# Life Cycle Assessment (LCA) 2022

Reducing greenhouse gas emissions is a challenge that road transport must also face. For an objective and appropriate assessment of the various drive technologies, it is essential to consider the fuels and drive energy, including the upstream chains, together with the production and disposal of the vehicles as part of a life cycle assessment (LCA).

The greenhouse gas balance in the production, use and disposal of vehicles and fuels is decisive for the climate impact of various drive technologies. In addition to carbon dioxide (CO2), which is mainly produced by the combustion of fossil fuels, methane emissions (CH4) from gaseous fuels and nitrous oxide (N2O) from the cultivation of biomass are also relevant. By-products arising from production processes must also be taken into account, for example when press cake from the processing of rapeseed replaces soy-based concentrated feed in livestock farming.

The term CO2 equivalent (CO2eq) is used to summarise the greenhouse-effective gases carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O), also known as laughing gas, according to their respective climate impact compared to carbon dioxide.

In addition to the greenhouse gases, however, the primary energy demand that must ultimately be made available for a drive technology must also always be considered. The primary energy demand describes the amount of energy, such as crude oil, natural gas, wind and sun, that must be extracted from nature in order to operate a vehicle.

## LCA tool

In order to be able to draw up a comparison of the greenhouse gas balance as well as the primary energy demand of different types of drive and fuel, also with regard to future developments, FIA and ÖAMTC commissioned a so-called "LCA tool" from the JOANNEUM RESEARCH in Graz in 2018. The project was also supported by ADAC and TCS.

An initial evaluation via the "LCA tool" on the part of ADAC was carried out in 2019 and published in the club magazine Motorwelt, September 2019 issue.

As there have been significant changes in the background data (electricity mix, locations of battery production, battery lifetime, etc.) in the meantime, the "LCA Tool" was updated by JOANNEUM RESEARCH on behalf of FIA. The current version now contains a total of 157 transport systems for an average compact class passenger car ("Golf class"), which can be analysed for the years 2022, 2030 and 2050. The tool contains pre-set "default data" for the calculations, but also allows calculations based on own data.

The "LCA tool" also serves as the basis for calculating the estimated greenhouse gas emissions and primary energy demand over the entire life cycle for the cars tested as part of Green NCAP assessment programme since 2019. For comparative purposes, a vehicle lifetime of 16 years and a total mileage of 240,000 km is assumed here. The calculations are based on the current forecast of the changing average energy mix of the EU states. Further information at European Life Cycle Assessment Results & Fact Sheets (greenncap.com)

Parallel to the "LCA tool", an "interactive LCA platform" was developed, with the help of which consumers can make independent comparisons of existing car models with regard to their LCA by integrating the ADAC car database. For more details, see the chapter "Interactive LCA platform".

Note: Since every LCA is based on certain assumptions and, especially regarding vehicle production, not all manufacturer- and model-specific criteria can be recorded and mapped, the individual LCA results should always be regarded as indicative. This also applies when comparing different drive technologies.

## Comparison of different types of drive on the basis of the "Golf class"

With the help of the LCA tool, different drive types are compared with each other in terms of their LCA balance. For the current comparison, common drive types with combustion engine (petrol E10, diesel B7, natural gas (fossil natural gas, 100 % bio-methane), plug-in hybrid drive (petrol E10/electricity mix Germany, petrol E10/electricity regenerative (wind)), electric drive (electricity mix Germany, electricity regenerative (wind)), fuel cell (hydrogen from natural gas steam reforming, hydrogen regenerative (wind)) and e-fuel from FT (Fischer-Tropsch) diesel ($CO_2$ air/$H_2$ wind, $CO_2$ biomass/$H_2$ wind) were selected.

## Comparison vehicles of the "Golf class"

The comparison of the different types of drive is based on the following data for the comparison vehicles.

| **Table 1: Comparison vehicles of the "Golf class" – assumptions** | | | | |
|---|---|---|---|---|
| **Fuel/electricity/energy consumption *** | | | | |
| | Fuel consumption | | Electricity consumption | Total energy consumption |
| | [l/100 km] | [kg/100 km] | [kWh/100 km] | [kWh/km] |
| **Petrol (E10)** | 7.3 | | | 0.62 |
| **Diesel (B7)** | 5.4 | | | 0.53 |
| **Natural gas/ bio-methane** | | 4.5 | | 0.63 |
| **Plug-in hybrid ** (petrol E10/ electricity)** | 3.2 | | 11.0 | 0.38 |
| **Fuel cell ($H_2$)** | | 1.0 | | 0.34 |
| **Electric (electricity)** | | | 19.0 | 0.19 |
| **E-Fuel (FT diesel)** | 5.1 | | | 0.50 |
| **Basic assumptions for all drive types** | | | | |
| **Annual mileage** | | | [km/a] | 15,000 |
| **Vehicle life** | | | [a] | 16 |
| **Engine power** | | | [kW] | 90 |
| **Additional assumptions for electric cars** | | | | |
| **Battery capacity** | | | [kWh] | 55 |
| **Battery life ***** | | | [km] | 240,000 |

**Notes:**

*) The assumed consumption values correspond to an average fuel/electricity consumption of the various drive types in the "Golf class". A higher calorific value and better fuel quality were assumed for e-fuel (FT diesel), which means that slightly lower consumption can be assumed compared to conventional diesel (B7).

**) For the plug-in hybrid, it is assumed that about 30 % of the kilometres are driven purely electrically.

***) The battery life of electric cars is set equal to the total life of the vehicle based on the experience of the last few years. Battery replacement is not taken into account.

## Further assumptions on LCA

The following assumptions were also made for the calculation of the LCA.

### Electricity mix

The electricity mix used for 2022 corresponds to the value of the average greenhouse gas emissions ($CO_2$eq) per unit of energy of the electricity taken from the grid for use in road vehicles with electric drives as determined by the Federal Environment Agency (UBA) (source: BAnz AT 28.10.2021 B10). The expected steady improvement in the electricity mix due to the expansion of renewable electricity sources over the life of the vehicle – i.e. until 2037 – was taken into account on a linear basis**.** This is based on projections by IINAS for 2030 and 2050 (source: short study "Der nichterneuerbare kumulierte Energieverbrauch und Treibhausgas-Emissionen des deutschen Strommixes im Jahre 2020 sowie Ausblicke auf 2030 und 2050", Nov. 2021).

**Table 2: Electricity mix Germany**

| Reference year | CO2eq [g/kWh] |
|---|---|
| **2022** | 428 |
| **2030** | 268 |
| **2050** | 32 |

### Renewable electricity

Wind energy was used as a representative of the renewable electricity sources. Electric propulsion with electricity from photovoltaic systems is in the comparable numerical range.

### Fuel/energy supply

Synthetic or biogenic fuels are considered "$CO_2$ -neutral" because the CO2 emitted during combustion in driving operation was removed from the atmosphere directly during fuel production (e.g. e-fuel) or via plant growth (e.g. bio-methane). In the balance sheet, therefore, the CO2 pollution of the atmosphere does not increase because the CO2 emitted by the vehicle has already been removed from the atmosphere, and the "CO2 cycle" is thus considered to be "closed" or "CO2-neutral".

These fuels are accounted for with CO2 during operation, and in return receive corresponding credits for fuel/energy supply. Credits are shown as negative values in diagrams.

### Disposal (End-of-Life)

For disposal, it is assumed that certain materials (mix steel, aluminium, copper) are recycled with a recycling rate of 60% and secondary raw materials are produced. This replaces primary metal raw materials and avoids greenhouse gas emissions that would occur during extraction and production. This credit is slightly higher for electric cars - because of the battery - than the expense of car disposal. For conventional vehicles, the gain from recycling raw materials almost offsets the expense of disposal. In addition, it is assumed for the battery of the electric car that some batteries will continue to be used in stationary use ("second life"), which means that the greenhouse gas emissions from battery production are divided between automotive and stationary use. Overall, however, the share of batteries that are reused was assumed to be 3%, whereas 97% are recycled. Credits are shown as negative values in the diagrams.

### Further background data

Information on the other background data of the LCA tool is summarised in a report. This is available at Life Cycle Assessment Methodology and Data - 2nd edition (greenncap.com)

## LCA balance of common drive types in the "Golf class"

The following figures show the LCA balance of the currently common types of drive with combustion engine (petrol E10, diesel B7, natural gas (fossil natural gas, 100 % bio-methane), plug-in hybrid drive (petrol E10/electricity mix Germany, petrol E10/electricity regenerative (wind)), electric drive (electricity mix Germany, electricity regenerative (wind)) and fuel cell (hydrogen from natural gas steam reforming, hydrogen regenerative (wind)).

The evaluations show that currently in the "Golf class" the electric vehicle has a good greenhouse gas balance when using the German electricity mix (operation 2022-2037). Its greenhouse gas emissions over the entire life cycle are lower than those of vehicles with internal combustion engines, including plug-in hybrids using fossil fuels (including blending of biofuels), and lower than those of fuel cell vehicles powered by hydrogen from steam reforming. The plug-in hybrid as a combination of a petrol engine and electric motor achieves a significant improvement with the application of the electricity mix for Germany (2022-2037) compared to the conventional petrol engine. A prerequisite for this, however, is the regular charging of the battery for the use of the electric drive (assumption here: 30 % of the kilometres are driven purely electrically).

When using renewable energy sources, the electric car shows the best greenhouse gas balance, closely followed by the fuel cell vehicle powered by "green" hydrogen. The balance of the natural gas vehicle also improves significantly when bio-methane is used, as does the balance of the plug-in hybrid vehicle when renewable electricity is used.

**Table 3: Greenhouse gas emissions CO2eq (g/km) – "Golf class" (total mileage: 240,000 km)**

| CO2eq (g/km) | Diesel B7 | Petrol E10 | Natural gas | Bio-methane | Plug-in hybrid (Petrol E10, Electricity mix D) | Plug-in hybrid (Petrol E10, Wind) | Electric (Electricity mix D) | Electric (Wind) | Fuel cell (H2 Steam reforming) | Fuel cell (H2 Wind) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Production vehicle** | 37 | 35 | 35 | 35 | 37 | 37 | 39 | 39 | 38 | 38 |
| **Production battery** | 0.5 | 0.5 | 0.5 | 0.5 | 3 | 3 | 19 | 19 | 0.7 | 0.7 |
| **Production fuel cell + hydrogen tank** | - | - | - | - | - | - | - | - | 15 | 15 |
| **Maintenance** | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **End-of-Life** | -5 | -4 | -4 | -4 | -5 | -5 | -7 | -7 | -5 | -5 |
| **Vehicle use + energy supply** | 169 | 206 | 155 | 66 | 123 | 92 | 57 | 4 | 124 | 12 |
| **Total** | 209 | 244 | 193 | 104 | 166 | 135 | 115 | 62 | 179 | 67 |

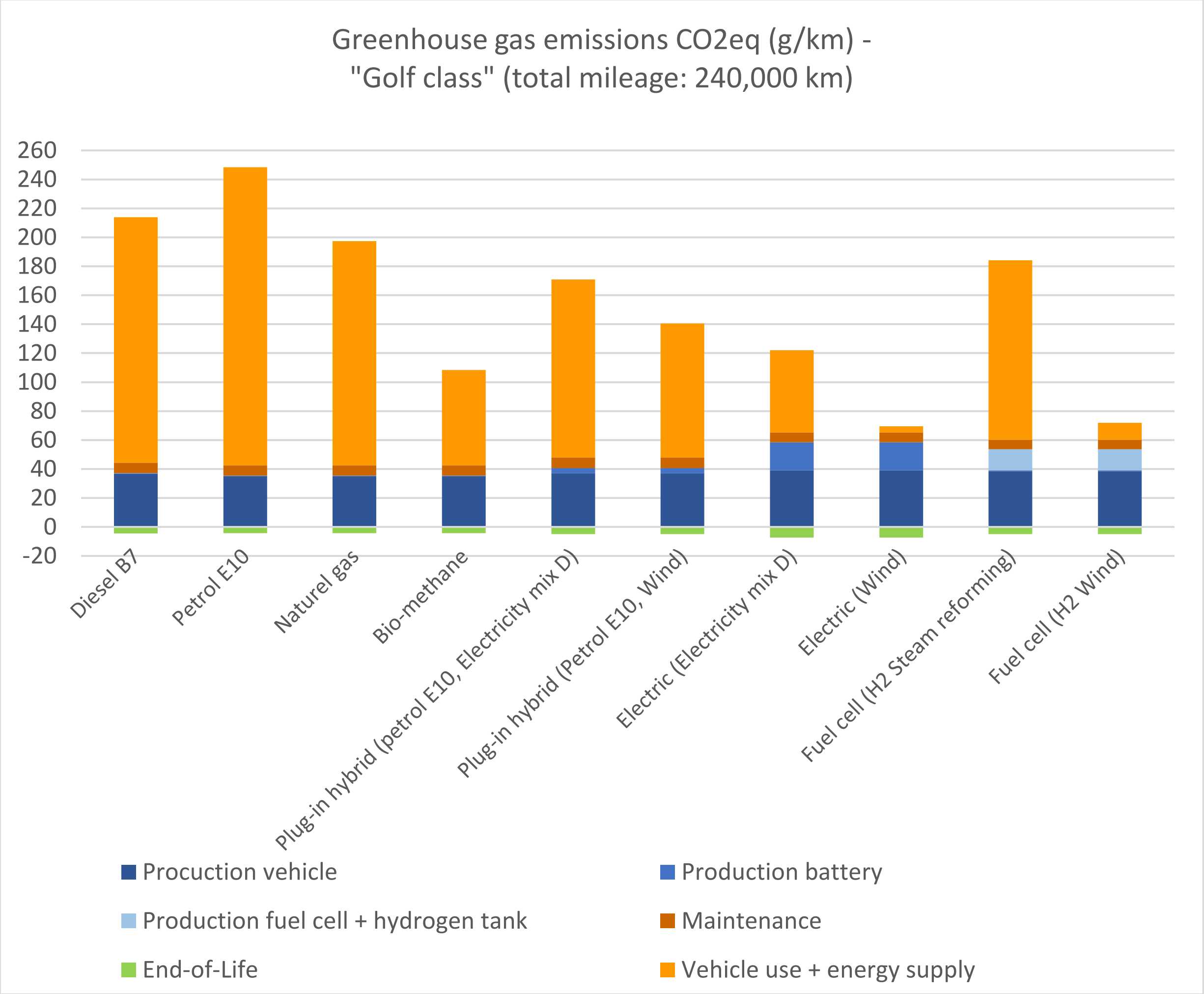

Figure 1: Greenhouse gas emissions CO2eq (g/km) of current drive types – "Golf class" (total mileage: 240,000 km)

In Table 3 and Figure 1, the CO2eq emissions of vehicle use and energy supply are presented together. The separate presentation is shown in Table 4 and Figure 2. This means that the credits (as negative values) for biogenic (e.g. bio-methane) and synthetic fuels (e.g. e-fuel) are shown separately for energy supply or deducted for diesel B7 and petrol E10.

**Table 4: Greenhouse gas emissions vehicle use/energy supply CO2eq (g/km) – "Golf class" (total mileage: 240,000 km)**

| CO2eq (g/km) | Diesel B7 | Petrol E10 | Natural gas | Bio-methane | Plug-in hybrid (Petrol E10, Electricity mix D) | Plug-in hybrid (Petrol E10, Wind) | Electric (Electricity mix D) | Electric (Wind) | Fuel cell (H2 Steam reforming) | Fuel cell (H2 Wind) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Fuel/energy supply** | 26 | 42 | 27 | -62 | 51 | 21 | 57 | 4 | 124 | 12 |
| **Vehicle use** | 143 | 164 | 128 | 128 | 72 | 72 | 0 | 0 | 0 | 0 |

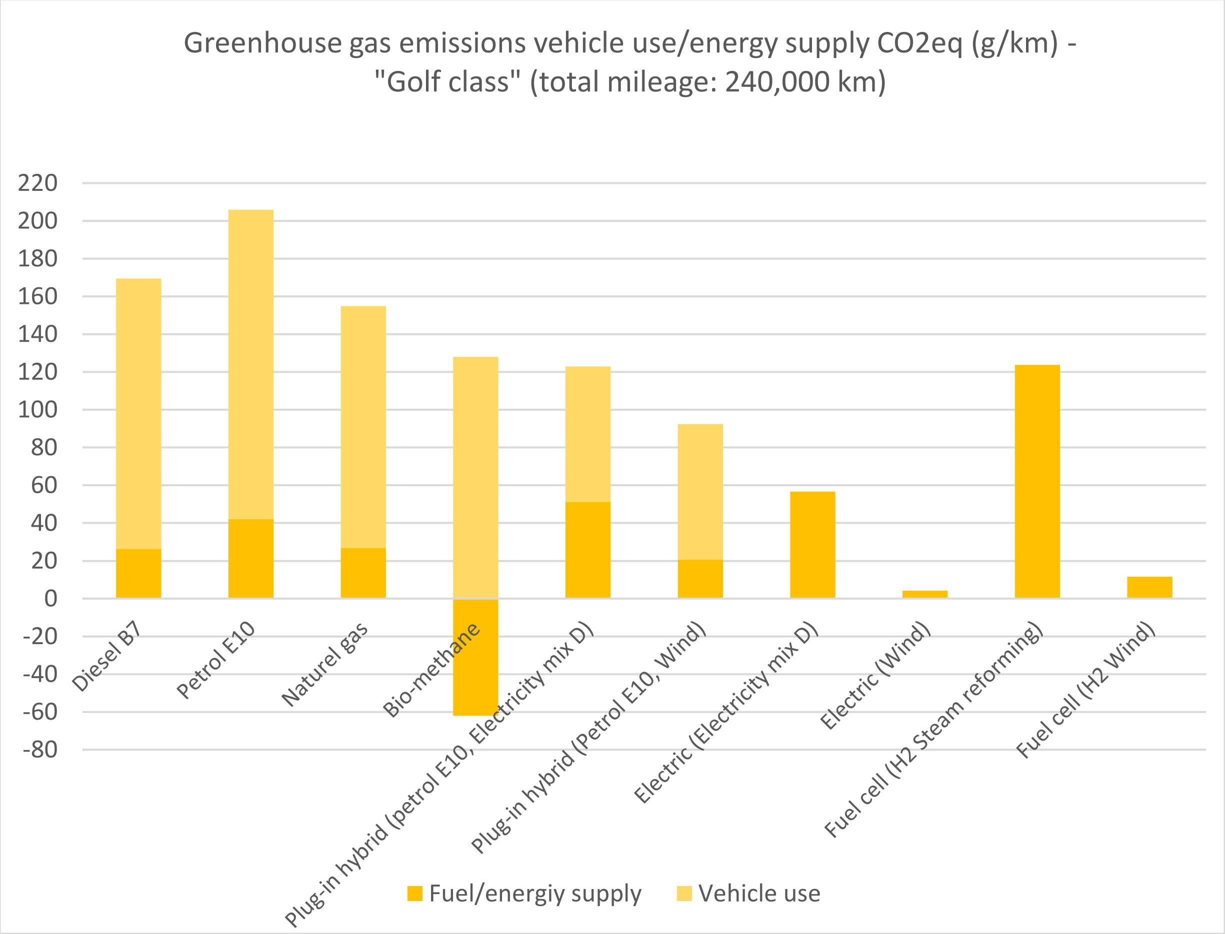

Figure 2: Greenhouse gas emissions vehicle use/energy supply CO2eq (g/km) of current drive types – „Golf class" (total mileage: 240,000 km)

## When will e-cars be more climate-friendly?

Figure 3 shows the greenhouse gas emissions of current drive types in the "Golf class" over the vehicle's lifetime (total mileage: 240,000 km (16 years, à 15,000 km)).

Compared to petrol E10 and diesel B7, the electric car running on German electricity mix can show its advantages after about 45,000 to 60,000 km. The more costly production of the batteries, which entails a larger "greenhouse gas backpack", can thus be amortised relatively quickly over the time of the vehicle's use.

When using renewable electricity (wind), the amortisation of the higher greenhouse gas emissions from production already takes place after about 25,000 to 30,000 km compared to petrol or diesel vehicles.

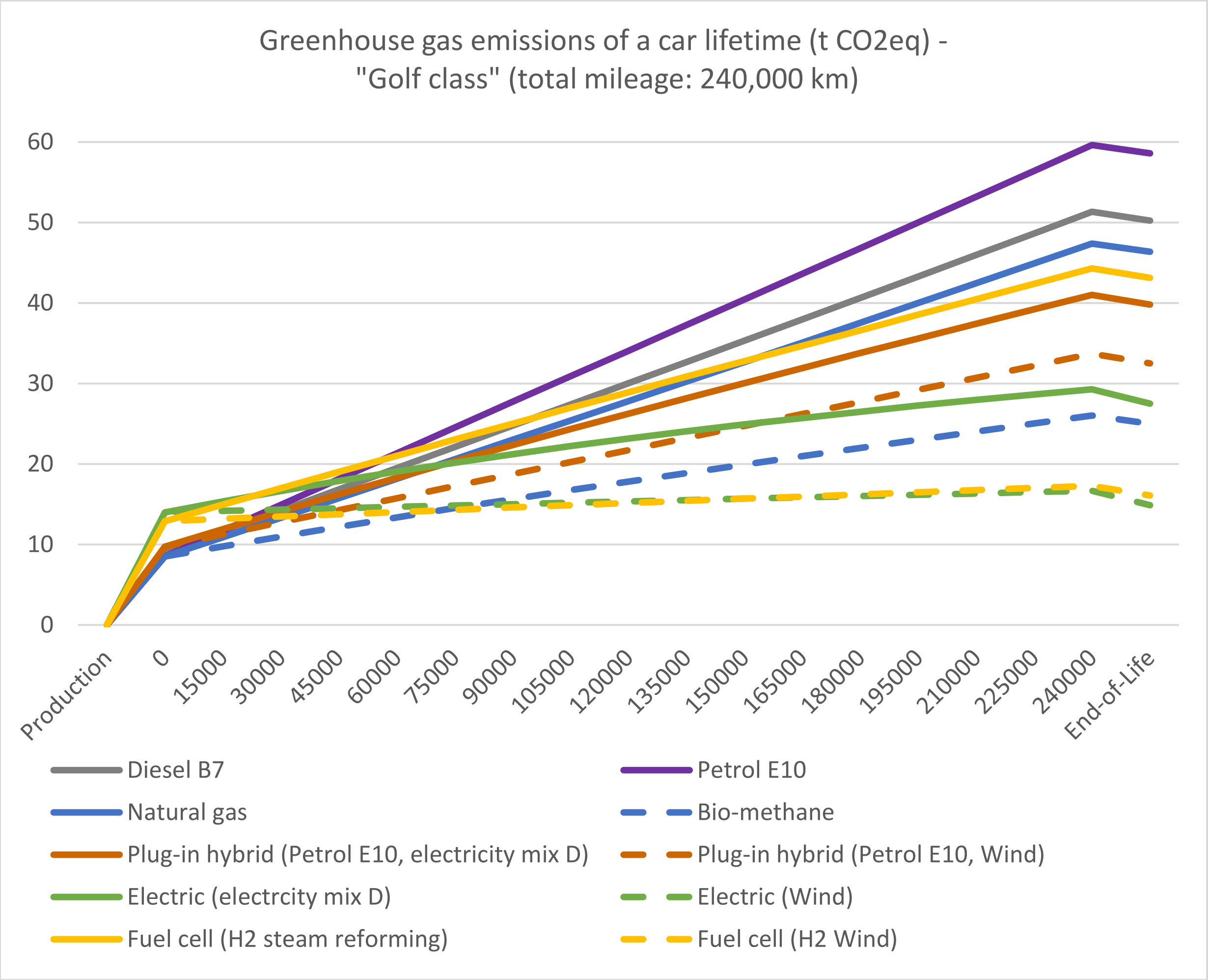

Figure 3: Greenhouse gas emissions of a car's lifetime CO2eq (t) of current drive types – "Golf class" (total mileage: 240,000 km (16 years à 15,000 km))

## Future drive types/fuels: In addition to the greenhouse gas balance, the primary energy demand is also decisive

In addition to the electric car, the fuel cell with hydrogen as fuel and synthetic fuels, so-called e-fuels, for combustion engines are also being discussed as future drive options. E-fuels have the advantage that they can also be used in existing vehicles. However, e-fuels are only in the development phase and are not yet available on the market.

Figure 4 and Table 5 show the greenhouse gas balance of the drive types electric, hydrogen and e-fuels; for comparison, the conventional diesel vehicle is also shown. FT diesel with hydrogen from wind power and CO2 from the atmosphere and FT diesel with hydrogen from wind power and CO2 from biomass were used as representatives of the e-fuels.

It can be seen that in addition to the electric car with regenerative electricity and the fuel cell vehicle with hydrogen from regenerative sources, e-fuels can also have a good greenhouse gas balance. Compared to conventional diesel (B7), all of them have a very high potential for reducing greenhouse gas emissions.

**Table 5: Greenhouse gas emissions CO2eq (g/km) – "Golf class" (total mileage: 240,000 km)**

| **CO2eq/km** | **Diesel B7** | **Electric (Electricity mix D)** | **Electric Wind)** | **Fuel cell (H2 Steam reforming)** | **Fuel cell (H2 Wind)** | **E-Fuel Diesel (CO2 Air, H2 Wind)** | **E-Fuel Diesel (CO2 Biomass, H2 Wind)** |
|---|---|---|---|---|---|---|---|
| **Production vehicle** | 37 | 39 | 39 | 38 | 38 | 37 | 37 |
| **Production battery** | 0.5 | 19 | 19 | 0.7 | 0.7 | 0.5 | 0.5 |
| **Production fuel cell + hydrogen tank** | - | - | - | 15 | 15 | - | - |
| **Maintenance** | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **End-of-Life** | -5 | -7 | -7 | -5 | -5 | -5 | -5 |
| **Vehicle use + energy supply** | 169 | 57 | 4 | 124 | 12 | 38 | 26 |
| **Total** | 209 | 115 | 62 | 179 | 67 | 77 | 66 |

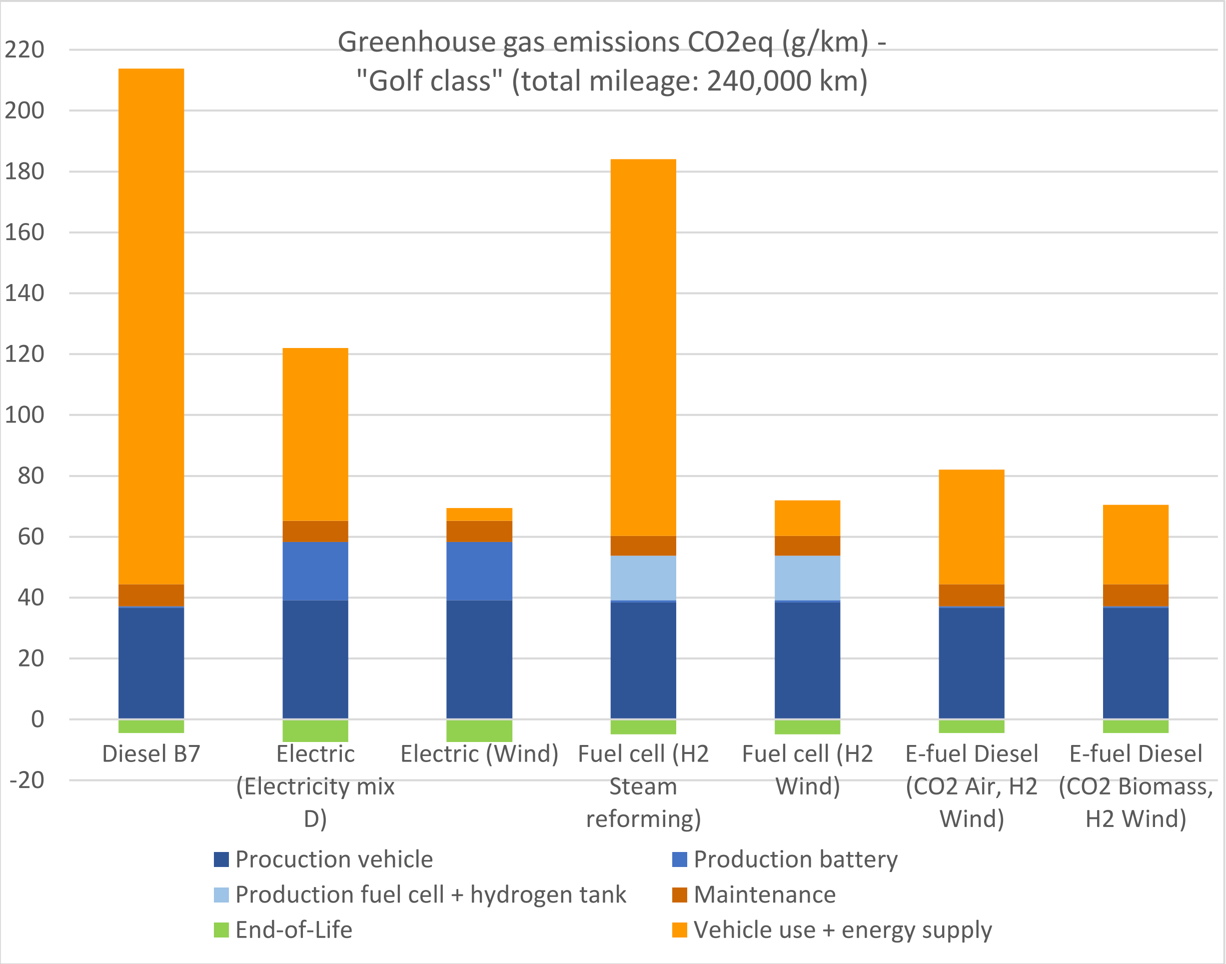

Figure 4: Greenhouse gas emissions CO2eq (g/km) of new drive types – "Golf class" (total mileage: 240,000 km)

In Table 5 and Figure 4, the CO2eq emissions of vehicle use and energy supply are presented together. The separate presentation is shown in Table 6 and Figure 5. This means that the credits (as negative values) for biogenic (e.g. bio-methane) and synthetic fuels (e.g. e-fuel) are shown separately for energy supply or deducted for diesel B7 and petrol E10.

**Table 6: Greenhouse gas emissions vehicle use/energy supply CO2eq (g/km) – "Golf class" (total mileage: 240,000 km)**

| CO2eq/km | Diesel B7 | Electric (Electricity mix D) | Electric Wind) | Fuel cell (H2 Steam reforming) | Fuel cell (H2 Wind) | E-Fuel Diesel (CO2 Air, H2 Wind) | E-Fuel Diesel (CO2 Biomass, H2 Wind) |
|---|---|---|---|---|---|---|---|
| **Fuel/energy supply** | 26 | 57 | 4 | 124 | 12 | -103 | -115 |
| **Vehicle use** | 143 | 0 | 0 | 0 | 0 | 141 | 141 |

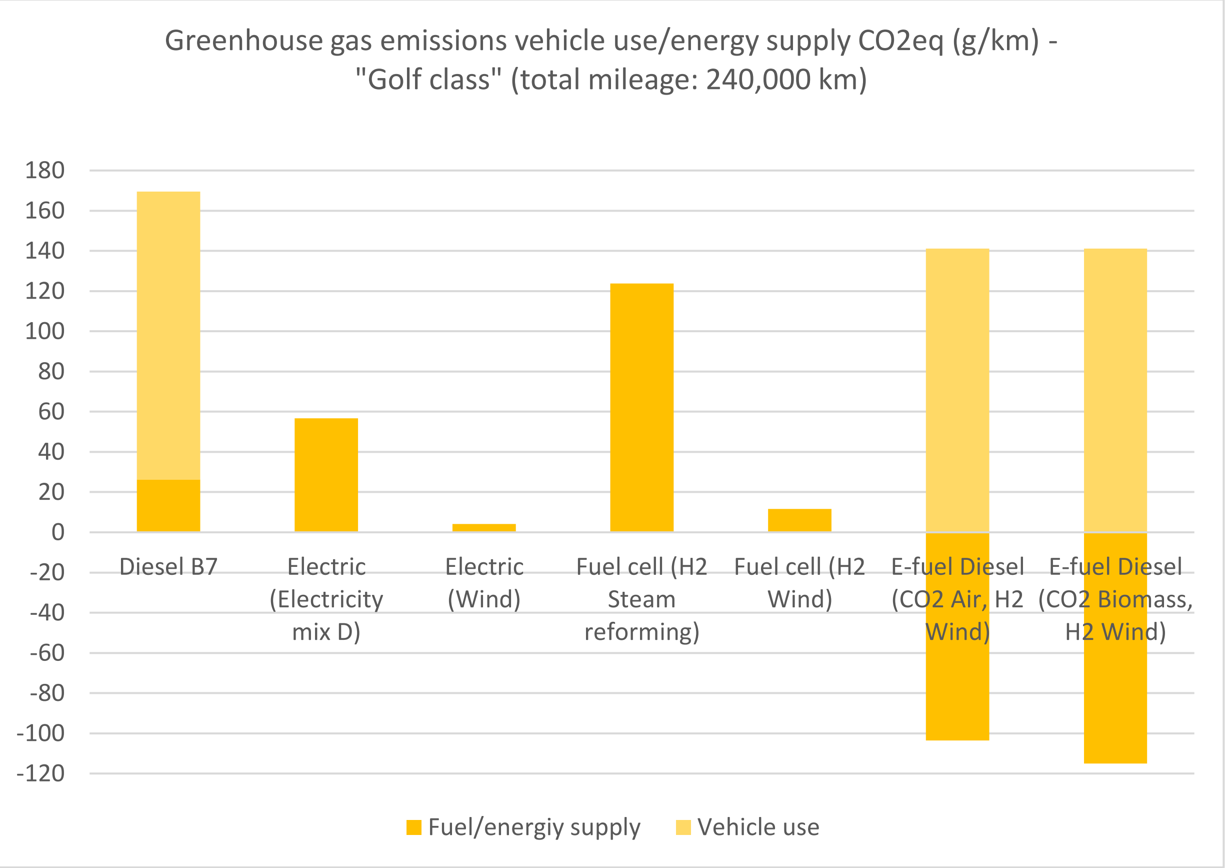

Figure 5: Greenhouse gas emissions vehicle use/energy supply CO2eq (g/km) of new drive types – "Golf class" (total mileage: 240,000 km)

In addition to the greenhouse gas balance, however, the primary energy demand of a type of drive or fuel must always be considered, and the share of renewable energy (wind, sun, water, biomass) must also be specified. Here, it becomes clear that in some cases considerably more energy has to be used to cover the same total mileage.

The current evaluations showed that the electric car is clearly ahead of the fuel cell vehicle and e-fuels in terms of primary demand, especially when renewable energy (wind) is used. This is especially true when the charging current is generated at exactly the same time as the consumer. If, with an increasing share of renewable electricity generation, intermediate storage of the electricity is necessary, there will also be unavoidable conversion processes in battery-electric electromobility that reduce the overall energy efficiency.

The main disadvantage of e-fuels is their poorer efficiency due to losses in conversion processes compared to electricity for battery-electric mobility and the higher demand for renewable energy in production. Therefore, it is important to produce e-fuels in regions of the world where sun and wind are more continuously and intensively available.

Further information on e-fuels can also be found in the current ADAC test: How environmentally friendly are e-fuels? | ADAC

**Table 7: Primary energy demand (kWh/km) – "Golf class" (total mileage: 240,000 km)**

| kWh/km | Diesel B7 | Electric (Electricity mix D) | Electric (Wind) | Fuel cell ($H_2$ steam reforming) | Fuel cell ($H_2$ Wind) | E-Fuel Diesel ($CO_2$ Air, $H_2$ Wind) | E-Fuel Diesel ($CO_2$ Biomass, $H_2$ Wind) |
|---|---|---|---|---|---|---|---|
| **Production vehicle** | 0.14 | 0.15 | 0.15 | 0.15 | 0.15 | 0.14 | 0.14 |
| **Production battery** | <0.005 | 0.09 | 0.09 | <0.005 | <0.005 | <0.005 | <0.005 |
| **Production fuel cell + hydrogen tank** | - | - | - | 0.07 | 0.07 | - | - |
| **Maintenance** | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 |
| **End-of-Life** | -0.02 | -0.03 | -0.03 | -0.02 | -0.02 | -0.02 | -0.02 |
| **Fuel/energy supply** | 0.67 | 0.36 | 0.21 | 0.62 | 0.57 | 1.58 | 1.11 |
| **Total** | 0.83 | 0.59 | 0.44 | 0.84 | 0.79 | 1.74 | 1.26 |
| **Share of renewable primary energy (%)** | 10 | 49 | 88 | 6 | 94 | 96 | 94 |

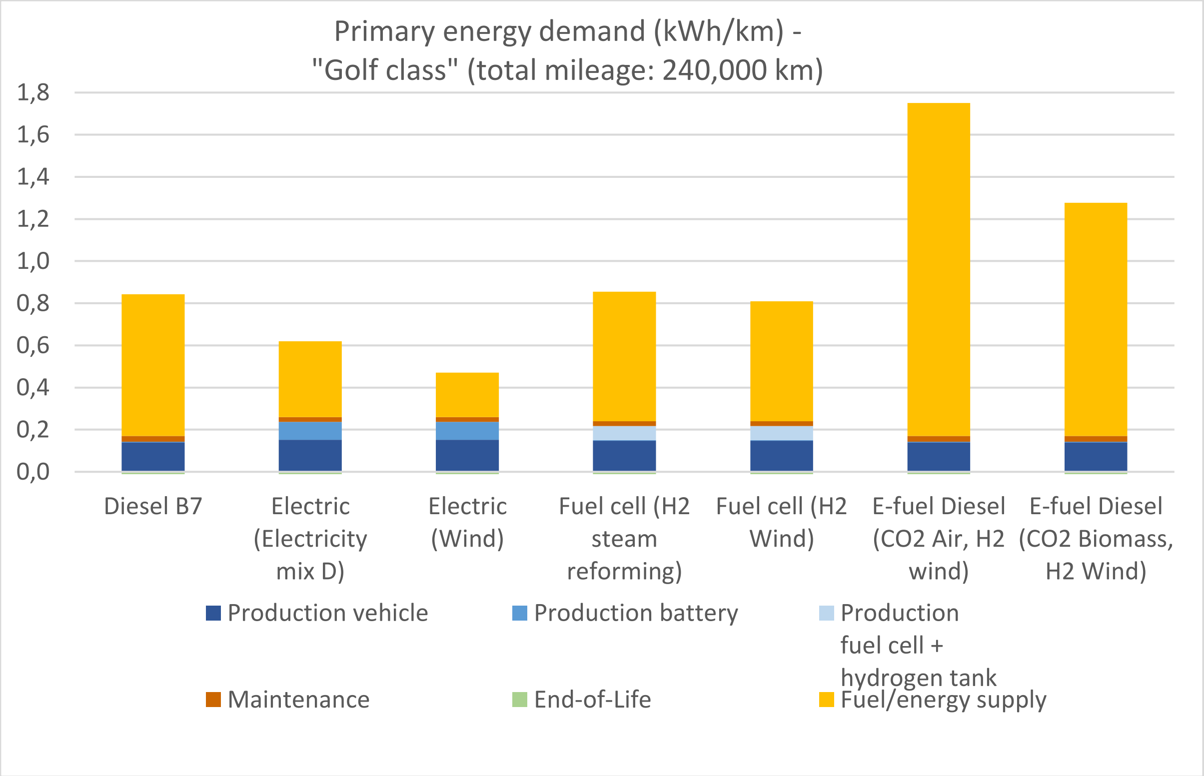

Figure 6: Primary energy demand (kWh/km) of new drive types – "Golf class" (total mileage: 240,000 km)

## Conclusion

The following basic conclusions can be derived from the current LCA study:

- Production of energy-intensive materials (steel, copper, battery components) must increasingly be done with renewable energies from additional regenerative sources: In principle, the greenhouse gas balance of a vehicle can be improved by using renewable energies in its production.
- Expansion of renewable sources for electricity generation and adaptation of supply networks is necessary: The use of renewable electricity shows a significant improvement in the greenhouse gas balance of electric vehicles. The expansion of renewable sources in electricity generation to create a sufficient supply of renewably generated energy, as well as adapted supply networks, are imperative.
- Conventional drives not at the end: The positive performance of the natural gas vehicle with biomethane shows how good conventional drives can be in the greenhouse gas balance. Synthetic fuels produced from renewable sources – such as electricity generated from renewable sources, so-called e-fuels – can also make a contribution to climate protection and can be used in combustion engines. However, their disadvantages include poorer efficiency due to losses in conversion processes compared to electricity for battery-electric mobility and the higher demand for renewable energy in fuel production. Imports from sun- and wind-rich regions of the world can reduce the cost disadvantage of the higher energy input and more costly production.
- Technology-neutral climate protection funding is needed**:** Funding instruments to reduce greenhouse gas emissions from passenger car transport should be technology-neutral.

## Interactive LCA platform

Based on the "LCA tool" developed by JOANNEUM RESEARCH, an interactive LCA platform was developed in cooperation with Green NCAP, which offers consumers the opportunity to understand the actual environmental impact of a vehicle throughout its entire life cycle.

With the help of the platform, consumers can determine the energy demand and greenhouse gas emissions of a vehicle over its entire life cycle and compare different models and drive types. The comparison parameters can be adapted to local and personal circumstances, including annual mileage and electricity mix. Depending on needs and conditions, up to three vehicle models can be compared. The platform also offers the possibility to examine the ecological footprint of an electric car in different European countries and shows the advantages of a higher share of renewable electricity.

Through the connection to the ADAC car database, the interactive LCA platform draws on a large database with over 30,000 models for which an individual LCA can be calculated. For vehicles tested by Green NCAP, the LCA can additionally be shown on the basis of more realistic, measured, fuel and/or energy consumption values.

Aimed at consumers considering the sustainability of their vehicle in the context of where they live and how they will use it in the long term, but also at scientists, industry and legislators, the interactive platform represents a real step towards global environmental awareness of climate-damaging emissions and the life-cycle energy required to produce environmentally friendly and sustainable vehicles.

This created the basis for mapping the LCA for future legal requirements as well.

The German version of the interactive LCA platform is available at Lebenszyklusanalyse (Life Cycle Assessment, LCA) (greenncap.com)

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ADAC e.V.
Test and technology
81360 Munich
E-mail tet@adac.de
www.adac.de