land-use changes taken into account in the study, contrary to European regulations to date.

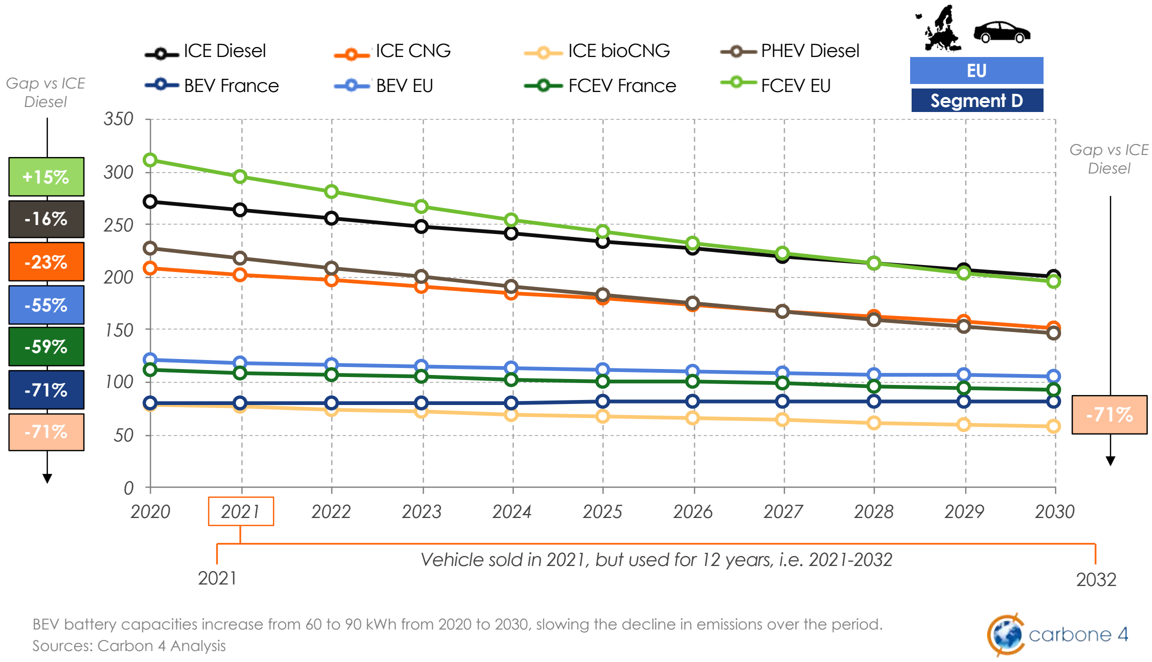

Figure 2 - Average carbon footprint over the lifetime of the vintage under consideration France - Segment D | gCO_2e/km

BEVs, ICEV-bioNGV or FCEVs (with a low carbon H_2) are therefore the 3 theorical alternatives allowing decarbonisation that is compatible with the carbon neutrality objectives within 30 years. For passenger vehicles, the battery solution seems the most relevant: nevertheless, while electricity is not a scarce resource as such, the batteries of electric vehicles are based on mineral resources that are neither infinite nor immediately mobilisable and for which the conditions of extraction can be problematic. **The decarbonisation of the vehicle fleet should therefore be achieved through the widespread electrification of vehicles, but under certain conditions**, such as:

- Encouraging their market penetration by moderating the size of the batteries; in order to reduce the strain on mineral resources and limit costs (having two 50 kWh batteries, rather than a single 100 kWh battery, makes it possible to put 2 BEVs on the road instead of 1, with an autonomy that remains in line with current usage);

- Supporting their dissemination with a more appropriate development of recharging infrastructures and similar services such as mobile recharging (low carbon) on demand.

A FOCUS ON "ZERO EMISSION" VEHICLES

In addition to their climate impact, personal vehicles are also faced with two other major health issues: local air pollution and noise pollution. Electric vehicles (BEVs, FCEVs), known as "zero-emission" vehicles, largely respond[6] to these issues when they replace internal combustion engines (gasoline, diesel and natural gas/biomethane vehicles).

As far as the climate impact is concerned, the expression "zero emissions" is misleading and should be understood as "zero tailpipe emissions". In fact, the life cycle vision clearly shows that the use of these vehicles generates significant GHG emissions, even if they are often lower than those produced by internal combustion vehicles.

The case of the hydrogen used in a FCEV is the most complex, as it can be produced in two different ways (by electrolysis and steam reforming), and in countries with different electrical characteristics.

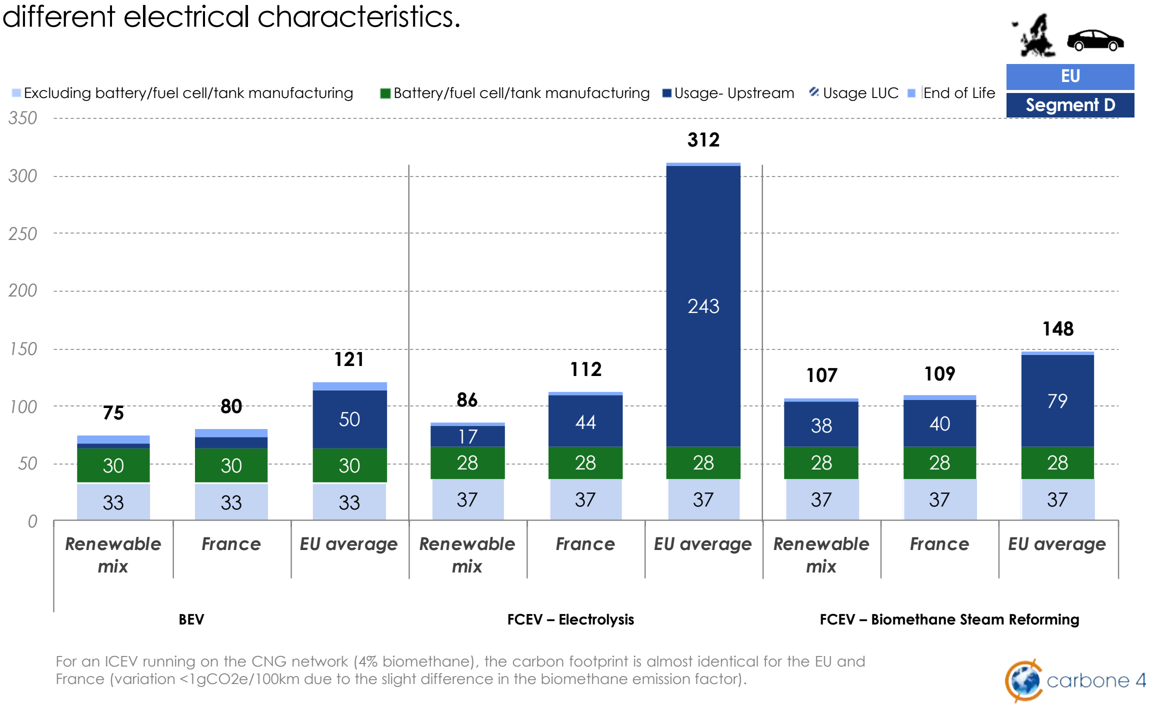

Figure 3 - Comparison of the average carbon footprint over the lifetime of a FCEV. Segment D sold in 2020, in France and Europe | gCO_2e/km

Outside of the French borders, producing hydrogen from the EU's average electricity mix is to be banned for many years to come, because of its higher life-cycle emissions than conventional ICEVs.

Concerning "zero-emission" vehicles, if the average European electricity mix disqualifies electrolysis, and if steam reforming of natural gas from fossil sources remains highly emissive, **biomethane steam reforming, low-carbon electrolysis and battery technology are truly decarbonising solutions.** They make it possible to reduce the carbon footprint by 60-70% compared with diesel vehicles (see **Figure 3**).

6. There is still air pollution for all vehicles, linked to tyre and brake wear, even if it is less for electric motors.

IS THERE STILL A PATHWAY FOR INTERNAL COMBUSTION ENGINES?

In a forward-looking vision, the assumptions used in the central scenario are by nature subject to discussion, and it is legitimate to ask in which framework these conclusions still apply. Two other scenarios based on different sets of assumptions have thus been developed: one more favourable to ICEVs, the other towards greater sobriety in use.

> **"Even in a scenario favourable to internal combustion engine vehicles, the battery-electric vehicle remains less emissive."**

First of all, the prospective vision in 2030 reduces the differences in the emissions between motor vehicles, without changing the conclusions that are visible in 2020 (see **Figure 4**). The mild hybridisation of ICEs makes it possible to make up part of the gap with BEVs, the latter improving more slowly due to the increase in battery capacity which counteracts the gradual decarbonisation of the electricity mix, but this remains small.

Moreover, even in a scenario favourable to thermal vehicles, in which we have deliberately opted for more optimistic assumptions for ICEVs and more pessimistic for BEVs (see details of the assumptions in the detailed publication), there is no inversion of the hierarchy: whatever the type of vehicle, the BEV remains less emissive than the ICE over its life cycle by around -35% on average for the EU, and -50% for France[7] , whether the latter is powered by petroleum fuels or fossil natural gas.

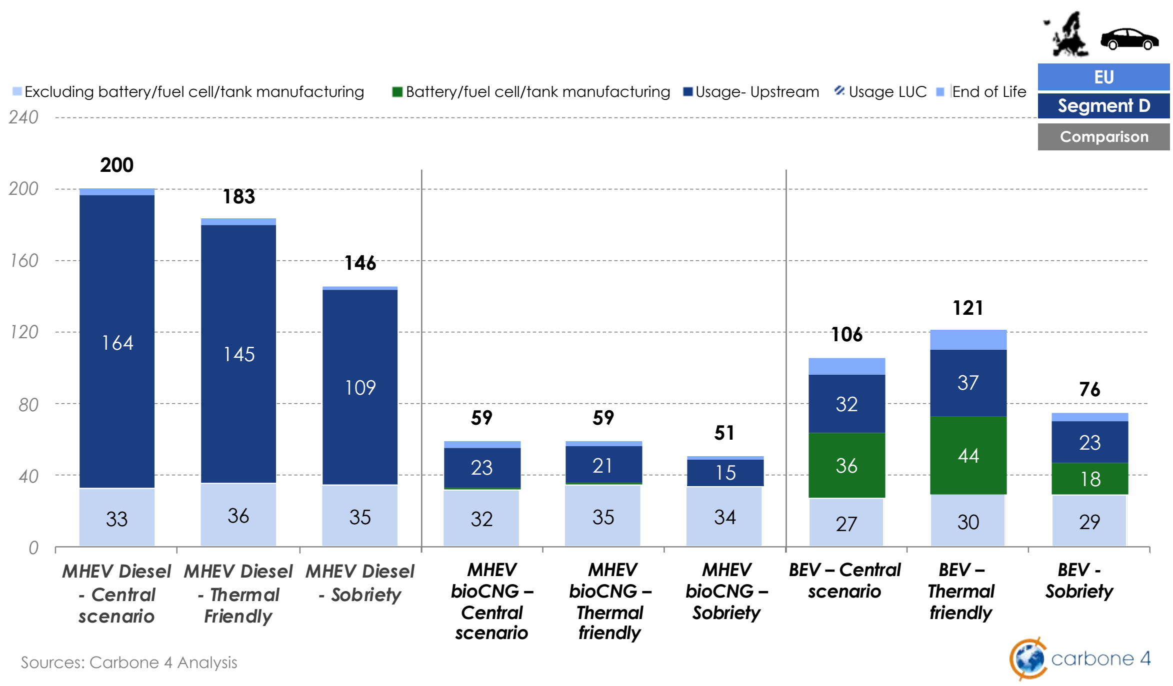

Figure 4 - Comparison of the average carbon footprint over the lifetime of a car sold in 2030; Europe - Segment D | gCO_2e/km

7. Not visible on the graph.

TECHNOLOGY IS NOT THE ONLY LEVER

From the point of view of GHG emissions, battery electrification therefore seems to be the most relevant path towards obtaining low carbon passenger vehicles.

However, the sobriety of use, in the broadest sense of the term, is also an indispensable lever. **Figure 4** shows that **additional gains of the order of 25%, for all vehicle types combined, can be obtained without any technological revolution**, by simply adopting assumptions in the sense of economy of use (e.g. weight reduction, extension of service life and stopping the race for battery capacity).

For example, from a carbon point of view, a high-powered BEV carrying a battery pack of 90 kWh or more (e.g. Audi E-Tron SUV) can generate life-cycle emissions in a country like Germany (Europe's largest automotive market) **comparable to or even higher than a smaller ICEV**. Moreover, even if their production is more CO_2-intensive, lighter materials than steel (such as aluminum, plastics and carbon fibre) help to reduce the overall emissions of combustion vehicles. For example, by substituting steel with 50% aluminium - 50% plastics, the net gain is about 10 gCO_2e/km (i.e. -4%) in the life cycle, for 200 kg less mass, on a segment D.

In light of our analysis, **we therefore recommend that the public authorities reconsider the " ground rules " on the measurement of the CO_2 emissions from new vehicles in Europe** (by considering the life cycle), in order to avoid the alleged incentive rules from being counterproductive and **to encourage sobriety of use with rules that are based on vehicle mass and battery capacity**.

Finally, it is crucial to remember that technology alone will not make it possible to reduce our emissions sufficiently in the coming decades. The alternative solutions studied here have many other impacts that must also be managed. Therefore, it is essential to mention here the other particularly effective reduction levers that already exist and that should be developed alongside:

- Reducing flows at source (number and scope of journeys)
- Better sharing of private vehicles (prevent lone driving), regardless of the type of vehicle
- Encourage a modal shift as much as possible towards more active modes and more carbon-efficient public transport, depending on the situation

TO BE FOUND IN OUR PUBLICATION

All results are not included in this synthesis and that is why we invite you to discover our complete publication on the subject. In particular, you will discover much more about the **factors in favour of or against** each of the alternatives, a **detailed focus** on certain energy carriers (liquid biofuels, biomethane, hydrogen) and **sensitivity analyses** (in particular on mass vs. the carbon footprint of materials). This includes all the **sources and assumptions** used.

It should be noted that this work also covers the case of **professional vehicles** (light-duty vehicles, buses and semi-trailer trucks), which were also examined in our analyses.

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Carbone 4 is the first independent consulting firm specialised in low carbon strategy and adaptation to climate change.

We are constantly on the lookout for weak signals, we deploy a systemic vision of the energy-climate constraint and put all our rigour and creativity to work in transforming our clients into climate challenge leaders.

Within Carbone 4, the Mobility Practice is fully committed to work together with actors concerned by the transformation of the transport sector.

Contact: mobilite@carbone4.com