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Expert Notification

On Estimating GHG Emissions and Primary Energy of Vehicles Tested in Green NCAP - LCA Methodology and Data

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Acknowledgement - This document was prepared by Dr. Gerfried Jungmeier from JOANNEUM RESEARCH, to further clarify, and as an addendum to provide further clarifications on the methodology paper published in April 2022. Both documents have been delivered under contract of FIA (Fédération Internationale de l'Automobile) and ÖAMTC (Österreichischer Automobil-, Motorrad- und Touring Club).

The PAUL SCHERRER INSTITUTE (PSI) in Switzerland reviewed the methodology, basic data and some draft results [Bauer 2022] of the LCA Expert Tool 2.1 [Jungmeier et al. 2022]. The recommendations of the review were largely taken into account in the revised and published versions of the methodology report and of the LCA Expert Tool 2.1.

Green NCAP is a consortium of public and private organisations, which include governmental authorities, mobility clubs, consumer organisations and test centres. Green NCAP provides independent consumer information, and does not represent the interests of the vehicle industry, component suppliers, oil and gas industry or environmental agencies.

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The goal of the Life Cycle Assessment (LCA) was to estimate the greenhouse gas emissions and the primary energy demand of the sixty-one vehicles previously assessed and documented by Green NCAP (www.greenncap.com), using their intensive laboratory and real-world test procedures (e.g. fuel/electricity consumption under different test and ambient conditions). The ICE (Internal Combustion Engine) vehicles are tested with petrol E10 and diesel B7. The Life Cycle Assessment was done for generic global supply chains of vehicle production and energy supply in Europe between 2021 and 2037. The lifetime millage of the vehicles was set to 240,000 km in 16 years. The main focus is to estimate significant differences between the vehicles and its main influencing parameters of propulsion system, fuel, energy consumption, vehicle weight, battery capacity, CH_4- and N_2O- emissions from vehicles equipped with an ICE.

The methodology and data used for the LCA are documented by JOANNEUM RESEARCH and the documentation is available on the Green NCAP webpage. *“Estimated Greenhouse Gas Emissions and Primary Energy Demand of Passenger Vehicles Tested in Green NCAP: Life Cycle Assessment: Methodology and Data”.*

The aim of this expert notification is to

- notify an incorrect data interface on battery density in a previous version leading to overestimate the GHG emissions of electric vehicle production (BEV and PHEV) and
- revisit the most common misunderstandings or misinterpretations, in order to rectify incorrect claims, made in (social) media.

CLARIFICATION ON DATA INTERFACE ISSUE

The data of the 61 tested vehicles were exchanged between Green NCAP and JOANNEUM RESEARCH by means of an electronic data interface. In that data interface, an issue on the battery energy density came up after the publication of the results, which was not realised by the partners before. This data interface issue led to an overestimation of the weight of the electric vehicles. This incorrect weight led mainly to overestimated GHG emissions and primary energy demand for the production of the electric vehicles. Additionally this led also to minor effects on maintenance and end-of-life. In total 13 vehicles from the 61 considered vehicle were affected by this issue - 7 battery electric (BEV), 5 plug-in-hybrids (PHEV) and 1 hydrogen fuel-cell (HFCV). BEV with a high battery capacity were affected most.

We apologize for this incorrect calculation and any inconvenience this may have caused.

The battery density was corrected as soon as it was detected and its effect on GHG emissions for the vehicle production (incl. battery) is shown for three examples in Table 1.

Table 1: Comparison of new results of GHG emissions from production of selected vehicles

		Lexus UX300e			**VW ID.3 (58 kWh)**			**VW Golf 1.5 TSI**
battery capacity	[kWh]	54.3			58			petrol
vehicle weight	[kg]		1,801			1,763		1,269
		old	**new**	dif.	old	**new**	dif.	no change
vehicle production								
	[t CO_2-eq]							
	total	20.3	**17.5**	-14%	20.4	**17.4**	-15%	8.5
	battery	6.5	**6.5**	0%	6.9	**6.9**	0%	0.0
	rest of vehicle	13.8	**11.0**	-20%	13.5	**10.5**	-22%	8.5
	[g CO_2-eq/km]							
	total	84	**73**	-14%	85	**73**	-15%	35
	battery	27	**27**	0%	29	**29**	0%	0
	rest of vehicle	57	**46**	-20%	56	**44**	-22%	35
specific characteristics								
battery production	[kg CO_2-eq/kWh]	119	**119**	0%	119	**119**	0%	-
rest of vehicle	[kg CO_2-eq/kg]	9.6	**7.7**	-20%	9.8	**7.7**	-22%	6.7

For comparison, in 2021 Volkswagen made its LCA by comparing an ICE Golf with the ID.3. (https://www.volkswagenag.com/en/news/stories/2021/02/e-mobility-is-already-this-much-more-climate-neutral-today.html). In this LCA the difference in the GHG emissions from producing the Golf (6.8 t CO_2-eq) and the ID.3 (13.7 t CO_2-eq) is about 50%, which is about the same (49%) as calculated here. However, owing to different background data used and necessary assumptions the absolute values are different. This fact underlines the goal of this assessment to analyse significant differences between the 61 vehicles in their whole life cycle in a common generic data framework, independently of data from individual vehicle manufacturers. The main individual vehicle parameters in this assessment influencing the GHG emissions and primary energy demand are: vehicle weight, battery capacity, energy consumption for operation, CH_4- and N_2O-emissions from vehicles equipped with an ICE[1].

Based on that, the published results were updated, all online data are correct to our best information.

COMMENTS ON ISSUES RAISED IN SOCIAL MEDIA

Throughout the project, our aim has been to be as transparent as possible on the LCA methodology and data used for the analysis and seek independent review of the approach. However, spurred perhaps by the incorrect values on battery density for 13 vehicles, speculations about and misleading interpretations on the LCA methodology were raised in some media. With the exception of the before mentioned unintentional mistake, we believe these allegations to be unfounded and would like to address them as follows.

The answers to the comments are formatted in Green.

Comment 1: Assumptions on Battery Production

Are Green NCAP and Joanneum overestimating battery production? Modern studies are known to claim battery production greenhouse gas emissions (GHG) of 50 -75 kg CO_2-eq./kWh, while Joanneum has used a value of 120 kg CO_2-eq./kWh.

The LCA of automotive batteries system and its components were modelled with the JOANNEUM RESEARCH in-house "JR Battery LCA-Tool", based on available international literature (see e.g.

[1] The CO_2-emissions from ICE are calculated based on the fuel characteristics (B7 and E10) and the fuel consumption.

Aichberger et al. 2020, Aichberger 2020a, Pucker-Singer et al. 2021), including contributions from the main processes:

- Raw material mining and refining
- Grade material production
- Battery system manufacturing
- Battery use
- Reuse
- Recycling and second life (Reuse)
- Transports

The LCA of battery systems was conducted for various locations of battery production (Europe, US and China). Based on the current locations of battery production, a global average weighted for battery production was used to calculate the GHG emissions and the primary energy demand (e.g. China 75%).

The calculated GHG emissions for battery production were also compared to other studies, which show comparable results, but also differences due to specific parameters e.g. energy density, material composition, chemistry, energy source and components included. In the LCA also recycling and reuse of batteries were considered summing up to GHG emissions of 99 kg CO_2-eq/kWh. (see Table 2 and Figure 1, where the mentioned GHG emissions of 50 – 75 kg CO_2-eq/kWh are quite on the lower range but are possible in Europe e.g. in new giga factories using a high share of renewable energy but still raw materials from global supply chains). Using new data for batteries in UK with a share of battery production in EU of 43% (Asia 30%, US: 14%, RoW: 13%) the average estimated GHG emissions of battery are 82 g CO_2-eq/kWh.

Table 2: Comparison of different sources for GHG emissions of battery systems in different regions / countries

Battery	Greenhouse Gas Emissions [kg CO_2-eq/kWh]				
	JOANNEUM	ICCT	ivl	Ricardo	ARGONNE
CN	107	72			100
EU	66	55			65
US	78	58			75
country mix *)					
average	99 **)	68	84	85	93
low			61	80	
high			106	90	
**) own calculation: CN 75%, EU 6% and US 19% for JOANNEUM, ARGONNE and ivl*					
sources: Hill et al. 2020, Kelly et al. 2019, Bieker 2021, Emilsson et al. 2019					
***) production: 119 kg CO_2-eq/kWh and credit for end of life 20 kg CO_2-eq/kWh*					

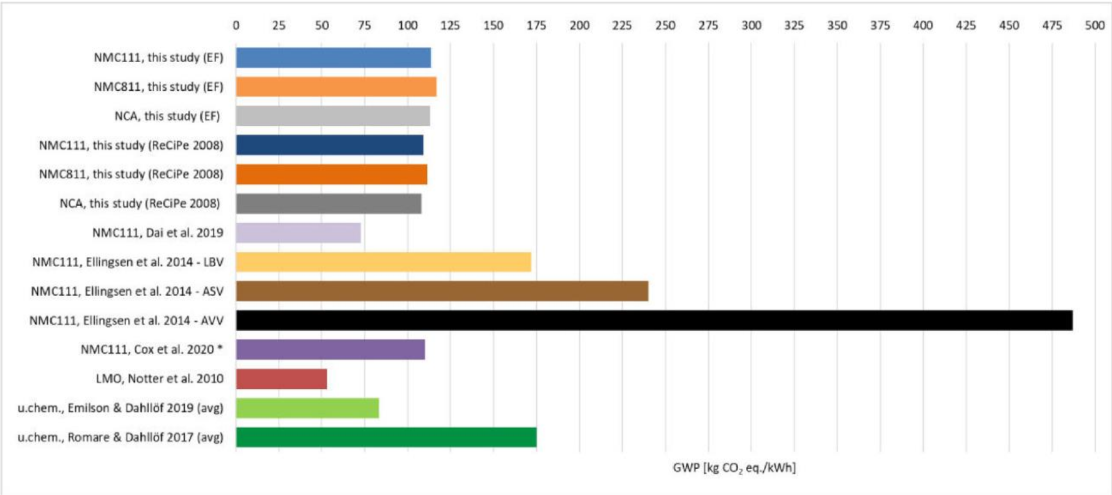

Figure 1: Climate change related impacts, based on current literature (Crenna et al. 2021)

LBV = low band value for electricity consumption; ASV = asymptotic value for electricity consumption; AVV = average value for electricity consumption; u.chem. = unspecified chemistry; avg = average; * graph interpretation, based on the average energy requirement in current battery production.
Remark: Notter et al, 2010 is outdated

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Comment 2: Electricity Mix Over the Lifetime

"*Green NCAP and Joanneum Research are blamed for ignoring the improvements in electricity mix over the lifetime (transition from fossil to renewable energy sources). In particular, the criticism suggests that estimates of 125 g/kWh incl. grid losses (see* https://www.eea.europa.eu/data-and-maps/daviz/co2-emission-intensity-9 *) should be used, whilst Joanneum Research has assumed 319 g/kWh. How does Joanneum Research come to this amount for the period 2022-2038?"*

The LCA results were based on the data of electricity supply from the state-of-the-art Ricardo study for 2020, 2030 and 2050 (Hill et al. 2020). Using these data, the changing annual electricity mix was interpolated and the average value between 2021 and 2037 (319 g CO_2-eq/kWh) was used in the LCA calculations (assuming the vehicle starts driving mid of 2021 and its end of life is mid of 2037). Statistical data of GHG emissions in the electricity sector, such as those by the European Environmental Agency, only cover the direct emissions at the chimneys of thermal power plants. In contrast, LCA based calculations of GHG emissions cover the construction and the operation (incl. fuel supply) of such plants. Accordingly, the LCA based GHG emissions of all electricity generation plants in Europe are significantly higher. This explains the difference in the GHG emissions of 125 g CO_2-eq/kWh (in 2030) and 319 g CO_2-eq/kWh.

Therefore, it is incorrect to assume that JOANNEUM's LCA methodology disregards the forecast of improving electricity mix.

Furthermore, Ricardo's analysis for the EC was used to calculate an average over the lifecycle of the vehicle. This analysis was based on EC modelling conducted prior to 2020. In fact, the European electricity grid has decarbonised considerably faster than predicted. In addition, the outlook for the period to 2030 and beyond has also shifted somewhat with the Fit-For-55 (FF55) package of measures announced last year. Ricardo is currently updating the databased modelling of electricity impacts on the 2020 electricity production mix (available from Eurostat) and public scenario data from the EC's most recent analysis. These results will be used in future LCAs when they are published, but currently the best available publicly referenceable projected LCA data (Hill et al. 2020) must be used.

Comment 3: GHG Emissions Related to Vehicle Production

Why does Joanneum assume that the production of an electric vehicle without its battery produces more GHG emissions than the production of a conventional ICE vehicle of comparable size? E.g. VW ID.3 (56.2 g CO_2/km vehicle + 28.8 g CO_2/km battery) und VW Golf Petrol (35.5 g CO_2/km)? What is the explanation for the difference between 56.2 g CO_2/km and 35.5 g CO_2/km for these vehicles of similar size. Why does VW's own LCA claim 14 tons CO2 for the total vehicle production (vehicle and battery), whereas Joanneum calculates 14 tons only for the vehicle?

Main aspects are already explained in the section "Clarification on data interface issue" above, and the battery density issue led to incorrect GHG emissions for the production of electric vehicles.

The communication of VW uses CO_2 and CO_2-eq, so it is not entirely clear, whether only CO_2 or also other GHG emissions are considered (https://www.volkswagenag.com/en/news/stories/2021/02/e-mobility-is-already-this-much-more-climate-neutral-today.html). In Green NCAP's LCA, the unit used is CO_2-equivalent always. covering CO_2, CH_4 and N_2O. The GHG emissions of the production of the ID.3 without battery are estimated with about 10.5 t CO_2-eq.

In Green NCAP's LCA analysis, the GHG emissions and primary energy for batteries of BEV were estimated separately and the estimated material mix of the vehicles is different for ICE, HEV, PHEV and BEV. Global generic supply chains were considered for the vehicle production, but brand specific production differences were not considered to guarantee the comparability between the vehicles, as Green NCAP wants to use public available data.

As more detailed data on vehicle production and vehicle characteristics (e.g. battery density, materials) will become available in future, the GHG emissions and primary energy will be calculated on a more detailed level in future LCA applications. This will allow a brand-specific comparison of vehicles, but only if the vehicle producer and its Tier I suppliers make their data publicly available and open to scrutiny by third parties. Unfortunately, this is not yet the case. Until this is solved, Green NCAP rejects the use of vehicle manufacturer's self-reported values for Green NCAP independent LCA analyses.

Comment 4: Comparison to VW LCA Numbers

Why are the numbers in VW's own LCA lower than the values in JOANNEUM's results?

Within the scope of this LCA it is not possible to make model- or brand-specific assessments. Instead, only scientifically proven, generic data are used to reflect typical vehicles with their different propulsion technologies to identify relevant and significant differences. These differences are mainly due to vehicle weight, battery capacity, energy consumption for driving and CH_4- and N_2O-emissions from ICE and PHEVs. See also comment 3 and section "Clarification on data interface issue".

Comment 5: Fuel/energy consumption

Where do the consumption values used in Green NCAP's LCA come from? How realistic are they?

This Answer is provided by Green NCAP.

Various methods exist to determine realistic vehicle fuel/electricity consumption figures:

- Real-World driving tests using portable emissions measurement equipment (PEMS testing)

  While time consuming, this could provide representative consumption figures for use in LCA. Unfortunately, the repeatability (and therefore comparability) of consumption measurements in such tests is currently doubtful owing to variability in weather and traffic conditions, the exact drive undertaken and the altitude at which it is done.

- Consumer-fed consumption figures

  Databases, like spritmonitor.de, exist which include self-reported consumption figures provided by drivers. Unfortunately, it is fact that such databases are easily manipulated and subject to high variability. They cannot be relied upon as an accurate source of data for LCA calculations.
- Laboratory Tests (roller bench tests)

  Green NCAP's consumption results are derived from the following laboratory tests: *WLTC+ cold* engine start, *WLTC+ warm* engine start, *WLTC+ Cold Ambient Test* (-7°C), as well as the motorway test *BAB130* (see www.greenncap.com). Green NCAP's LCA analysis is

based on the average fuel/energy consumption from the *WLTC+ cold*, *WLTC+ warm* and *BAB130* tests (all conducted at 14°C ambient temperature). To provide even more realistic test conditions, Green NCAP performs all laboratory tests with auxiliaries activated and cabin climatization engaged. The best consumption values presented in the LCA for indicative purposes are in most cases those of the eco-friendly on-road test *PEMS+ Eco*, whereas the worst values are measured mainly in *WLTC+ Cold Ambient Test* (-7°C) or *BAB130*.
On average, the tested electric vehicles showed an average consumption (as defined above) that was 37% higher than the declared WLTP values, owing to motorway testing, air-conditioning demand and measured charging losses. For the conventional vehicles (incl. non-rechargeable hybrids), the average consumption figures were 6% higher than the declared WLTP values.

Note on the consumption values of Plug-in Hybrids (PHEV):
Declared PHEV's CO_2 and fuel/energy consumption values, as determined by the official PHEV test procedure, lead to non-understandable numbers for the average consumer and non-realistic consumption figures in many real usage situations. Green NCAP's test matrix pursues the goal to measure a more realistic fuel and electric energy consumption by testing under more representative conditions and postprocessing the results in a more sensible way by weighing the possible operating modes (electric or combustion) in accordance with the measured useful electric range.

Comment 6: Biofuels

What is the justification for calculating the impact of biofuel blending to fossil fuels? Why are biofuels assumed to produce zero GHG emissions at combustion? Are land use change effects considered for biofuels (i.e. the cultivation of biofuels displaces agricultural land for food stock production)?
Diesel B7 (7 vol.-% FAME) and petrol E10 (10 vol.-% EtOH) were used in the testing of ICE and PHEV by Green NCAP, as biofuel blending is state of the art in Europe. Most of this biofuel used is produced in Europe with European feedstock, e.g. wheat, corn, rapeseed and waste cooking oil.
Based on the current legislation in Europe (RED-Renewable Energy Directive) these biofuels fulfil relevant sustainability criteria e.g. minimum GHG reduction. The combustion of biofuels in ICE

and PHEV is therefore "CO_2-neutral". So the effect of CO_2-emissions of biofuel blending from ICE is less than 7% compared to pure diesel or petrol due to the lower volumetric heating value of biofuels.

The GHG emissions of biofuel production (e.g. N_2O-emissions from agricultural cultivation) were calculated based on LCA incl. possible direct land use change. Indirect land use change effects were not considered as they are out of the scope of the LCA applied. In other studies addressing land use, possible indirect land use change effects are analysed based on global economic models, e.g. EtOH 43 – 61 g CO_2/kWh and FAME 119 – 238 g CO_2/kWh (EU 2015) for single feedstocks, which might lead to additional CO_2-emissions in the life cycle of 25 – 65 g CO_2/km using pure biofuel with current feedstock mix; with E10 and B7 it is correspondingly much lower. The European biofuel industry follows strict legislation, uses synergy effects (e.g. animal food production, starch products, glycerine). However, it shall be acknowledged that biofuel-production might conflict with food- and feedstock production globally, these effects are difficult to quantify.

Comment 7: GHG from Fuel Production

Ignoring the GHG emissions related to the fuel production process is a common mistake. Studies suggest additional 24% of the tailpipe CO2 emissions for diesel and 30% for gasoline."

The LCA based GHG emissions and primary energy of the supply of fuels (e.g. petrol E10, diesel B7, CNG) were considered from the extraction of e.g. raw oil via refinery to the filling station. This is clearly explained in the methodology paper. For the supply of diesel the GHG emission are 58 g CO_2-eq/kWh and for petrol 76 g CO_2-eq/kWh, which is about 21% and 28% from the tailpipe CO_2-emissions of petrol and diesel combustion. For the considered fuels B7 and E10 for the Green NCAP vehicles, the %-values are different because of biofuel blending into fossil fuels.

Comment 8: Maintenance

Why are the maintenance GHG emissions of a BEV similar or even higher to those of an ICE vehicle?

The aspects explained in "clarification" also effect the GHG emissions from maintenance of BEV and PHEVs.

The GHG emissions and primary energy demand from vehicle maintenance were included covering tyres, engine oil and spare parts (as % of vehicle materials). Both vehicle types - BEV and ICE vehicles - have a lot of parts in common, which must be replaced: tyres, suspension and undercarriage parts like brakes. The heavier the car is, the bigger these parts are and so are the related GHG emissions. One reason for differences may arise from the fact that BEVs are relatively heavier. ICE does have additional oil changes, spark plugs, belts and more maintenance of brakes and AdBlue. It is however acknowledged that the incorrect battery vehicle weight calculations mentioned earlier, also had a small knock-on effect on the maintenance numbers. This has also been corrected.

JOANNEUM RESEARCH and Green NCAP are currently conducting further research to assess the contribution of maintenance in more detail for future LCA applications. In any case, the contributions on GHG emissions and primary energy from maintenance are relatively small in the total lifetime of the vehicle.

Comment 9: Data sources

Joanneum is being accused of ignoring studies of "proven" quality like the one from "ICCT" and the "Ricardo" study.

JOANNEUM RESEARCH used the LCA data for the electricity mixes (all EU countries and average) from the study done by Ricardo for the European Commission (Hill et al. 2020). The results for GHG emissions of batteries in Europe are similar to other studies. (see comparison above in comment 1, e.g. Bieker 2021; ICCT). The applied LCA methodology is state-of-the art and in line with most of the recent LCA studies, but the specific goal and scope of each LCA must be kept in mind and is a main reason for different results. The development of LCA methodology is ongoing and continuously adapted to new applications and new data, which will generate further improvements and new findings in future.

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