Guernsey Electricity Limited

LIFE CYCLE STUDY OF VEHICLE GHG IMPACTS IN GUERNSEY

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WSP

4th Floor
6 Devonshire Square
London
EC2M 4YE

Phone: +44 20 7337 1700

WSP.com

EXECUTIVE SUMMARY

Guernsey Electricity Ltd (here on referred to as GEL) is an integrated utility company that generates, transmits and distributes electricity across the island of Guernsey. GEL undertakes operations that use electricity including works power, office activities and the charging of company electric vehicles.

WSP UK was commissioned by GEL to conduct a study into the life cycle greenhouse gas (GHG) emissions intensity of different types of passenger cars. This study was conducted to provide a comparison between:

- battery electric vehicles (BEVs);
- conventional internal combustion engine (ICE) vehicles using petrol, diesel or biofuel diesel (hydrotreated vegetable oil (HVO)) as fuel; and
- fuel cell electric vehicles (FCEVs) which use hydrogen from different production methods.

GEL stated FCEVs were of particular interest to the public and generated substantial discussion during a Q4 2021 Facebook post by GEL. As a results, WSP have included FCEVs in the 2022 study. Additional detail on FCEVs has also been provided in this study.

The results of the 2022 study show that the ICE vehicle that is fuelled by RD100 (HVO diesel biofuel) show the lowest emissions in gCO_2e per km compared to other vehicle types and fuel consumption. It should also be noted that RD100 is a diesel biofuel. While biofuels have lower life cycle GHG emissions than conventional fuels (circa 90%)[1] this value is not zero due to the production of non CO_2 GHGs upon the combustion of the biofuel, most notably methane and nitrous oxide. The CO_2 emissions produced upon combustion of biofuels are assumed to be net '0' to account for the CO_2 absorbed by fast-growing bioenergy sources during their growth[2].

BEVs and FCEVs have higher production emissions than ICE vehicles (circa 40%), the reason for the difference being higher emissions from battery production for BEVs and FCEVs[3]. This results in BEVs and FCEVs GHG emissions (gCO_2e per km) being higher than HVO powered vehicles. However, it is expected there will be a steep reduction in the carbon emissions from EV battery production in the next five to ten years through the introduction of regulation and circular economy[1,4]. Future BEVs and FCEVs have the potential to produce less gCO_2e per km compared to RD100 vehicles in the near future.

Vehicles operating on petrol and diesel (non-biofuel) represent the highest contributors to GHG emissions, primarily as a result of the operation life cycle stage i.e., in-use fuel consumption which significantly outweighs the higher production and end of life emissions associated with BEVs and FCEVs.

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[1] https://www.supplychainschool.co.uk/wp-content/uploads/2023/05/Collaboration-Group-on-HVO-Sponsorship-opportunity.pdf
[2] https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2022
[3] https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-race-to-decarbonize-electric-vehicle-batteries
[4] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/943714/Modelling-2050-Electricity-System-Analysis.pdf

OBJECTIVE

The objective of this study was to calculate the GHG emissions released per km driven for popular models of ICEs, BEVs and FCEVs, accounting for the GHG emissions across the complete life cycle of production, operation and end-of-life (EOL). For BEV charging, the life cycle intensity of GEL's electricity supply (both Total GEL mix and GEL importation mix only) was considered, in comparison with the UK grid factor. The study also compares three types of hydrogen production: steam methane reformation, both with and without carbon capture, and renewable electrolysis.

METHODOLOGY

For this study, WSP assessed the emissions from the production, operation and EOL life cycle stages of each in-scope vehicle type. Production emissions are those arising from raw materials extraction and processing. Operational emissions included the emissions generated by the combustion of fuel or the generation of electricity/hydrogen, well-to-tank emissions from the production of each fuel and vehicle maintenance activities. EOL emissions occur from the management and disposal of parts at the end of a vehicles' lifetime.

A summary of the life cycle stages assessed are in Figure 1-1.

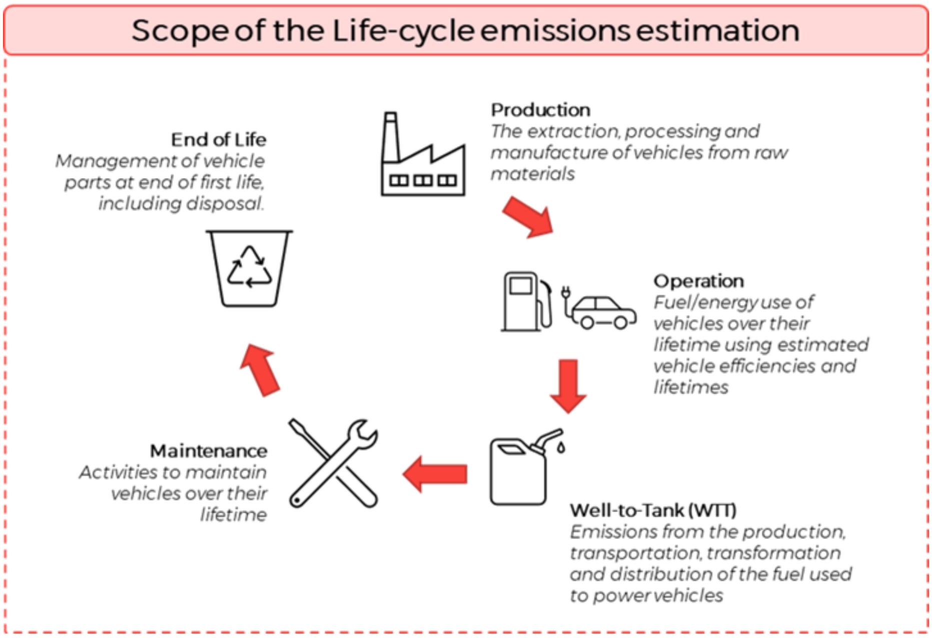

Figure 1-1 – Scope of the life cycle emissions estimation

As part of this assessment, a literature review was conducted to obtain GHG emission values for the production and EOL stages of the vehicle's life cycle. The following steps have then been used to calculate the operational GHG emissions for each vehicle:

- **Emissions from energy usage (diesel/petrol) (Equation 1a)**

  Vehicle fuel efficiency x average lifetime usage x fuel emissions factor

- **Emissions from energy usage (electric) (Equation 1b)**

  Vehicle electricity efficiency x average lifetime usage x GEL electricity intensity or UK average grid emissions intensity (including transmission and distribution)

- **WTT emissions (diesel/petrol/HVO vehicles) (Equation 2a)**

  Lifetime fuel used x WTT fuel emission factor for diesel/petrol/HVO vehicles
- **WTT emissions (hydrogen) (Equation 2b)**

  Vehicle electricity efficiency x average lifetime usage x GHG emission factor for the production of hydrogen
- **Operation emissions (Equation 3)**

  Equation 1 + Equation 2 + maintenance activity emissions

The final step to calculate life cycle emissions is:

- **Life cycle emissions (Equation 4)**
  Operation emissions + Production emissions + EOL emissions

Where this information was not available, they were estimated using available literature. The full list of emission values for each vehicle's life cycle stage can be found in Table 1 which is found in the Appendix along with the corresponding literature source.

Average lifetime usage: According to available scientific literature, different brands of ICE vehicles, BEVs and FCEVs lifetimes range significantly depending on the study. Some studies show BEVs and FCEVs with longer lifetimes than ICE vehicles and others show ICE vehicles have longer lifetimes than BEVs and FCEVs. An average lifetime usage was assumed for all vehicles in this study. [5]

Vehicle fuel efficiency: Is defined as a measure of how much a car will convert energy in fuel into kinetic energy to travel. Vehicle efficiencies have been sourced from a variety of sources and are summarised in Table 1 which is found in the Appendix.

Vehicle types: Based on the available literature[6] and vehicle sales statistics in the UK[7], WSP used professional judgement to select representative ICE vehicles, BEVs and FCEVs for inclusion in this study. Additionally, an average diesel and petrol vehicle along with a BEV were also included. The types of vehicles incorporated in this study are therefore:

- BEV GEL Imports Only – Average
- BEV GEL Imports Only – Fiat 500 EV
- BEV GEL Imports Only – Tesla M3
- BEV Renewable Charged (0 gCO2e/kWh) – Average
- BEV Total GEL Mix – Average
- BEV Total GEL Mix – Fiat 500 EV
- BEV Total Gel Mix – Tesla M3

[5] https://www.mdpi.com/2071-1050/12/22/9390/htm. This paper is a review of several other life cycle assessments (LCAs) and provides an overall figure for each life cycle stage based on all the LCAs.
[6] https://www.mdpi.com/2071-1050/12/22/9390/htm.
[7] https://www.best-selling-cars.com/britain-uk/2022-full-year-britain-best-selling-car-models-in-the-uk/

- BEV UK Charged – Average
- BEV UK Grid Charged – Fiat 500 EV
- BEV UK Grid Charged – Tesla M3
- Diesel – Average
- Diesel – BMW 3 series, Euro 6
- Diesel – VW Golf Tdi
- FCEV – Toyota Mirai [Renewable electrolysis]
- FCEV – Toyota Mirai [Steam methane reformation with carbon capture]
- FCEV – Toyota Mirai [Steam methane reformation without carbon capture]
- HVO – Average (RD100)
- Petrol – Average

The following updates have been made in this revision of study:

- Department for Business, Energy & Industrial Strategy (BEIS) emission factors for ICE vehicles (fuel operation (combustion), WTT) have been updated with the latest UK Greenhouse Gas Reporting Conversion Factors for 2022[8].
- The emission factors specific to GEL, GEL's electricity supply life cycle intensity, have been updated. These factors were sourced from the Annual Greenhouse Gas Emissions Database for 2022.[9]
- BEIS emission factors for BEVs (UK Grid factor and transmission & distribution UK electricity factor) have been updated with the latest UK Greenhouse Gas Reporting Conversion Factors for 2022[8].
- Fuel efficiency values for all vehicle types have been reviewed. Sources are summarised in Table 1 which is found in the Appendix.
- The average lifetime usage was updated for all vehicles from the latest scientific literature[10].
- The inclusion of FCEVs is new for the 2022 study. Additional detail on FCEVs is provided below.

FUEL CELL ELECTRIC VEHICLES

For the 2022 review GEL requested WSP UK include FCEVs in the emission study. FCEVs are defined as "*vehicles that produce electricity using hydrogen gas and produce no harmful tailpipe emissions, just water vapor*"[11].

The Toyota Mirai (hydrogen fuel cell design) was identified as a representative FCEV as it is only one of two models available in the UK. GHG emissions from the production, maintenance and EOL life cycle stages were assumed from scientific literature[12] and a life cycle inventory published by

[8] https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2022
[9] *WSP GHG Review Spreadsheet_RP of 2022_v1.0_14042023.xlsx*
[10] https://www.mdpi.com/2071-1050/12/22/9390/htm.
[11] https://www.phoenix.gov/sustainabilitysite/Documents/Electric_Vehicle_Acronyms_and_Glossary.pdf
[12] https://www.mdpi.com/2071-1050/12/22/9390/htm.

Toyota[13]. Fuel efficiency for the Toyota Mirai was sourced from the latest literature[14] and GHG emission factors for the production of hydrogen from a UK Government study[15]. The source of the hydrogen used by the FCEV has the biggest impact on the life cycle emissions of the FCEV.

This study covers the three production methods for hydrogen most relevant to future FCEV use:

- Steam methane reformation without carbon capture
- Steam methane reformation with carbon capture (where possible emissions are captured and stored or repurposed)
- Renewable electrolysis (clean electricity is used to electrolyse water, splitting it into hydrogen and oxygen)

ASSUMPTIONS AND LIMITATIONS

The following assumptions and limitations apply to this study:

- In the absence of Guernsey-specific data on the average lifetime usage of a car, 184,000 km was assumed, based on estimates available from literature[12].
- The production, maintenance and EOL life cycle stage emissions for all vehicle types are based on averages of these vehicle types from a range of Life Cycle Assessment (LCA) studies from the following review paper: *Review and Meta-Analysis of EVs: Embodied Emissions and Environmental Breakeven (Dillman et al 2020)*[12]*.* The FCEV (the MIRAI) has been assumed to have the same production, maintenance and EOL life cycle stage emissions as a BEV due to the similarity in the MIRAI emission profile stated in Life Cycle Assessment Report "The MIRAI Life Cycle Assessment for communication" produced by Toyota[12].
- EOL emissions have been discerned from the following review paper: *Review and Meta-Analysis of EVs: Embodied Emissions and Environmental Breakeven (Dillman et al 2020)*[12]*.* It should be noted that the review highlighted an inconsistency regarding emissions from the EOL stage and battery replacement; the review asserted that this was because of a lack of available data on recycling technologies and their success (as BEVs and FCEVs have only relatively recently entered the mass market and many are yet to reach EOL). The BEV EOL emissions factor is the average of the meta-analysis of a range of EV Life Cycle Assessments, of which a few of these studies included recycling aspects.

[13] https://global.toyota/pages/global_toyota/sustainability/esg/challenge2050/challenge2/life_cycle_assessment_report_en.pdf
[14] https://www.zemo.org.uk/assets/reports/Zemo_Hydrogen_Vehicle_Well-to-Wheel_GHG_and_Energy_Study_2021.pdf
[15] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1175494/UK-Hydrogen-Strategy_web.pdf

RESULTS 2022

Figure 1-2 presents a comparison of life cycle emissions (gCO_2e/km) of different types of vehicles stated in the methodology (some operating with various fuels). Table 1, which is found in the Appendix, contains the full set of results and associated sources.

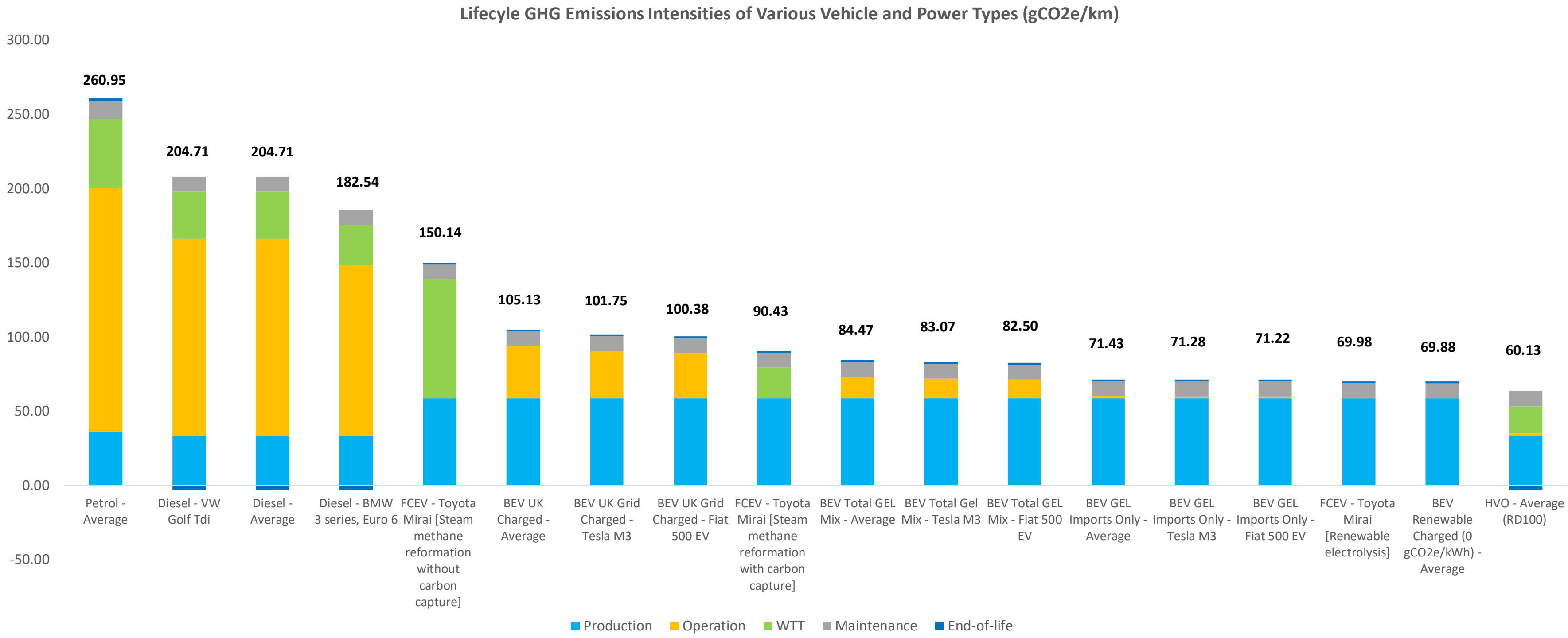

Figure 1-2 Life Cycle Emissions Intensities 2022

The results show that the ICE vehicle HVO – Average (RD100) that is fuelled with RD 100 (a HVO diesel biofuel) has the lowest emissions in gCO_2e per km compared to other vehicle types and fuel consumption. This is primarily the result of the lower emissions for the production of diesel cars compared to BEVs and FCEVs at present. While biofuels have lower life cycle GHG emissions than conventional fuels (circa 90%)[16], this value is not zero due to the production of non CO_2 GHGs upon the combustion of the biofuel, most notably methane and nitrous oxide. The CO_2 emissions produced upon combustion of biofuels are assumed to be net '0' to account for the CO_2 absorbed by fast-growing bioenergy sources during their growth[17].

Production emissions from BEVs and FCEVs are 40% higher than ICE vehicles, the reason for the difference being higher emissions from battery production for use in BEVs and FCEVs[18]. However, it is expected there will be a steep reduction in the carbon emissions from EV battery production in the next five to ten years through the introduction of regulation and circular economy initiatives[16, 19]. Future BEVs and FCEVs have the potential to produce less gCO_2e per km compared to RD100 vehicles in the near future.

As stated in the methodology, BEVs and FCEVs are assumed to produce the same emissions during the production, maintenance and EOL life cycle stages. The difference in life cycle emissions between BEVs and FCEVs are solely the result of differing operational emissions. As hydrogen production via steam methane reformation without carbon capture is the most GHG intensive process, the FCEV that is fuelled through this method of hydrogen production has significantly higher life cycle emissions compared to other BEVs and FCEVs.

Vehicles operating on petrol and diesel (non-biofuel) represent the highest contributors to GHG emissions, primarily as a result of the operation life cycle stage i.e., in-use fuel consumption which significantly outweighs the higher production and EOL emissions associated with BEVs and FCEVs.

BEV AND FCEV BATTERIES

Batteries used within BEVs and FCEVs are of particular interest to the public. Most notably their production, lifespan/replacement and disposal. This study only covers elements related to the GHG emission impact of these items.

As stated above, production emissions from BEVs and FCEVs are 40% higher than ICE vehicles[15]. This is believed to be due to the higher GHG emissions from the production of BEV and FCEV batteries. However, as seen by Figure 1-2, production emissions are minimal compared to operational emissions from non-biofuel ICE petrol and diesel cars.

The battery life was considered in the LCA studies from the following review paper: Review and Meta-Analysis of EVs: Embodied Emissions and Environmental Breakeven (Dillman et al 2020)[20]. Eight of the nine studies that considered battery lifetime considered the battery lifetime to be longer than or equal to the vehicle lifetime; therefore, no battery replacement would be required (this is why

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[16] https://www.supplychainschool.co.uk/wp-content/uploads/2023/05/Collaboration-Group-on-HVO-Sponsorship-opportunity.pdf
[17] https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2022
[18] https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-race-to-decarbonize-electric-vehicle-batteries
[19] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/943714/Modelling-2050-Electricity-System-Analysis.pdf
[20] https://www.mdpi.com/2071-1050/12/22/9390/htm.

the maintenance of BEVs/FCEVs are assumed to be the same as ICE vehicles). One study considered a battery replacement once over the BEVs lifetime. The emissions from a full BEV battery replacement and disposal can be estimated to be 25 gCO_2e/km[21]. Replacement of one battery in a BEV/FCEV over the vehicles lifetime would significantly increase the maintenance emissions from a BEV/FCEV compared to other ICE vehicles. However, full life cycle emissions would still be significantly lower than vehicles operating on petrol and diesel (non-biofuel) as a result of the operation life cycle stage where emissions from fuel consumption significantly out ways the replacement of one battery over the lifetime of a BEV/FCEV.

From a GHG perspective, EOL is not considered a GHG emissions intensive process with <1% of emissions coming from this life cycle stage for the average petrol vehicle and other ICEs having a negative GHG emission impact during this stage. EOL for the whole BEV/FCEV is assumed to be 1.09 gCO_2e/km which is minimal compared to other life cycle stages for BEVs/FCEVs. As the battery is only part of the vehicle being recycled/disposed of during the EOL stage, emissions from battery disposal is also considered to be minimal compared to other life cycle stages for BEVs/FCEVs.

[21] Production of a BEV/FCEV is considered to be 58.70 gCO_2e/km. If 40% of these are emissions are from battery production, 23.48 gCO_2e/km can be assigned to BEV/FCEV battery production. Disposal of a full BEV/FCEV is stated to be 1.09 gCO_2e/km and has been used as a worst-case scenario regarding disposal of a BEV/FCEV battery.

APPENDIX – FULL RESULTS

Table 1 - Emissions (gCO_2e/km) from a typical vehicle over its life cycle

Vehicle type	Emissions (gCO_2e/km)					
	Production[1]	Operation	WTT	Maintenance[1]	EOL[1]	Total
BEV GEL Imports Only - Average	58.70	1.55[1,6]	-	10.10	1.09	71.43
BEV GEL Imports Only - Fiat 500 EV	58.70	1.34[2,6]	-	10.10	1.09	71.22
BEV GEL Imports Only - Tesla M3	58.70	1.40[3,6]	-	10.10	1.09	71.28
BEV Renewable Charged (0 gCO_2e/kWh) - Average	58.70	0.00[1]	-	10.10	1.09	69.88
BEV Total GEL Mix - Average	58.70	14.59[1, 6]	-	10.10	1.09	84.47
BEV Total GEL Mix - Fiat 500 EV	58.70	12.62[2,6]	-	10.10	1.09	82.50
BEV Total Gel Mix - Tesla M3	58.70	13.19[3,6]	-	10.10	1.09	83.07
BEV UK Charged - Average	58.70	35.25[1,7]	-	10.10	1.09	105.13
BEV UK Grid Charged - Fiat 500 EV	58.70	30.50[2,7]	-	10.10	1.09	100.38
BEV UK Grid Charged - Tesla M3	58.70	31.87[3,7]	-	10.10	1.09	101.75
Diesel - Average	33.15	133.01[1,7]	31.71[7]	10.10	-3.26	204.71
Diesel - BMW 3 series, Euro 6	33.15	115.10[4,7]	27.44[7]	10.10	-3.26	182.54
Diesel - VW Golf Tdi	33.15	150.15[7]	35.80[7]	10.10	-3.26	225.94
FCEV - Toyota Mirai [Renewable electrolysis]	58.70	-	0.10[5,8]	10.10	1.09	69.98
FCEV - Toyota Mirai [Steam methane reformation with carbon capture]	58.70	-	20.54[5,8]	10.10	1.09	90.43
FCEV - Toyota Mirai [Steam methane reformation without carbon capture]	58.70	-	80.26[5,8]	10.10	1.09	150.14

HVO - Average (RD100)	33.15	1.85[1,7]	18.29[7]	10.10	-3.26	60.13
Petrol - Average	35.87	164.30[1,7]	46.61[7]	12.00	2.17	260.95

Production

[1] All vehicles production emissions: https://www.mdpi.com/2071-1050/12/22/9390/htm

Operation - Efficiencies

[1] https://www.mdpi.com/2071-1050/12/22/9390/htm

[2] https://www.parkers.co.uk/fiat/500-electric/specs/

[3] https://ev-database.org/car/1060/Tesla-Model-3-Standard-Range

[4] https://www.cars-data.com/en/bmw-318d-specs/95188/tech

[5] https://www.zemo.org.uk/assets/reports/Zemo_Hydrogen_Vehicle_Well-to Wheel_GHG_and_Energy_Study_2021.pdf

Operation - Emission factors for fuel use

[6] WSP GHG Review Spreadsheet_RP of 2022_v1.0_14042023.xlsx

[7] https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2022

WTT

[5] https://www.zemo.org.uk/assets/reports/Zemo_Hydrogen_Vehicle_Well-to Wheel_GHG_and_Energy_Study_2021.pdf

[7] All ICE WTT emissions: https://www.mdpi.com/2071-1050/12/22/9390/htm

[8] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011283/UK-Hydrogen-Strategy_web.pdf

Maintenance

[1] All vehicles maintenance emissions: https://www.mdpi.com/2071-1050/12/22/9390/htm

EOL

[1] All vehicles EOL emissions: https://www.mdpi.com/2071-1050/12/22/9390/htm

4th Floor
6 Devonshire Square
London
EC2M 4YE