Zemo Partnership
Accelerating Transport to Zero Emissions

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Powered Light Vehicles Life Cycle Analysis Study

Published by Zemo Partnership
at the request of MCIA

December 2021

Zemo.org.uk

This report has been published by Zemo Partnership, December 2021

Zemo Partnership
3 Birdcage Walk,
London,
SW1H 9JJ

T: +44 (0)20 7304 6880
E: Hello@Zemo.org.uk
Visit: Zemo.org.uk

Authors:

Alec Thomson BSc BEng MSc
Project Officer

James McGeachie CEng MIET MSc
Technical & Programme Director

Reviewed by:

Andy Eastlake CEng FIMechE
Chief Executive

Zemo Partnership
Accelerating Transport to Zero Emissions

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Executive Summary

The MCIA have commissioned Zemo Partnership to perform a greenhouse gas (GHG) lifecycle analysis (LCA) study on a series of L-category vehicles and selected baseline M1 and N_1-category comparator vehicles (cars and vans). Eight separate use case scenarios are modelled in the study, these being:

1. A battery electric moped being used for inner city commuting
2. A 125cc motorcycle being used for last mile delivery/urban commuting
3. A 11kW battery electric motorcycle being used for last mile delivery/urban commuting
4. A 35kW 650cc petrol motorcycle being used for extra urban commuting and leisure
5. A 35kW electric motorcycle being used for extra urban commuting and leisure
6. A 950cc petrol performance motorcycle being used for weekend leisure
7. A 79kW premium battery electric motorcycle being used for weekend leisure
8. A battery electric cargo quadricycle being used on inner city and urban delivery routes

In each case, alternative vehicles that could be used for the same type of activity and operating under identical circumstances are also modelled for comparison.

The study focuses solely on the GHG emissions resulting from the production, use and disposal of the vehicle. Therefore, the life cycle impact assessment method is 'Global Warming Potential' of emissions with the reference unit being mass of CO_2 equivalent (kgCO_2e). For a fair and balanced comparison between the different modes of transport, the calculated gCO_2e per km travelled is reported in the study, in addition to the more traditional figure of total cumulative GHG emissions over the vehicle lifetime.

Table E.0 provides a summary of results from the eight use case scenarios considered in this report, with the highlighted areas denoting the vehicle with the lowest GHG emission footprint in each case.

In almost every scenario examined in the study, the L-category vehicle produces a lower lifetime GHG emission per km travelled than the comparison passenger car and van performing the same task. This is found to apply even where a shorter operational lifetime is assumed for the L-category vehicle.

Table E.0: Scenario Output Summary

Scenario	Use case	Vehicles			
1	**Inner city commute**	L1 BEV	Small M1 BEV		
2	**Local commute & delivery**	L3 ICE (125cc)	Small M1 BEV	M1 Mild Hybrid	Small N1 BEV
3	**Local commute & delivery**	L3 BEV (11kW)	Small M1 BEV	M1 Mild Hybrid	Small N1 BEV
4	**Daily commute**	L3 ICE (650cc)	Small M1 BEV	M1 Mild Hybrid	
5	**Daily commute**	L3 BEV (35kW)	Small M1 BEV	M1 Mild Hybrid	
6	**Leisure & pastime**	L3 ICE (950cc)	Medium M1 BEV	Medium M1 ICE	
7	**Leisure & pastime**	L3 BEV (79kW)	Premium M1 BEV	Premium M1 ICE SUV	
8	**Inner city & urban delivery**	L7 BEV	Small N1 BEV	Small N1 ICE	

In general, where the vehicles share the same powertrain solution, i.e. both are battery electric or both feature an internal combustion engine, the L-category vehicle is consistently found to be the vehicle with lower GHG emissions.

Where comparisons are drawn across vehicles with different powertrain solutions, lifetime operational mileage is identified as a key area of sensitivity for the study. This is evident in the daily commute type activity which heavily favours the use of a small battery electric car over a medium capacity petrol motorcycle. The report examines in detail the reasons behind this but in brief these are found to be related to the GHG emissions generated during the production phase of the battery electric vehicle and those generated during the operational or in-use phase of the petrol motorcycle. Other sensitivities identified of a similar nature include passenger number, payload and traction battery replacement strategy.

Overall, the study finds that L-category vehicles are particularly suited to single person commuting or light delivery, especially where relatively low annual mileages are involved. By comparison, for a specific high mileage operation considered in the study, a battery electric car was found to be more appropriate than an L-category vehicle equipped with a petrol engine. The study also highlights that where multiple person occupancy or sizeable payloads apply, an L-category vehicle may be limited in its application, highlighting the importance of selecting the right vehicle for the desired journey or activity.

1. Introduction

1.1 Background

At the request of the MCIA, Zemo Partnership have undertaken a project to perform a greenhouse gas (GHG) lifecycle analysis (LCA) study on a series of L-category vehicles and selected baseline M1 and N_1-category comparator vehicles (cars and vans). Both the vehicle specifications and the use cases against which they are assessed have been discussed and agreed in advance with the MCIA, the details of which can be found in later sections of this document.

This report presents the output of the analysis in graphical form scenario by scenario, supported by a high level commentary of the results in each case and where appropriate, key observations are made when drawing comparisons with the baseline comparator vehicles.

Zemo Partnership has performed the GHG LCA activity using an in-house LCA modelling tool, updated as part of the project to include L-category vehicles. It should be noted that the purpose of the analysis is to allow comparisons to be made between the different vehicle types being considered in each scenario. The figures generated are not intended for use for any other purpose nor should they be viewed in isolation as discrete and absolute numbers.

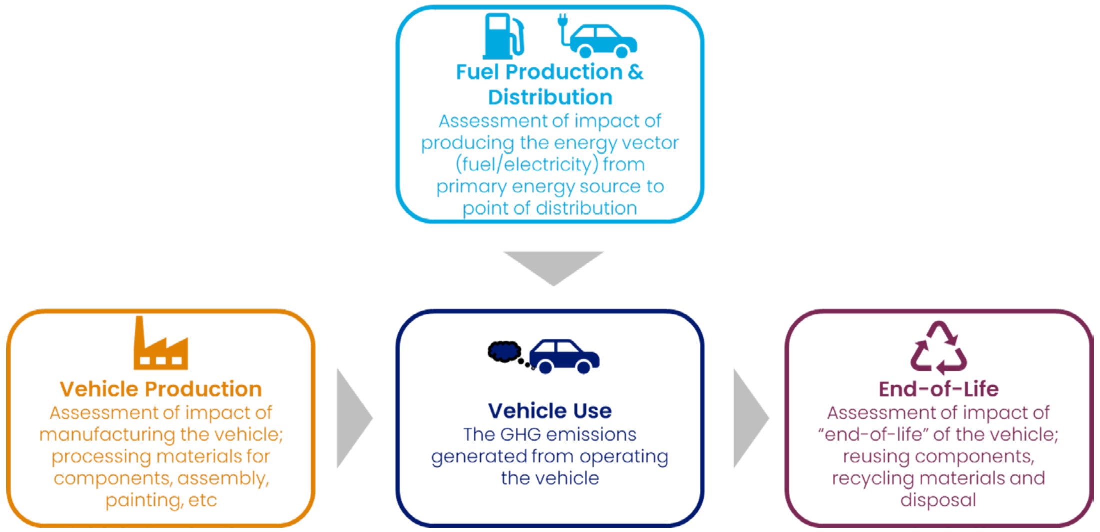
1.2 What is LCA?

Lifecycle analysis, also known as lifecycle assessment, is the holistic approach of analysing a product's full environmental impact; from product creation, to in use operation, to eventual disposal. As such, it is a technique for quantifying the environmental impacts in a rigorous manner that allows for a fair comparison to be made with other products and their impacts.

Formal Definition:

> *"It is a process to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used and wastes released to the environment. The assessment includes the entire life cycle of product, process or activity, encompassing extracting and processing raw materials, manufacturing, transport and distribution; use, reuse, maintenance; recycling, and final disposal"*
>
> **"Technical Framework for Life-Cycle Assessment", SETAC, 1991**

Figure 1.0 - Lifecycle Block Diagram



It's important to note that the LCA conducted in this study focuses on CO_2 equivalent greenhouse gas emissions (CO_2e), and not on other environmental, human health or ethical impacts, such as NOx emissions or landscape changes resulting from mined materials.

1.3 Limitations of LCA

For LCA to be effective, system boundaries need to be chosen and stated clearly. Proceeding without having taken this step can result in the study quickly becoming unwieldy with different assumptions being made at increasingly granular levels and requiring ever more complex datasets that it may not be possible to obtain with any degree of accuracy. Conversely, LCA studies with too narrow a focus may miss the bigger picture, with secondary impacts and unintended consequences completely missed.

The results of an LCA study should only be used as part of a more comprehensive decision-making process. Results of different LCA studies can only be compared if the assumptions used, as well as the context they are used in, are the same. It is therefore important that the assumptions used should be explicitly stated in any LCA reporting.

2. Methodology

2.1 Scenario / Use Case Description

The study focuses solely on the GHG emissions resulting from the production, use and disposal of the vehicle. Therefore, the life cycle impact assessment method is 'Global Warming Potential' of emissions, over a time horizon of 100 years, with the reference unit being mass of CO_2 equivalent (kgCO_2e).

Eight separate use case scenarios are modelled in the study, each with different vehicles and different journey profiles, ranging from mopeds doing short inner-city commutes to quadricycles carrying parcels on last mile urban delivery routes. In summary, the eight scenarios and vehicles are:

1. L1 battery electric scooter being used for inner city commuting
2. L3 125cc motorcycle being used for last mile delivery/urban commuting
3. L3 11kW battery electric motorcycle being used for last mile delivery/urban commuting
4. L3 35kW 650cc petrol motorcycle being used for extra urban commuting and leisure
5. L3 35kW electric motorcycle being used for extra urban commuting and leisure
6. L3 950cc petrol performance motorcycle being used for weekend leisure
7. L3 79kW premium battery electric motorcycle for weekend leisure
8. L7 battery electric cargo quadricycle being used on inner city and urban delivery routes

For each scenario, alternative vehicles that could be used for the same type of activity operating under identical circumstances are also modelled for comparison. This is typically a standard version of a 40kWh battery electric car, a standard version of a mild hybrid petrol car and a 33kWh small battery electric van. In the case of Scenarios 6 and 7 which are focussed on leisure activities, vehicles of a more premium or powerful nature are used as the comparator rather than the standard daily commuter models.

2.2 Vehicle Assumptions

The primary focus of this study is the L-Category segment of vehicles, also known as "Powered Light Vehicles" (PLVs). L-Category vehicles are a group described in EU Regulation 168/2013, which range from powered two-wheelers such as motorbikes and mopeds, up to heavier and larger quadricycles.

Figure 2.0 - Examples of L-Category Powered Light Vehicles

SOURCE: ZEMO PARTNERSHIP POWERED LIGHT VEHICLES REPORT, 2019

In the LCA model run for this study, the different comparator vehicles are idealised versions, based on the technical specifications of popular UK road motorcycles, cars and vans. Each vehicle has an assumed lifetime mileage and operating life, before a vehicle is disposed of and components are recycled, this being stated at the start of each use case scenario. The assumed lifetime mileage varies depending on the use case being considered, ranging from the vehicle being heavily utilised on a daily basis for commuting purposes to more infrequent use for weekend leisure activities.

The comparator vehicle set used in this study is briefly summarised below:

- Small Battery Electric Car (40kWh)
- Small Battery Electric Van (33kWh)
- Small Diesel Van (1.6L)
- Mild Hybrid Petrol Car (1.8L)
- Medium Segment Battery Electric Car (55kWh)
- Medium Segment Performance Petrol Car (2.0L)
- Premium Segment Diesel SUV (3.0L)
- Premium Segment Battery Electric Car (100kWh)

For the purposes of this study, other key assumptions are:

- All vehicles are assembled in the UK and operated in the UK
- High voltage traction batteries are manufactured using worldwide emission factors
- The Well-to-Tank emission factors of fuels do not change during the lifetime of the vehicle
- The carbon intensity of electricity does not change during the lifetime of the vehicle
- The vehicles' fuel or electricity consumption does not change with vehicle age
- No major parts are replaced during the lifetime of the vehicle, with the exception of the high voltage battery. Therefore, the carbon impact of maintenance is assumed to be negligible and has not been considered in this study

As referred to above, high voltage battery replacements are included in this study, with the assumption that once the 8-year warranty expires, the battery pack is replaced on a passenger car or van, rather than the whole vehicle being scrapped. It should be noted that data beginning to emerge from the real-world operation of battery electric vehicles suggests that the type and number of charging cycles are key factors affecting battery health, potentially above that of vehicle mileage and age. However, for the purposes of this study and in the absence of a comprehensive dataset in this area that covers the use case scenarios being considered, it is assumed a battery replacement occurs for electric passenger cars and vans that are older than 8 years, unless stated otherwise. The impact of the replacement battery strategy and the assumed shorter life of L-category vehicles are clearly shown on every graph to ensure transparency of these core assumptions. No consideration of battery re-use (second life) has been included in this analysis.

Assumptions regarding vehicle fuel and electricity consumption are based on available public domain information and are not based on any vehicle simulation.

It should also be noted that vehicle End-of-Life (EoL) has not been considered in detail within the LCA activity. Instead, a factor has been applied to estimate CO_2e emissions from vehicle EoL recycling and disposal, based on a proportion of the embedded CO_2e emissions from vehicle production.

2.3 Emission Factor Assumptions

In this study, standardised figures are used to determine the CO_2 equivalent emissions for the production and use of electricity and fuels consumed in the vehicle production and operational phases of a vehicle's lifetime.

These emission factors are shown in the following tables and are taken from the official figures used for reporting by the UK Government Department of Business, Energy and Industrial Strategy (BEIS).

Table 2.0: Carbon Intensity of Energy used for Vehicle Production

Energy Vector	Units	Emission Factor	Year	Source	Comments
Electricity	[kgCO_2e/kWh]	0.25	2020	BEIS (2020)	BEIS GHG Conversion Factor for Electricity CONSUMED
Natural Gas	[kgCO_2e/kWh]	0.18	2018	BEIS (2018)	

Table 2.1: Well-to-Tank (WTT) Emissions Factors for Fuels and Energy Vectors

Energy Vector	Units	Emission Factor	Year	Source	Comments
Petrol	[kgCO_2e/L]	0.59	2020	BEIS (2020)	Retail blend, with up to c.5%vol ethanol
Diesel	[kgCO_2e/L]	0.61	2020	BEIS (2020)	Retail blend, with up to c.7%vol biodiesel
Electricity	[kgCO_2e/kWh]	0.25	2020	BEIS (2020)	BEIS GHG Conversion Factor for Electricity CONSUMED

2.4 Key Reporting Terms

In the LCA model outputs, the total GHG emissions associated with a vehicle over its whole lifetime are reported in segments, a summary of which is given below:

Table 2.2: Key Reporting Terms

Vehicle Production	The embedded carbon of a vehicle as it rolls off the production line. Incorporates the assumptions made about the materials that go into the vehicle as well as the energy used to make and assemble all the components, including the battery for electric vehicles
Fuel Production	A value for the extraction, refining and transportation of liquid fuel (retail blend Petrol and Diesel in this study)
Electricity Production	The associated emissions of generation and transmission of electricity within the UK grid that is used to charge the battery of electric vehicles
Vehicle Use	The "Tank-to-Wheel" or tailpipe emissions of a vehicle while it goes about its operation
Battery Replacement	For electric vehicles that have an operational life longer than that of the battery warranty, the embedded carbon of the production of a replacement battery needs to be factored into the overall life cycle of the vehicle
Vehicle End-of-Life	The GHG emissions associated with the deconstruction, recycling and disposal of a vehicle and its component materials once it has reached the end of its useful life

For a fair and balanced comparison between different modes of transport, the calculated gCO_2e per km travelled is reported in this study, in addition to the more traditional total cumulative GHG emissions figure over the vehicle lifetime. This approach is necessary to accommodate the fact that the vehicles under comparison have a variety of different lifespans ranging from 3 to 14 years.

3. Scenario One - Electric Moped for Urban Commute

For scenario one, an L1 battery electric moped (pictured below) is used as the basis for the LCA activity. In this scenario, the moped is used for single person, inner-city commuting, typically travelling 100-150km per week in an urban setting.

A comparison is made with a small battery electric car performing the same inner-city commute.

Figure 3.0 Example of L1 Electric Moped

Assumptions associated with this scenario are:

- Annual operational mileage - 5,520km*
- L1 operational lifetime - 5 years
- Small battery electric car (40kWh) operational lifetime - 14 years

*** based upon a commuting scenario of 24km per day, 5 days per week, 46 weeks a year.**

3.1 Model Results & Commentary

Figure 3.1 -GHG emissions per km over whole lifetime of vehicle

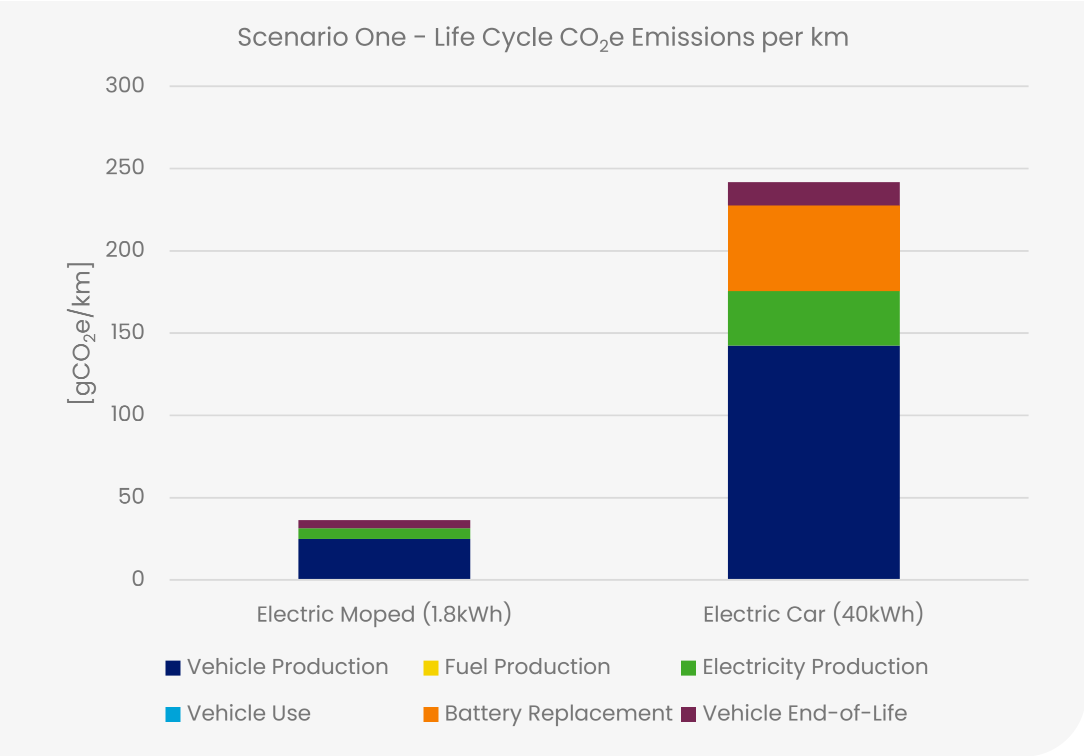


Figure 3.2 - Cumulative GHG emissions over whole life (tonnes CO_2e)

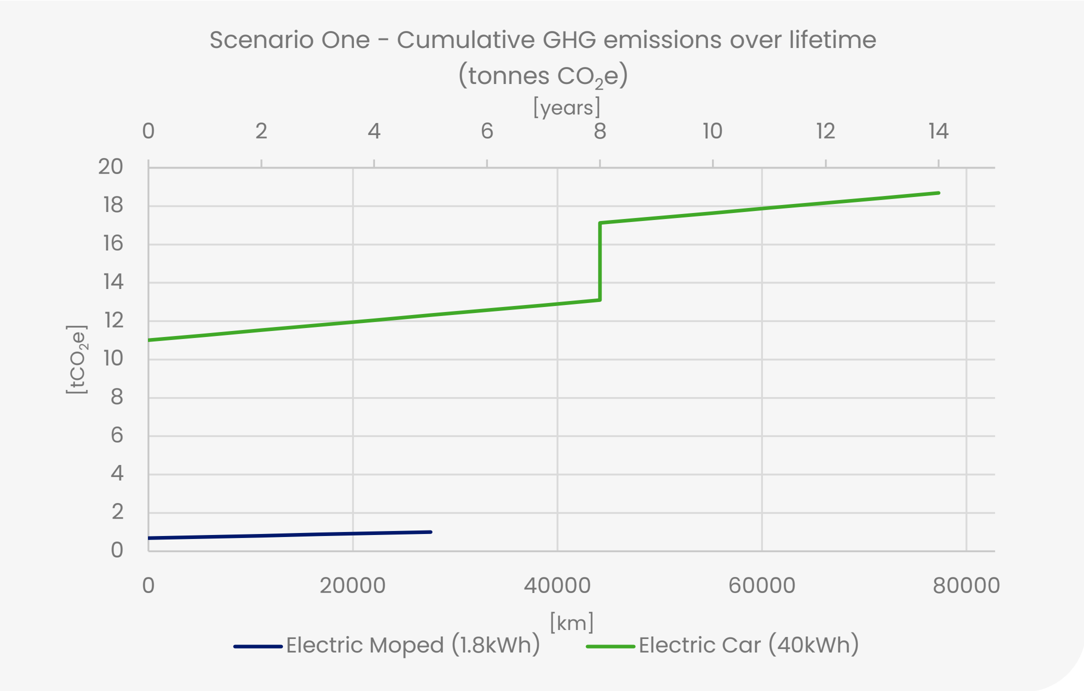


Figure 3.1 illustrates a fact common to battery electric vehicles of all types, this being that a large percentage of the lifetime GHG emissions of the vehicle are associated with its production phase. At present, the most significant, individual factor in this area is the manufacture of the high voltage traction battery.

In the case of the L1 moped, being a smaller, lighter and less powerful vehicle than the car against which it is compared, means that it can function with a greatly reduced battery capacity which in turn results in significantly lower GHG emissions during the production phase. These same characteristics also mean that the L1 moped consumes less energy during its operation and end-of-life phases, resulting in much lower GHG lifetime emissions per km. Similarly, the cumulative GHG emissions shown in Figure 3.2 are far lower for the L1 moped than the comparator vehicle.

On this basis and when viewed in GHG emission terms, the L1 moped can be said to be better suited to the inner-city commute use case scenario considered here than the vehicle against which it is being compared. However, it should be highlighted that different figures will be obtained if the car was permitted to operate to the full extent of its capability i.e. to carry 4 people. It should also be noted that having a shorter operational lifetime, the L1 moped requires replacement far earlier than the car.

For clarity, the large uptick in cumulative GHG emissions shown in Figure 3.2 for the battery electric car denotes the high voltage traction battery being replaced in the vehicle after 8 years. Due to the comparatively short operational lifetime of the L1 moped, the vehicle itself is assumed to be replaced rather than the traction battery.

Finally, in the case of Figure 3.2, the GHG emissions associated with the disposal of a vehicle at end of life have been amortised across the lifetime of the vehicle and incorporated into the cumulative GHG emission figures shown in the graph.

4. Scenario Two – 125cc Petrol Motorcycle for Local Delivery

For scenario two, an L3 125cc petrol motorcycle (pictured below) is used as the basis for the LCA activity. In this scenario, the motorcycle is used for local delivery, typically travelling 35-60km daily in an urban setting, or for single person commuting.

A comparison is made with a small battery electric car and a petrol mild hybrid car performing the same local commute, in addition to a small battery electric van being used for local deliveries.

Figure 4.0 Example of 125cc Petrol Motorcycle

Assumptions associated with this scenario are:

- Annual operational mileage - 10,500 km
- L3 125cc petrol motorcycle operational lifetime - 3 years*
- Small battery electric car (40kWh) operational lifetime - 14 years
- Petrol mild hybrid car (1.8L) operational lifetime - 14 years
- Small battery electric van (33kWh) operational lifetime - 10 years

*** based upon commercial/business use for local delivery purposes.**

4.1 Model Results & Commentary

Figure 4.1 - GHG emissions per km over whole lifetime of vehicle

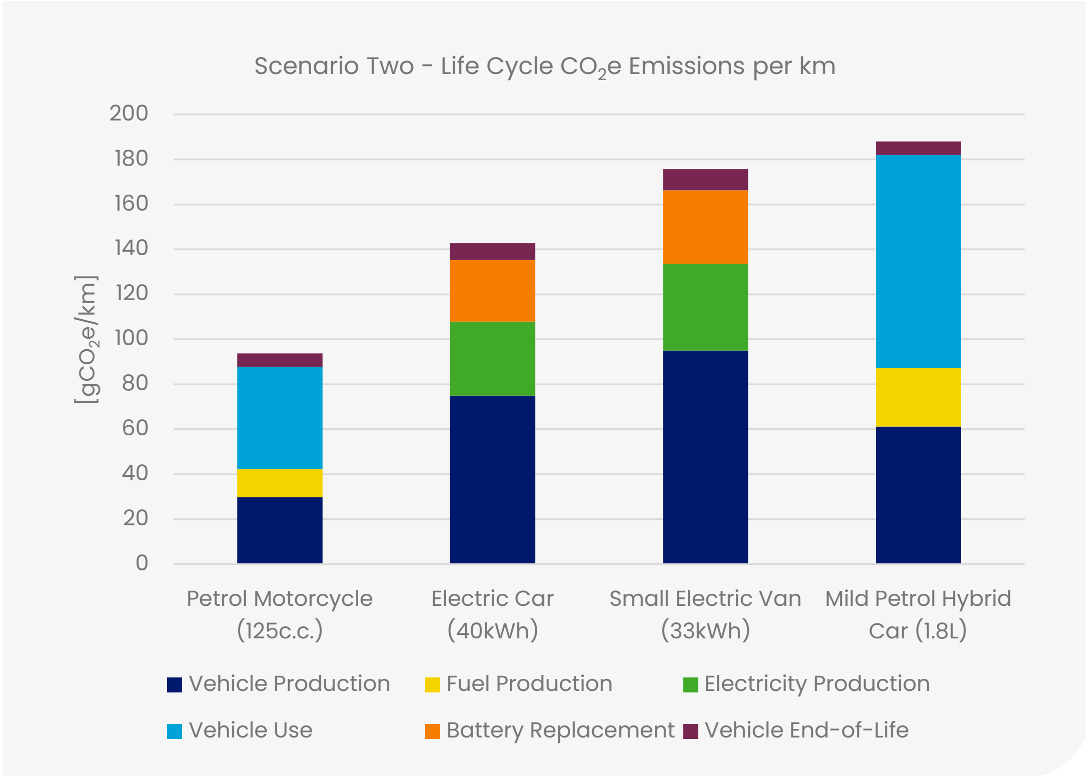
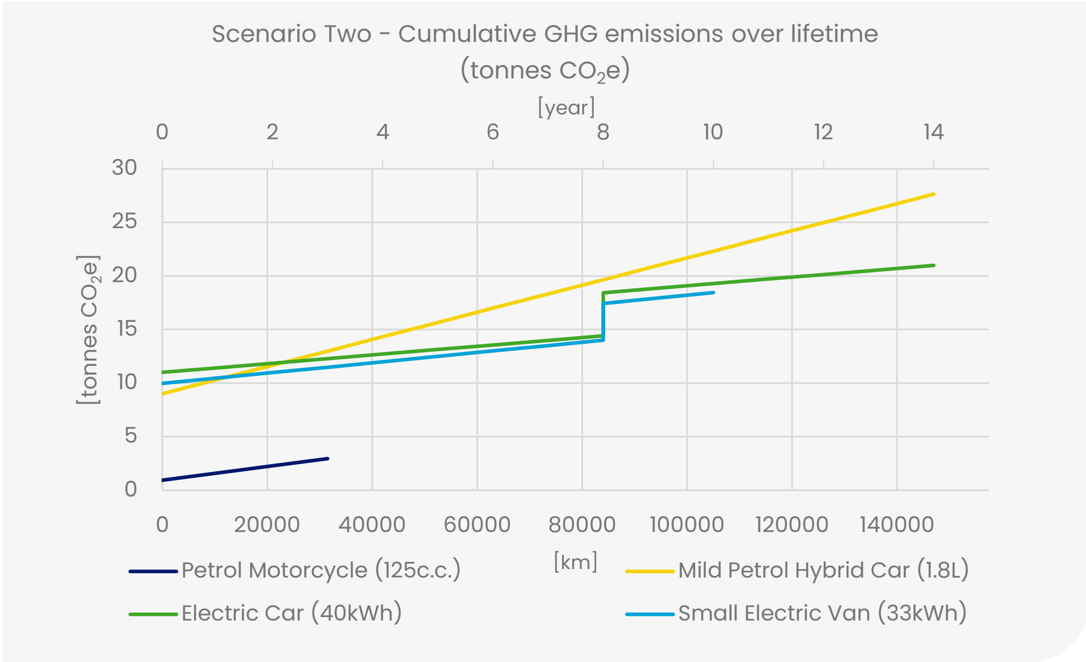


Figure 4.2 Cumulative GHG emissions over whole life (tonnes CO_2e)



For scenario 2, the 125cc petrol motorcycle exhibits a saving in lifetime GHG emissions per km over the comparator vehicles, particularly the petrol fuelled car, as illustrated in Figure 4.1. Being a smaller, lighter and less powerful vehicle, this is to be expected. It should be noted that if a battery replacement wasn't assumed for the small battery electric car in year 8 and the battery lasted the lifetime of vehicle, then the lifetime GHG emissions per km for the battery electric car would be significantly closer to that of the 125cc petrol motorcycle.

The primary contributor to the GHG emissions per km figure for the petrol motorcycle occurs in its operational phase and is associated with the production and consumption of fuel, the same also being true for the petrol mild hybrid car. In the case of the battery electric vehicles, the GHG emissions per km attributed to the production phase continue to dominate. At first glance, the lifetime GHG emissions per km for the small battery electric van being greater than the small battery electric car in Figure 4.1, appears to be at odds with the fact that the car is both heavier and is fitted with a larger capacity battery. The reason for this lies in the vehicle assumptions where the van is considered to have a shorter operational lifetime of 10 years compared to the car at 14 years, hence the van travels fewer kilometres in its lifetime resulting in a higher lifetime GHG emission per km.

When examining the lifetime cumulative GHG emissions shown in Figure 4.2, the 125cc petrol motorcycle sits substantially below the petrol car and electric 4-wheel vehicles. In part, this is caused by the short operational lifetime of 3 years specified for the 125cc petrol motorcycle, effectively requiring the motorcycle to be replaced twice to match the operational lifetime of the next closest vehicle, this being the small battery electric van at 10 years. If such a replacement strategy was employed, the lifetime cumulative GHG emissions for the 125cc petrol motorcycle solution would increase accordingly.

This observation aside and when viewed in GHG emission terms, the L3 125cc petrol motorcycle can be said to be better suited to the local delivery/commute use case scenario considered here than the vehicles against which it is being compared. However, as before, it should be highlighted that different figures will be obtained if both the car and van were permitted to operate to the full extent of their capability i.e. to carry 4 people or perform more than a single parcel/food delivery.

For clarity, the uptick in cumulative GHG emissions shown in Figure 4.2 for the battery electric car and van denote the high voltage traction battery being replaced in the vehicle. Again, the GHG emissions associated with the disposal of a vehicle at end of life have been amortised across the lifetime of the vehicle and incorporated into the cumulative GHG emission figures shown in Figure 4.2.

5. Scenario Three - 11kW Electric Motorcycle for Local Delivery

For scenario three, an L3 11kW battery electric motorcycle (pictured below) is used as the basis for the LCA activity. In this scenario, the motorcycle is used for local delivery, typically travelling 35-60km daily in an urban setting, or for single person commuting.

A comparison is made with a small battery electric car and a petrol mild hybrid car performing the same local commute, in addition to a small battery electric van being used for local deliveries.

Figure 5.0 Example of 11kW Electric Motorcycle

Assumptions associated with this scenario are:

- Annual operational mileage - 10,500 km
- L3 11kW battery electric motorcycle (3.2kWh) operational lifetime - 3 years*
- Small battery electric car (40kWh) operational lifetime - 14 years
- Petrol mild hybrid car (1.8L) operational lifetime - 14 years
- Small battery electric van (33kWh) operational lifetime - 10 years

*** based upon commercial/business use for local delivery purposes.**

5.1 Model Results & Commentary

Figure 5.1 - GHG emissions per km over whole lifetime of vehicle

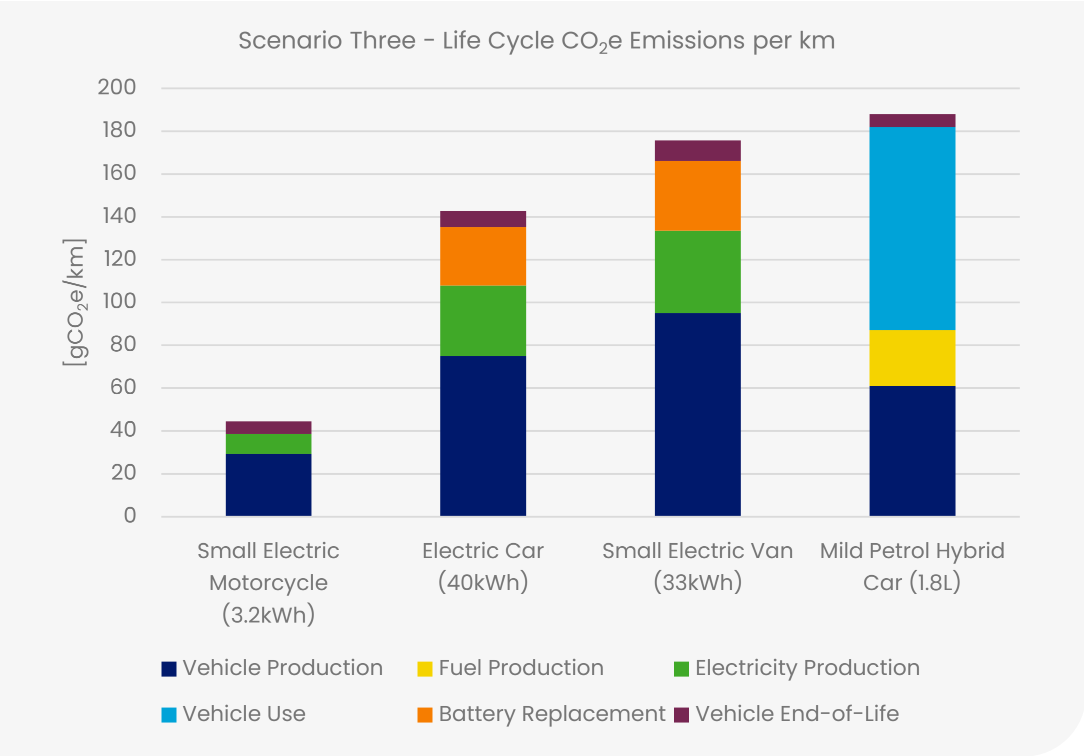
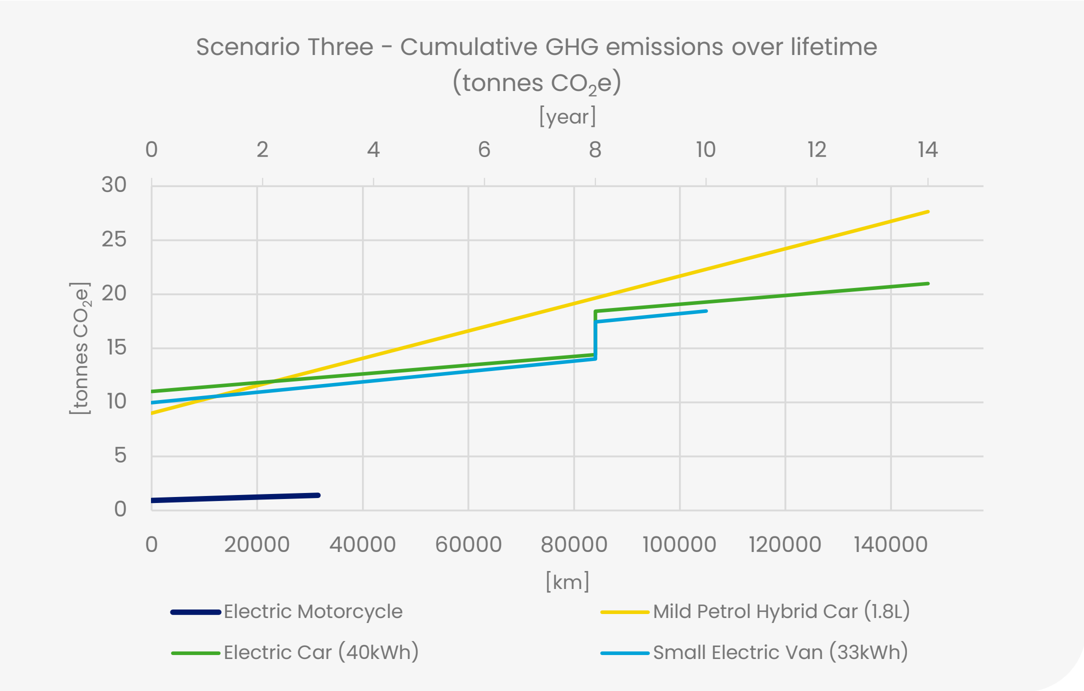


Figure 5.2 Cumulative GHG emissions over whole life (tonnes CO_2e)



Many of the same conclusions can be drawn for scenario 3 as for scenario 2.

As shown in Figure 5.1 and Figure 5.2, the 11kW battery electric motorcycle exhibits both lower lifetime GHG emissions per km and lower cumulative lifetime GHG emissions than the vehicles with which it is being compared. This is principally due to the battery electric motorcycle consuming far less energy in operation than either of the cars or the van, which is more than sufficient to offset the relatively high GHG emissions per km figure associated with the manufacture of a motorcycle with a short 3 year operational lifetime.

As per scenario 2, the same observation holds true regarding the battery electric motorcycle being required to be replaced twice to match the operational lifetime of the next closest comparator vehicle. However, the incremental increase in cumulative lifetime GHG emissions associated with such a replacement strategy will be less in scenario 3 than scenario 2, due to the lower lifetime GHG emissions per km generated by the battery electric motorcycle compared to its petrol counterpart.

On this basis and when viewed in GHG emission terms, the 11kW battery electric motorcycle can be said to be better suited to the local delivery/commute use case scenario considered here than the vehicles against which it is being compared. However, as before, it should be highlighted that different figures will be obtained if both the car and van were permitted to operate to the full extent of their capability i.e. to carry 4 people or perform more than a single parcel/food delivery.

For clarity, the uptick in cumulative GHG emissions shown in Figure 5.2 for the battery electric car and van denote the high voltage traction battery being replaced in the vehicle. Due to the comparatively short operational lifetime of the L3 motorcycle, a traction battery replacement is assumed not to be required. Again, the GHG emissions associated with the disposal of a vehicle at end of life have been amortised across the lifetime of the vehicle and incorporated into the cumulative GHG emission figures shown in Figure 5.2.

6. Scenario Four - 650cc Petrol Motorcycle for Daily Commute

For scenario four, an L3 35kW 650cc petrol motorcycle (pictured below) is used as the basis for the LCA activity. In this scenario, the motorcycle is used for single person, daily commuting, typically travelling 90km each day in an extra urban setting.

A comparison is made with a small battery electric car and a petrol mild hybrid car performing the same daily commute.

Figure 6.0 Example of 35kW 650cc petrol motorcycle

Assumptions associated with this scenario are:

- Annual operational mileage - 20,000 km
- L3 35kW 650cc petrol motorcycle operational lifetime - 7 years
- Small battery electric car (40kWh) operational lifetime - 14 years
- Petrol mild hybrid car (1.8L) operational lifetime - 14 years

6.1 Model Results & Commentary

Figure 6.1 - GHG emissions per km over whole lifetime of vehicle

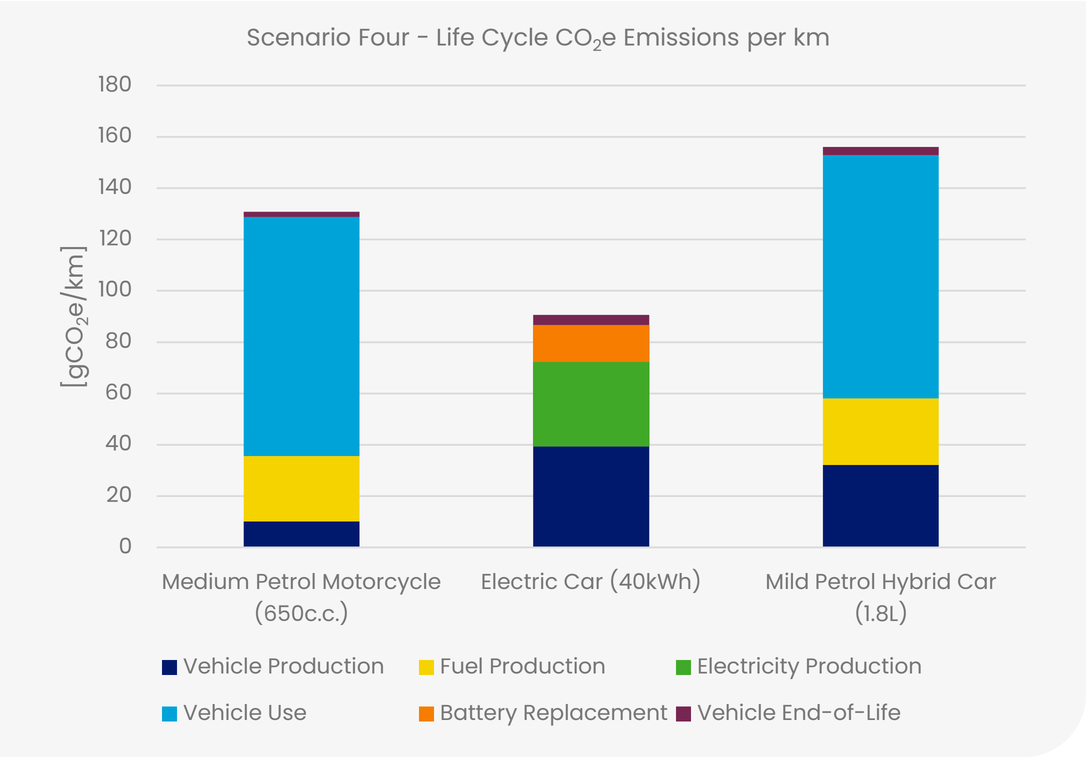


Figure 6.2 - Cumulative GHG emissions over whole life (tonnes CO_2e)

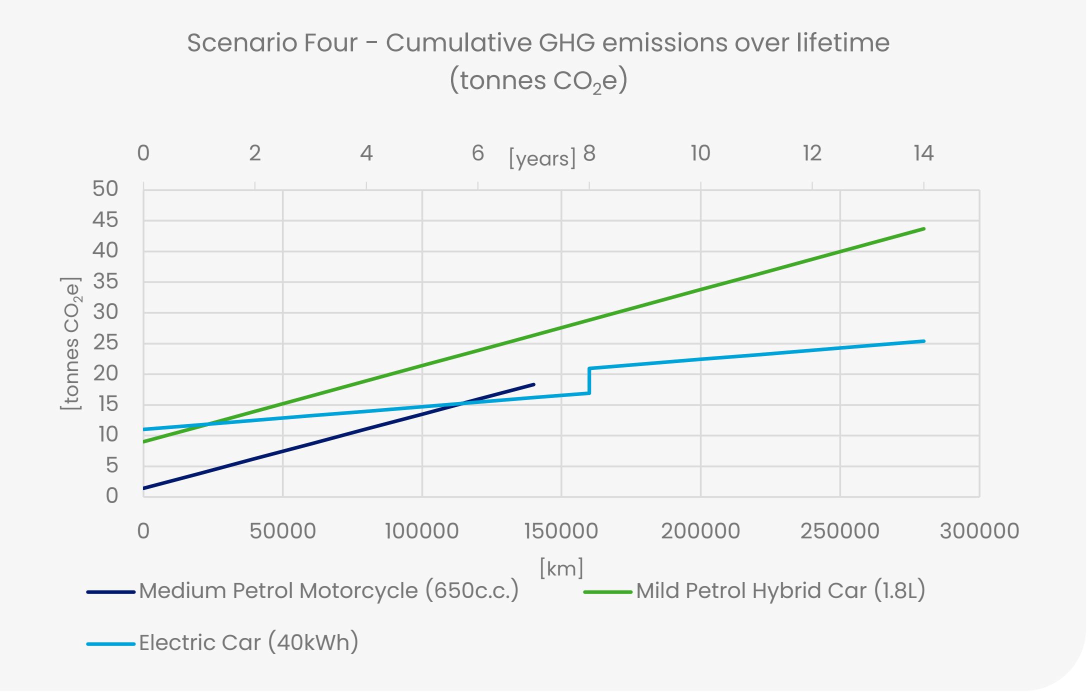


Figure 6.1 shows that the 35kW 650cc petrol motorcycle has slightly lower lifetime GHG emissions per km than the petrol mild hybrid car. Whilst both achieve similar figures for the operational or in-use phase of the vehicle, the smaller and lighter nature of the motorcycle results in production and end-of-life figures below that of its 4-wheel petrol counterpart. This situation is also reflected in Figure 6.2, where the cumulative GHG emissions for the motorcycle are consistently lower than the petrol mild hybrid car.

By comparison, the small battery electric car has significantly lower lifetime GHG emissions per km than either of the petrol vehicles. In terms of cumulative GHG emissions, the electric car starts at a disadvantage to the 35kW 650cc petrol motorcycle and the petrol mild hybrid car before outperforming both and going on to offer ever increasing savings after approximately 5-6 years of operation.

The key to the advantage held by the small battery electric car in this instance is the relatively large annual operational mileage being undertaken by the vehicles. As stated previously, battery electric vehicles typically have high cumulative GHG emissions during the production phase compared to petrol or diesel vehicles due to the nature of the materials and processes used, principally concerning the traction battery. In the operational phase, the roles are reversed with an internal combustion engine vehicle generating higher GHG emissions as a consequence of the production and consumption of fossil fuel. In practice, this means that the higher the annual operational mileage, the bigger the advantage becomes for the battery electric vehicle as the GHG emissions associated with the production and consumption of fuel for the petrol/diesel vehicle outstrips the GHG emissions associated with the production of the battery electric vehicle.

It is this situation that we see emerge in scenario 4. On this basis and when viewed in GHG emission terms, the small battery electric car can be said to be better suited to the daily commute use case scenario considered here than the 35kW 650cc petrol motorcycle or petrol mild hybrid car.

For clarity, the uptick in cumulative GHG emissions shown in Figure 6.2 for the battery electric car denote the high voltage traction battery being replaced in the vehicle. Again, the GHG emissions associated with the disposal of a vehicle at end of life have been amortised across the lifetime of the vehicle and incorporated into the cumulative GHG emission figures shown in Figure 6.2.

7. Scenario Five - 35kW Electric Motorcycle for Daily Commute

For scenario five, an L3 35kW battery electric motorcycle (pictured below) is used as the basis for the LCA activity. In this scenario, the motorcycle is used for single person, daily commuting, typically travelling 90km each day in an extra-urban setting.

A comparison is made with a small battery electric car and a petrol mild hybrid car performing the same daily commute.

Figure 7.0 - Example of 35kW battery electric motorcycle

Assumptions associated with this scenario are:

- Annual operational mileage - 20,000 km
- L3 35kW battery electric motorcycle operational lifetime - 7 years
- Small battery electric car (40kWh) operational lifetime - 14 years
- Petrol mild hybrid car (1.8L) operational lifetime - 14 years

7.1 Model Results & Commentary

Figure 7.1 - GHG emissions per km over whole lifetime of vehicle

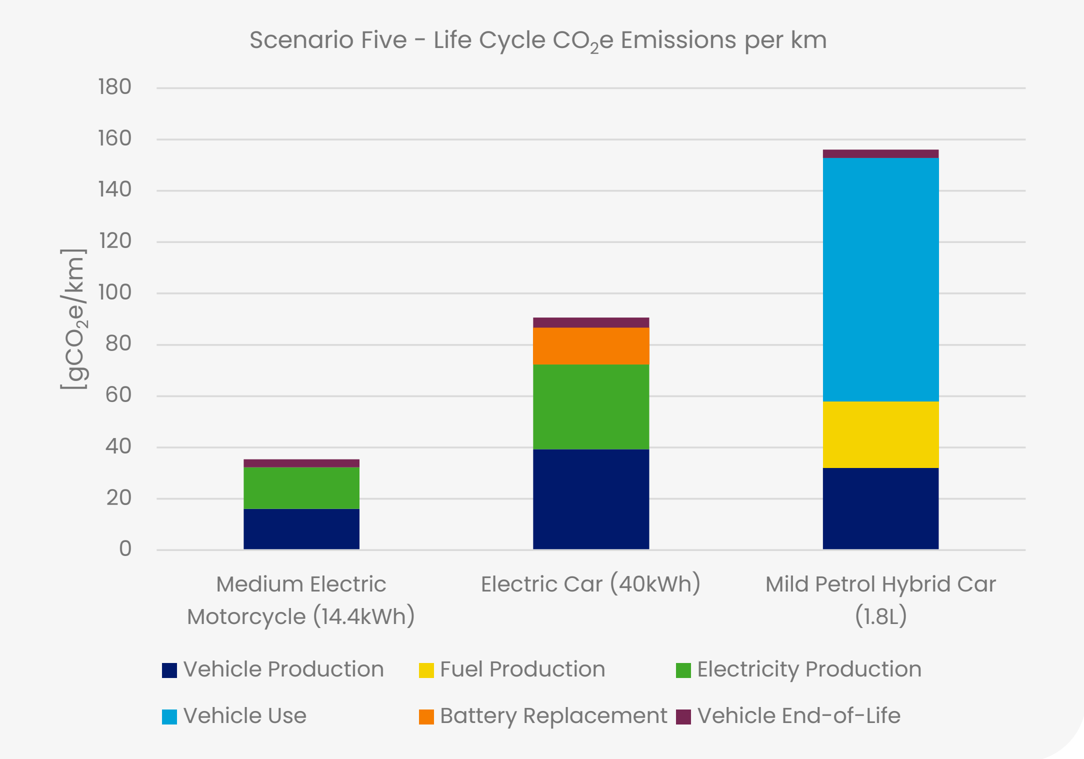
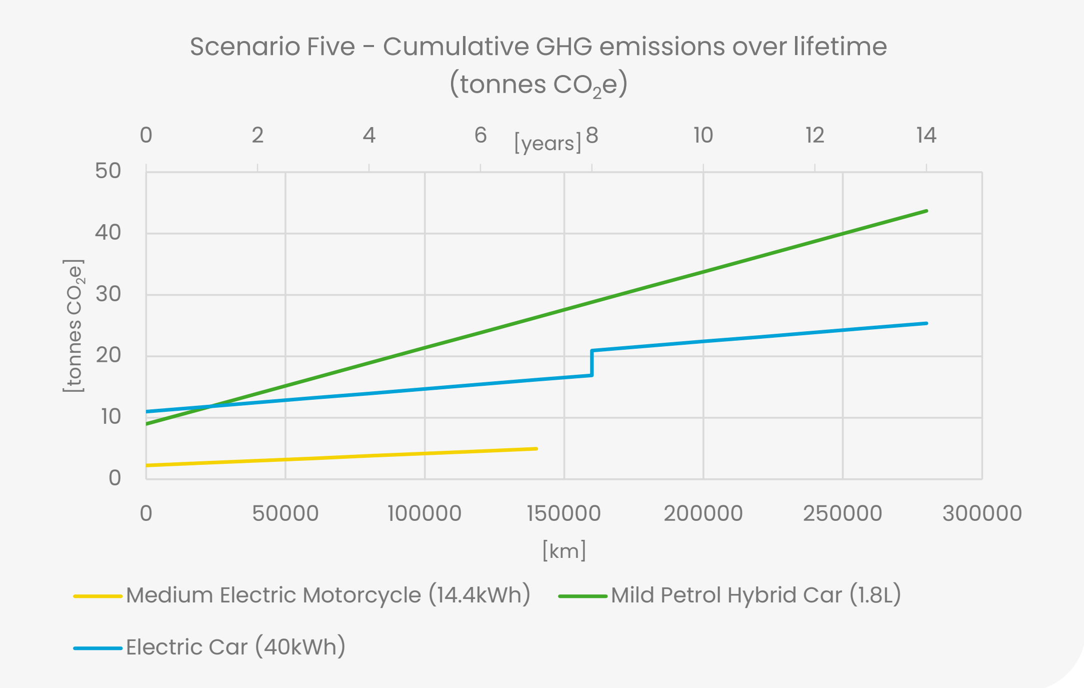


Figure 7.2 - Cumulative GHG emissions over whole life (tonnes CO_2e)



Many of the same conclusions can be drawn for scenario 5 as for scenario 4, particularly relating to comparisons between the small battery electric car and the mild hybrid petrol car.

However, the move to a battery electric drivetrain for the 35kW motorcycle results in lifetime GHG emissions per km and cumulative lifetime GHG emissions that are significantly lower for the L3 vehicle than either comparison car, as illustrated in Figure 7.1 and Figure 7.2 respectively. A combination of a lighter, smaller vehicle with lower operational GHG emissions are key factors for the battery electric motorcycle in this area.

On this basis and when viewed in GHG emission terms, the 35kW battery electric motorcycle can be said to be better suited to the daily commute use case scenario considered here than the vehicles against which it is being compared. As before, it should be highlighted that different figures will be obtained if both cars were permitted to operate to the full extent of their capability i.e. to carry 4 people.

Again, for clarity, the uptick in cumulative GHG emissions shown in Figure 7.2 for the battery electric vehicles denote the high voltage traction battery being replaced in the vehicle. In this instance, the operational lifetime and annual mileage specified for the 35kW battery electric motorcycle is considered sufficient to warrant the whole motorcycle being replaced after 7 years rather than just the battery.

As for previous scenarios, the GHG emissions associated with the disposal of a vehicle at end of life have been amortised across the lifetime of the vehicle and incorporated into the cumulative GHG emission figures shown in Figure 7.2.

8. Scenario Six - Performance Petrol Motorcycle for Leisure

For scenario six, an L3 950cc petrol motorcycle (pictured below) is used as the basis for the LCA activity. In this scenario, the motorcycle is used for leisure and pastime activities, travelling on average 4,000km (2,500 miles) per annum.

A comparison is made with a medium segment battery electric car and a medium segment performance petrol car performing the same type of activity.

Figure 8.0 Example of 950cc performance motorcycle

Assumptions associated with this scenario are:

- Annual operational mileage - 4,000 km
- L3 950cc petrol motorcycle operational lifetime - 14 years
- Medium segment battery electric car (55kWh) operational lifetime - 14 years
- Medium segment performance petrol car (2.0L) operational lifetime - 14 years

8.1 Model Results & Commentary

Figure 8.1 - GHG emissions per km over whole lifetime of vehicle

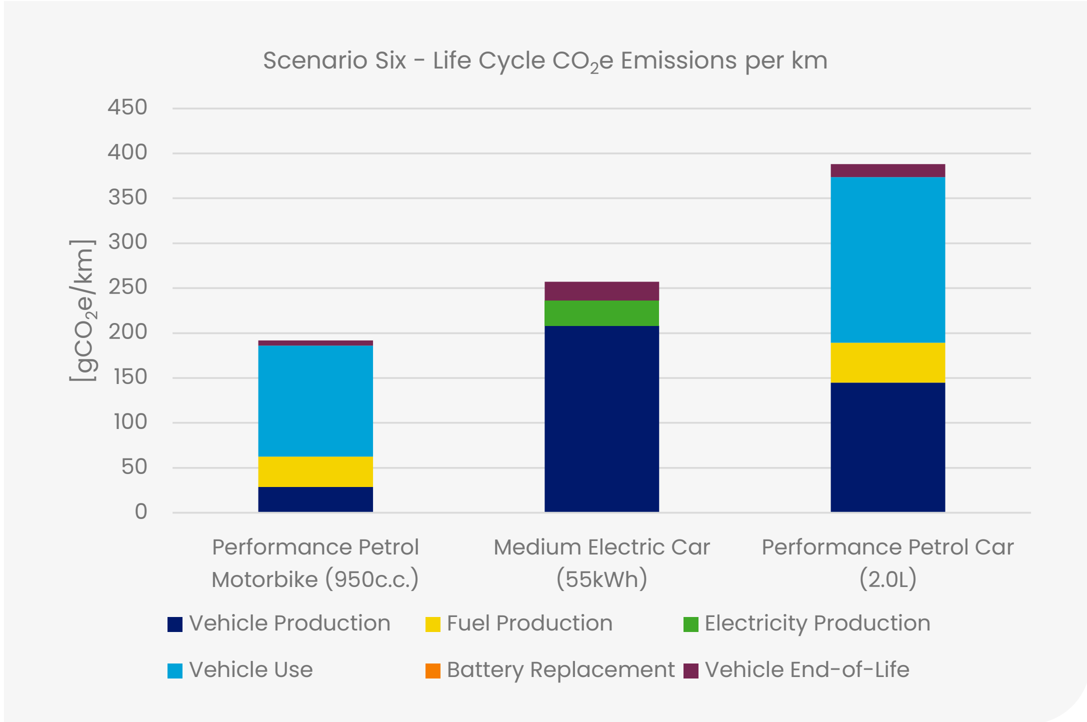
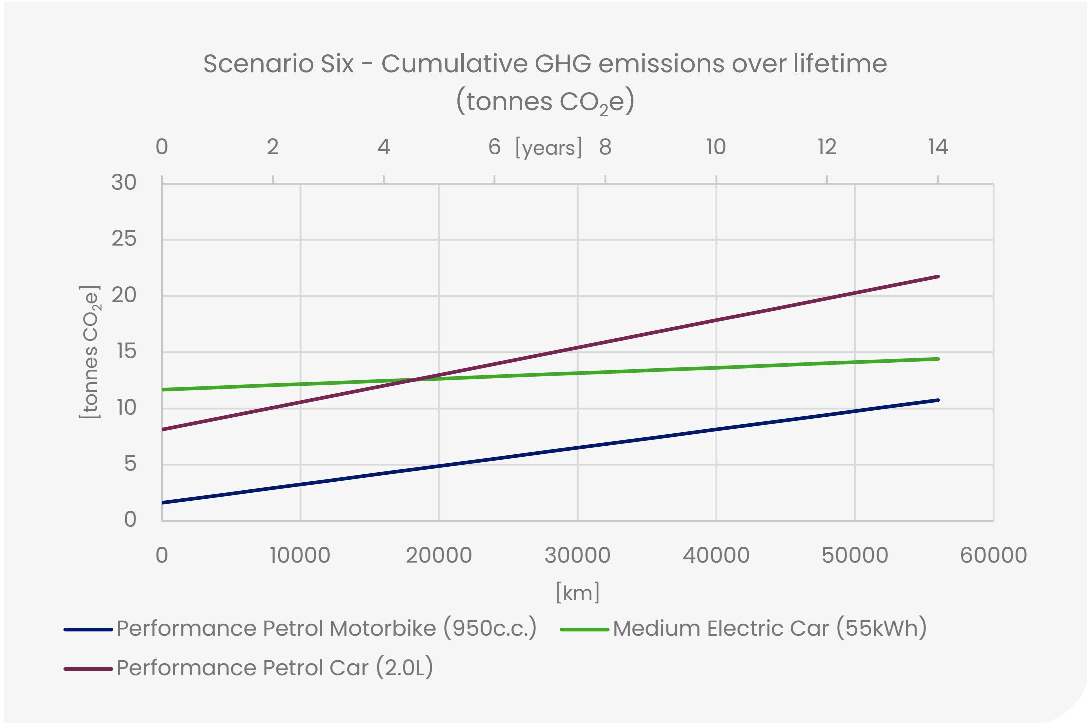


Figure 8.2 - Cumulative GHG emissions over whole life (tonnes CO_2e)



In many ways, the trend in the results seen here for scenario 6 mirror those present in scenario 2, albeit with significantly different vehicles involved.

The 950cc petrol motorcycle exhibits a saving in lifetime GHG emissions per km over the comparator vehicles, as shown in Figure 8.1. The primary contributor to the GHG emissions per km figure for the petrol motorcycle occurs in its operational phase and is associated with the production and consumption of fuel, the same also being true for the medium segment performance petrol car. In the case of the battery electric car, the GHG emissions per km attributed to the production phase continue to dominate, mainly due to the size of the battery pack fitted to the vehicle and the very low annual operational mileage associated with the scenario 6 use case.

However, given the small gap that exists between the figures for the petrol motorcycle and medium segment battery electric car in Figure 8.1, a relatively small increase in annual operational mileage is likely to result in the lifetime GHG emissions per km for the 950cc petrol motorcycle exceeding that of the battery electric vehicle.

Examining the lifetime cumulative GHG emissions shown in Figure 8.2, the 950cc petrol motorcycle sits below both cars, although it can be seen to converge with the medium segment battery electric car over the 14 year operational period. Comparing the two cars, the battery electric vehicle starts to offer a saving over the performance petrol vehicle after 4-5 years of operation.

On this basis and when viewed in GHG emission terms, the L3 950cc petrol motorcycle can be said to be better suited to the specific leisure activity use case considered here than the other comparator vehicles. As before, it should be highlighted that different figures will be obtained if both cars were permitted to operate to the full extent of their capability i.e. to carry 4 people. However, whether this is considered feasible or realistic when the use case is leisure focused is debatable. As mentioned, it is worth noting that if the annual operational mileage were to increase, the graph trends suggest that the battery electric car would become the lower GHG emission solution.

Given the low lifetime operational mileage specified for scenario 6, a traction battery replacement for the battery electric vehicles has been assumed not to be required.

As for previous scenarios, the GHG emissions associated with the disposal of a vehicle at end of life have been amortised across the lifetime of the vehicle and incorporated into the cumulative GHG emission figures shown in Figure 8.2.

9. Scenario Seven - Premium Electric Motorcycle for Leisure

For scenario seven, an L3 79kW premium battery electric motorcycle (pictured below) is used as the basis for the LCA activity. In this scenario, the motorcycle is used for leisure and pastime activities, travelling on average 4,000km (2,500 miles) per annum.

A comparison is made with a premium segment diesel SUV and a premium segment battery electric car performing the same type of activity.

Figure 9.0 Example of Premium Electric Motorcycle

Assumptions associated with this scenario are:

- Annual operational mileage - 4,000 km
- L3 79kW battery electric motorcycle operational lifetime - 14 years
- Premium segment battery electric car (100kWh) operational lifetime - 14 years
- Premium segment diesel SUV (3.0L) operational lifetime - 14 years

9.1 Model Results & Commentary

Figure 9.1 - GHG emissions per km over whole lifetime of vehicle

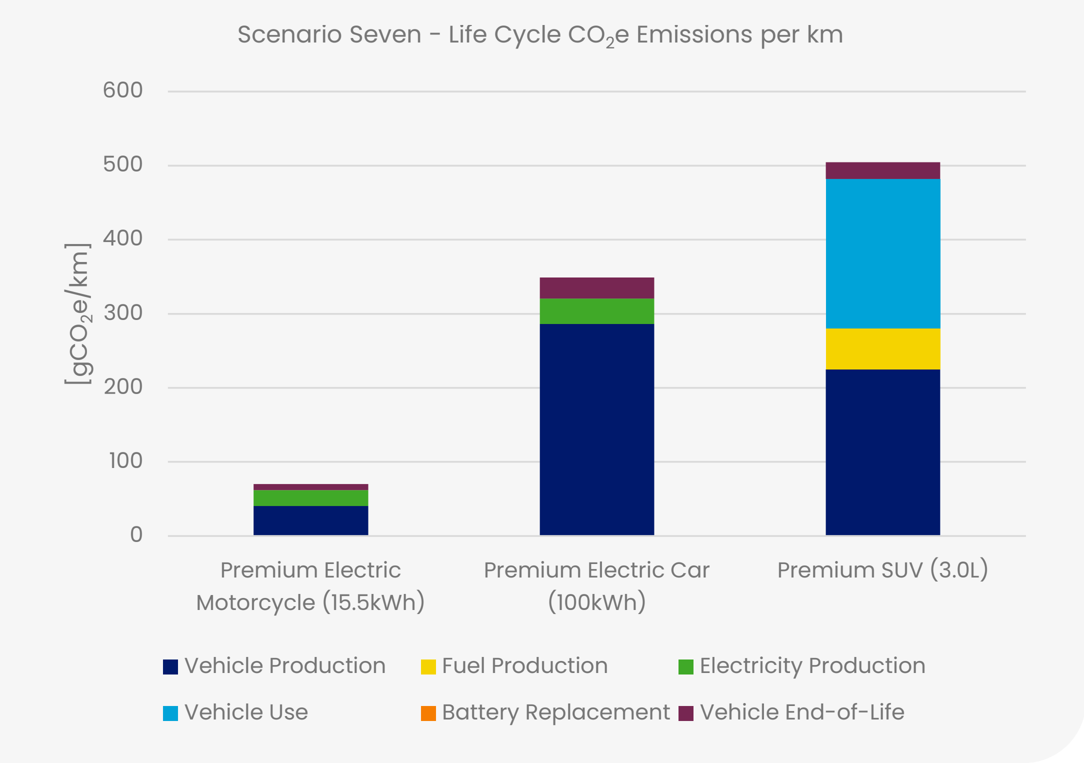
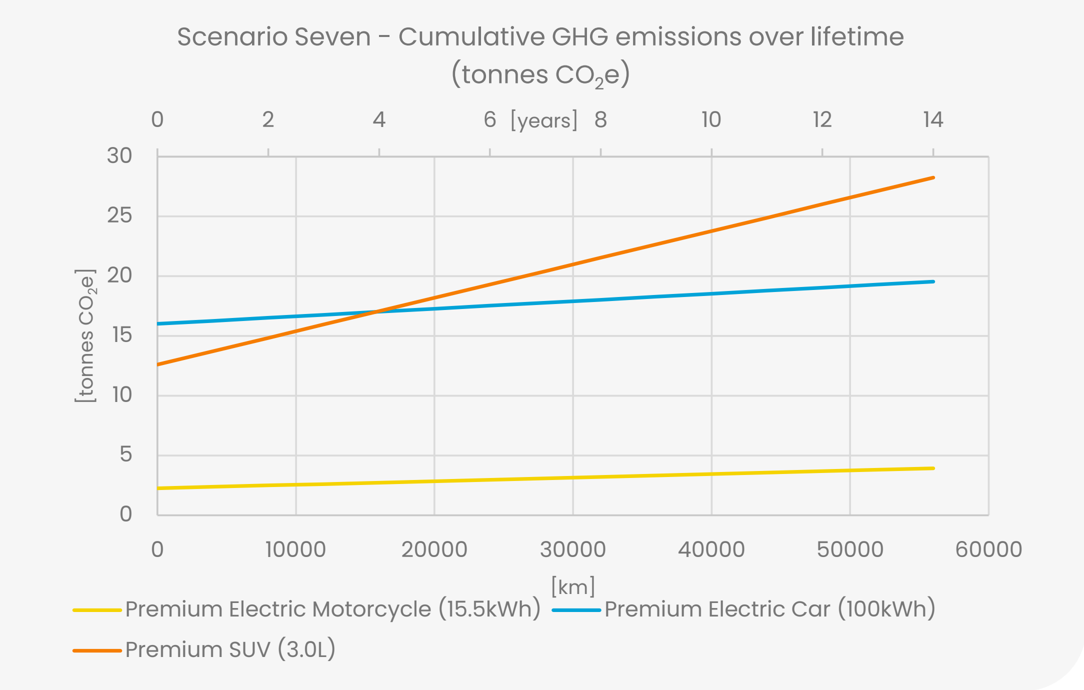


Figure 9.2 - Cumulative GHG emissions over whole life (tonnes CO_2e)



As shown in Figure 9.1 and Figure 9.2, the lifetime GHG emissions per km and lifetime cumulative GHG emissions for the 79kW battery electric motorcycle are significantly lower than either car for this use case scenario. This demonstrates the advantage of selecting a relatively small vehicle, in comparison to a car, for low annual mileage applications.

The premium segment battery electric car and premium segment diesel SUV are significantly higher in terms of lifetime GHG emissions per km than the battery electric motorcycle. However, in reality, it's likely that neither car would be subject to such a low annual mileage. A higher mileage would see the gap widen further between the two vehicles, as the SUV operational emissions exceed that of the battery electric car by some margin.

In terms of lifetime cumulative GHG emissions, the battery electric car starts to offer a saving over the diesel SUV after approximately 4 years of operation. Once again, given the low lifetime operational mileage specified for scenario 7, a traction battery replacement for the battery electric vehicles has been assumed not to be required.

Based on the results presented and when viewed in GHG emission terms, the L3 79kW battery electric motorcycle can be said to be better suited to the specific leisure activity use case considered here than the other comparator vehicles. As mentioned in scenario 6, a change in annual operational mileage will produce different results but given the margin of difference involved, the battery electric motorcycle is likely to retain its advantage from a GHG emission perspective whilst the mileage remains leisure related. Passenger number will have more of an effect in this instance but as also noted in scenario 6, multiple passengers in this type of leisure use case would be considered unusual.

As for previous scenarios, the GHG emissions associated with the disposal of a vehicle at end of life have been amortised across the lifetime of the vehicle and incorporated into the cumulative GHG emission figures shown in Figure 9.2.

10. Scenario Eight - L7 Cargo Quadricycle

For scenario eight, an L7 battery electric cargo quadricycle (pictured below) is used as the basis for the LCA activity. In this scenario, the cargo vehicle is used for inner-city and local urban deliveries, travelling on average 19,200km (12,000 miles) per annum.

A comparison is made with a small battery electric van and a small diesel van performing the same delivery activity.

Figure 10.0 Example of L7 Cargo Quadricycle

Assumptions associated with this scenario are:

- Annual operational mileage - 19,200 km
- L7 battery electric quadricycle (9kWh) operational lifetime - 5 years*
- Small battery electric van (33kWh) operational lifetime - 10 years
- Small diesel van (1.6L) operational lifetime - 10 years

*** based upon information supplied by vehicle operators and manufacturers of L7 battery electric cargo quadricycles.**

10.1 Model Results & Commentary

Figure 10.1 - GHG emissions per km over whole lifetime of vehicle

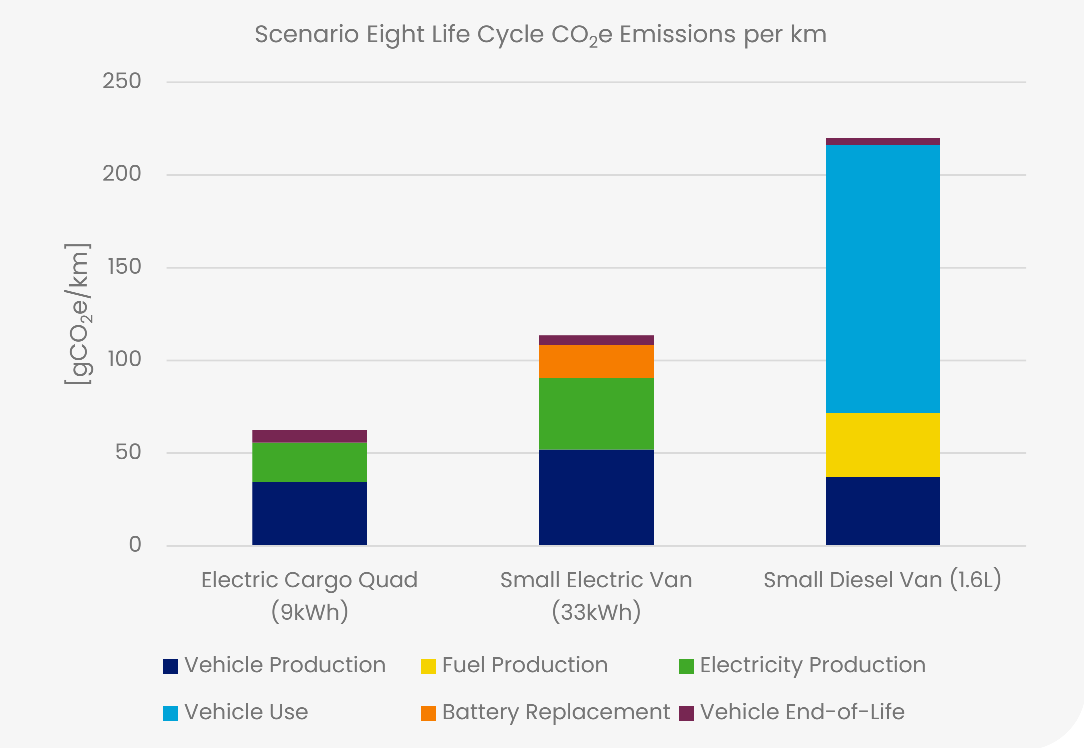
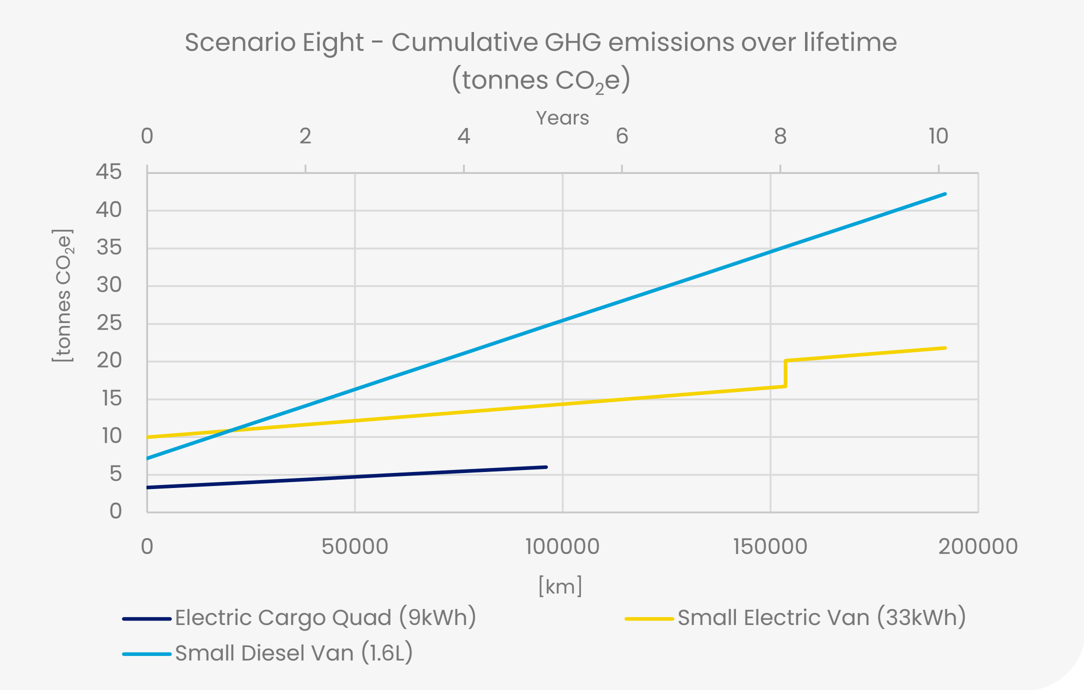


Figure 10.2 - Cumulative GHG emissions over whole life (tonnes CO_2e)



For both GHG emission metrics, the battery electric vehicles significantly outperform the small diesel van in scenario 8. A combination of high annual mileage and the low GHG emission levels offered by a battery electric solution in the operational phase mean that the diesel van is unable to compete in this regard. This is further emphasized by the fact that the GHG emission per km figure associated with the production phase of the L7 quadricycle is virtually identical to that of the diesel van, an area where a combustion engine vehicle traditionally holds an advantage over a battery electric variant.

Comparing the two battery electric vehicles, by virtue of its smaller size and lower capacity battery, the L7 quadricycle has both lower lifetime GHG emissions per km and lower lifetime cumulative GHG emissions than the battery electric van.

On this basis and when viewed in GHG emission terms, the L7 battery electric quadricycle can be said to be better suited to the specific urban delivery activity use case considered here than the other vehicles used for comparison.

However, at 5 years, the L7 quadricycle has half the operational lifetime and therefore mileage of the van, a significant factor influencing the GHG emission per km figures produced. If the quadricycle solution was required to achieve a 10 year operational lifetime equivalent to that of the van, then a replacement L7 vehicle would be needed for the second 5 year period. Under such circumstances, the combined lifetime cumulative GHG emissions of two L7 quadricycles would still be lower overall than the battery electric van, a situation exacerbated by the traction battery replacement taking place in year 8 for the van.

Similarly, it should be noted that, payload mass and volume are not taken into account in the analysis, with the battery electric van likely to have the greater capacity in both areas. If it became necessary to match the maximum payload capability of the battery electric van, then more than one L7 quadricycle vehicle would be required.

Again, for clarity, the uptick in cumulative GHG emissions shown in Figure 10.2 for the battery electric van denotes the high voltage traction battery being replaced in the vehicle. In this instance, the operational lifetime and annual mileage specified for the battery electric quadricycle is considered sufficient to warrant the whole vehicle being replaced after 5 years rather than just the battery. As for previous scenarios, the GHG emissions associated with the disposal of a vehicle at end of life have been amortised across the lifetime of the vehicle and incorporated into the cumulative GHG emission figures shown in Figure 10.2.

11. Conclusion

Table 11.0 below provides a summary of results from the eight use case scenarios considered in this report, with the highlighted areas denoting the vehicle with the lowest GHG emission footprint in each case.

Table 11.0: Scenario Output Summary

Scenario	Use case	Vehicles			
1	Inner city commute	L1 BEV	Small M1 BEV		
2	Local commute & delivery	L3 ICE (125cc)	Small M1 BEV	M1 Mild Hybrid	Small N1 BEV
3	Local commute & delivery	L3 BEV (11kW)	Small M1 BEV	M1 Mild Hybrid	Small N1 BEV
4	Daily commute	L3 ICE (650cc)	Small M1 BEV	M1 Mild Hybrid	
5	Daily commute	L3 BEV (35kW)	Small M1 BEV	M1 Mild Hybrid	
6	Leisure & pastime	L3 ICE (950cc)	Medium M1 BEV	Medium M1 ICE	
7	Leisure & pastime	L3 BEV (79kW)	Premium M1 BEV	Premium M1 ICE SUV	
8	Inner city & urban delivery	L7 BEV	Small N_1 BEV	Small N1 ICE	

In virtually all scenarios, the L-category vehicle is shown to have the lowest lifetime GHG emission per km and lifetime cumulative GHG emission figures of the vehicles under comparison.

Where the comparison is taking place between vehicles using the same powertrain solution, that is to say all vehicles are battery electric or all vehicles utilise an internal combustion engine, this conclusion is not unexpected. Being smaller, lighter and in several cases, less powerful, the L-category vehicles require less energy to manufacture, operate and dispose of than a passenger car (M1) or a van (N1), resulting in lower GHG emissions being generated. However, there are a number of additional factors to be considered that will have an influence on the result in this area, these include:

- L-category vehicles typically have a shorter operational lifetime than a car or van, the most extreme example in this study being 3 years for the 125cc/11kW motorcycle examined in scenarios 2 and 3. To match the operational lifetime of the 4-wheel comparison vehicles, a number of motorcycle replacements would be required, increasing the lifetime cumulative GHG emission figures overall
- L-category vehicles carry fewer people. For the purposes of this study, a single occupant has been specified for all vehicles. If the passenger car was instead assumed to carry 4 people on the same journey, it could be argued that 4 L-category vehicles would be required to complete the same activity, increasing both lifetime GHG emission per km and lifetime cumulative GHG emissions
- L-category delivery vehicles typically have a smaller payload capacity than a van. For the purposes of this study, a delivery payload suitable for the L-category vehicle has been assumed for the other comparator vehicles. If this was increased to match that of a van, then several L-category vehicles would be required to achieve the same objective, increasing lifetime GHG emission per km and lifetime cumulative GHG emissions

Where things become less clear cut is when the comparison is taking place between an L-category vehicle equipped with a petrol engine and a battery electric car or van.

For the local commute and delivery described in scenario 2, the petrol motorcycle achieves a lower GHG emission profile than the small battery electric passenger car. The same is true for the leisure and pastime activity associated with scenario 6, the large capacity petrol motorcycle outperforming the medium segment battery electric car in this regard. However, the roles are reversed for the daily commute specified in scenario 4, with the small battery electric car having lower lifetime GHG emission figures than the medium capacity petrol motorcycle.

The key factor here is the lifetime operational mileage involved. As explained in the body of the report, the higher the annual operational mileage, the bigger the advantage becomes for the battery electric vehicle, as the GHG emissions generated through the production and consumption of fuel for the petrol vehicle outstrips the GHG emissions associated with the manufacturing phase of the battery electric vehicle.

For scenario 2 and 6, with relatively low lifetime figures of 31,500km and 56,000km respectively, such mileage proves insufficient for the battery electric vehicle involved to overcome the initial disadvantage that it has in terms of production related emissions. Conversely, the lifetime operational mileage of 140,000km for the motorcycle seen in scenario 4, is more than sufficient for the small battery electric car to achieve significant lifetime GHG emission savings over the petrol motorcycle.

In summary, for the majority of the specific use case scenarios considered in the study, the L-category vehicles involved are shown to produce lower lifetime GHG emissions figures than the passenger car and van comparison vehicles. Sensitivities are identified that have the potential to influence this outcome, including lifetime operational mileage, passenger number, payload and traction battery replacement strategy.

Overall, from a GHG emission perspective, L-category vehicles are found to be particularly suited to single person commuting and light delivery, especially where relatively low annual mileages are involved. By comparison, for a specific high mileage operation considered in the study, a battery electric car was found to be more appropriate than an L-category vehicle equipped with a petrol engine. The study also highlights that where multiple person occupancy or sizeable payloads apply, an L-category vehicle may be limited in its application, highlighting the importance of selecting the right vehicle for the desired journey or activity.

11.1 Other Considerations

As highlighted in this report, additional factors and sensitivities exist that may potentially have an influence on the results presented but due to the short nature of the project were unable to be explored in detail. These include:

- The effect of battery replacement strategy. What is an appropriate battery replacement period, particularly in use cases where the lifetime operational mileage is very low?
- Applying an additional metric to the study in the form of gCO_2e per passenger km travelled to illustrate the effect of multiple person occupancy in a vehicle
- Applying an additional metric to the study in the form of gCO_2e per kilogram km travelled to illustrate the effect of payload mass
- Applying an adjustment to vehicle energy consumption figures to illustrate the effect of different driving operations i.e. city, urban, motorway, etc
- The effect of the "greening grid" is not factored into the study. The UK electricity grid decarbonised significantly over the last decade and will continue to do so moving forward, leading to lower lifetime GHG emission figures than those presented for the battery electric vehicles
- The effect of varying the country of assembly and manufacture for both the vehicle and key components such as the traction battery. For example, it could be argued that a battery electric moped is more likely to be produced in China which has a less decarbonised energy system than either Europe or the UK

Zemo Partnership would welcome the opportunity to undertake further research in these areas.

Zemo Partnership
Accelerating Transport to Zero Emissions

Zemo Partnership
3 Birdcage Walk, London, SW1H 9JJ

T: +44 (0)20 7304 6880
E: Hello@Zemo.org.uk
Visit: Zemo.org.uk

@Zemo_org
Zemo
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