Lifecycle CO_2e Assessment

Prepared for Transport Scotland

October 2020

Andrew Fraser

CEng FIMechE

Technical Consultant

Study Objectives

1. To quantify the whole-life CO_2e emissions of two different forms of road passenger transport, specifically a medium sized battery electric car (e.g. Nissan Leaf) and a single-decker bus (e.g. ADL ENV200).
2. To identify the impact of vehicle manufacturing and operating location on whole-life CO_2e, and from this, potential actions to help improve this as part of the net-zero objective.
3. To compare the relative CO_2e of both passenger transport modes in terms of specific emissions per passenger-km.
4. To help support a compelling case to migrate Scotland's service bus fleet to a zero tailpipe operation, in parallel with initiatives to require all passenger car sales to also become EV.

Note: "Equivalent CO_2", or "CO_2e", combines CO_2 with other emissions, e.g. methane, based on their Global Warming Potential

LCA for Scottish Passenger Transport - Context

- LowCVP always encourages the use of complete vehicle life-cycle assessment for CO_2 emissions, as the more common use of tailpipe only emissions gives incomplete and often misleading outcomes.
- The move to achieve net-zero GHG emissions also requires that all aspects of the vehicle lifecycle are assessed and incorporated in future policies and technology selection, otherwise key areas such as imported CO_2e in products will be missed.
- A key element of passenger transport decarbonisation plans in both the UK and Scotland is to encourage greater use of public transport vs. private cars. It is therefore desirable to understand how the lifecycle CO_2e of these modes compare on a passenger-kilometre basis.

LCA for Scottish Passenger Transport - Approach

- Modelling was conducted using the LowCVP LCA tool, updated with the most recent data on vehicle characteristics such as mass and battery sizes, CO_2e intensity for materials and fuel types (using WTW figures for fuels), embedded battery energy for Li-Ion batteries, and national electricity grid intensities.
- A medium sized car (Ford Focus/Nissan Leaf) was chosen as a typical passenger car, with appropriate mass and material content.
- A single decker bus was used for the bus analysis, typically represented by an ADL ENV200, with 29-40 seats, as these are the most prevalent, representing around 65% of the UK fleet. It is also felt that potential future expansion of bus routes into more suburban and rural areas are more likely to use single deck buses.
    - Vehicle details are contained in Appendix

Bus Lifecycle Analysis – Four Scenarios.

1. Conventional diesel bus built in UK, BEV built in China, comparison of operating energy sources on lifetime CO_2e; with bus operating in UK.
2. Comparison of lifetime CO_2e of BEV bus built in China, operated on four differing grid intensities.
3. Comparison of vehicle production location, showing benefit of lower grid carbon intensity, especially for battery manufacture.
4. Benefit of future improvements in Scottish grid CO_2e on lifecycle emissions.

Poland and China are used for comparisons of manufacture, as both are currently major centres of vehicle battery production.

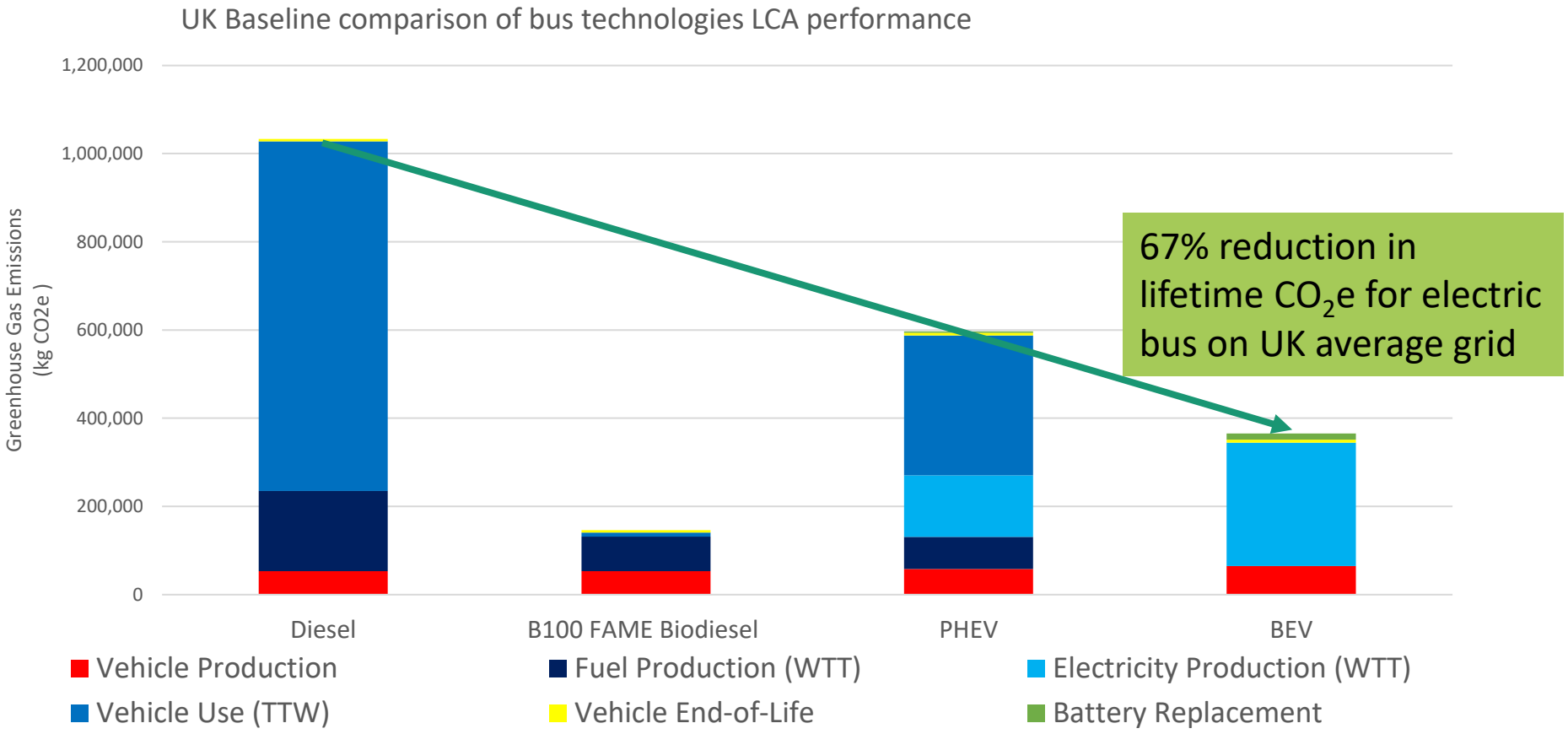
1: Single Deck Bus: UK Baseline lifecycle CO_2e Performance

Lifetime GHG saving Vs Diesel Baseline

B100: 86%
PHEV: 42%
BEV: 67%

Emissions from operation make up the largest portion of total while grid still has significant fossil-fuel element.

(BEIS 2019 UK Grid 278g/kWh CO_2e)



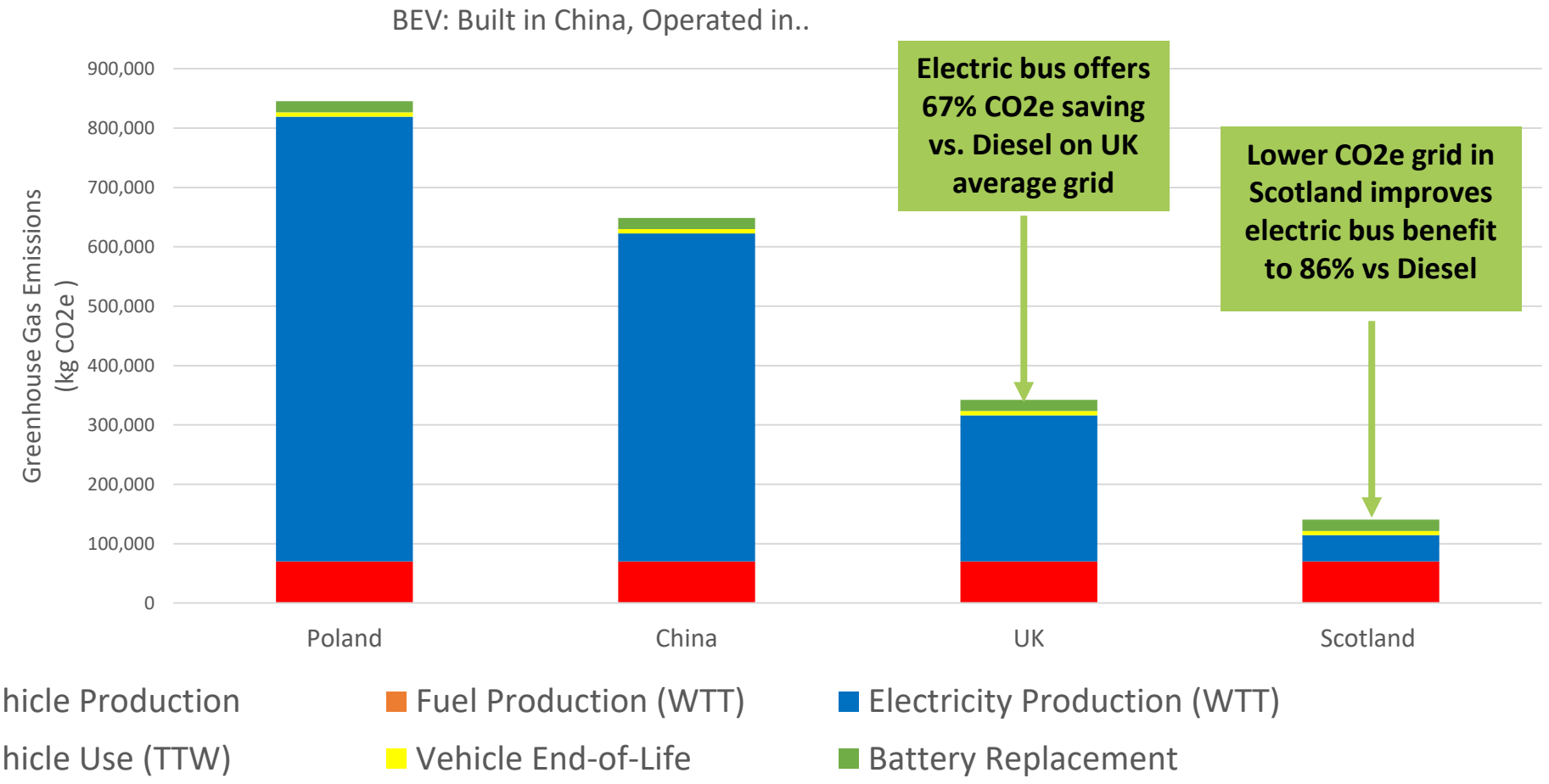
2: Single Deck Bus: Impact of Carbon Intensity of Electricity Grids

Lifetime GHG saving vs UK Diesel:

Poland = 18%
China = 37%
UK = 67%
Scotland= 86% saving

With a very low carbon grid, a BEV operated in Scotland produces 6 times less GHG over its lifetime vs the same bus in Poland.

The very low operational emissions in Scotland means that more scrutiny should be placed on vehicle production emissions

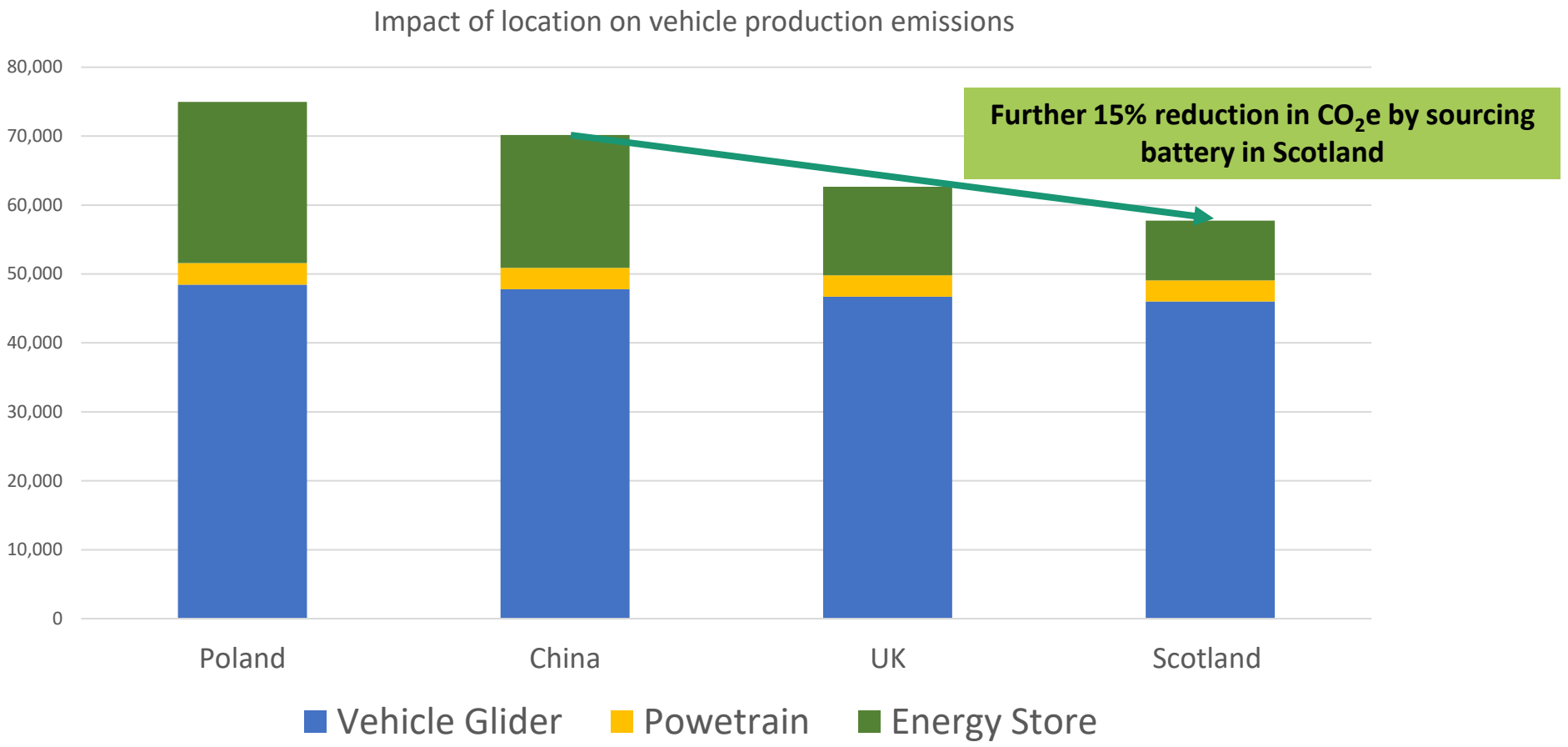


3: Single Deck Bus: Impact of Manufacturing Location on Vehicle Production CO_2e Emissions

The impact of location on the vehicle production emissions is relatively small in comparison to operational emissions .

This is down to the vehicle glider emissions varying relatively little due to steel and other energy intense materials being used.

However, manufacturing cells and battery in Scotland vs. China reduces embedded CO_2 by 10,600 kg, due to much lower carbon grid

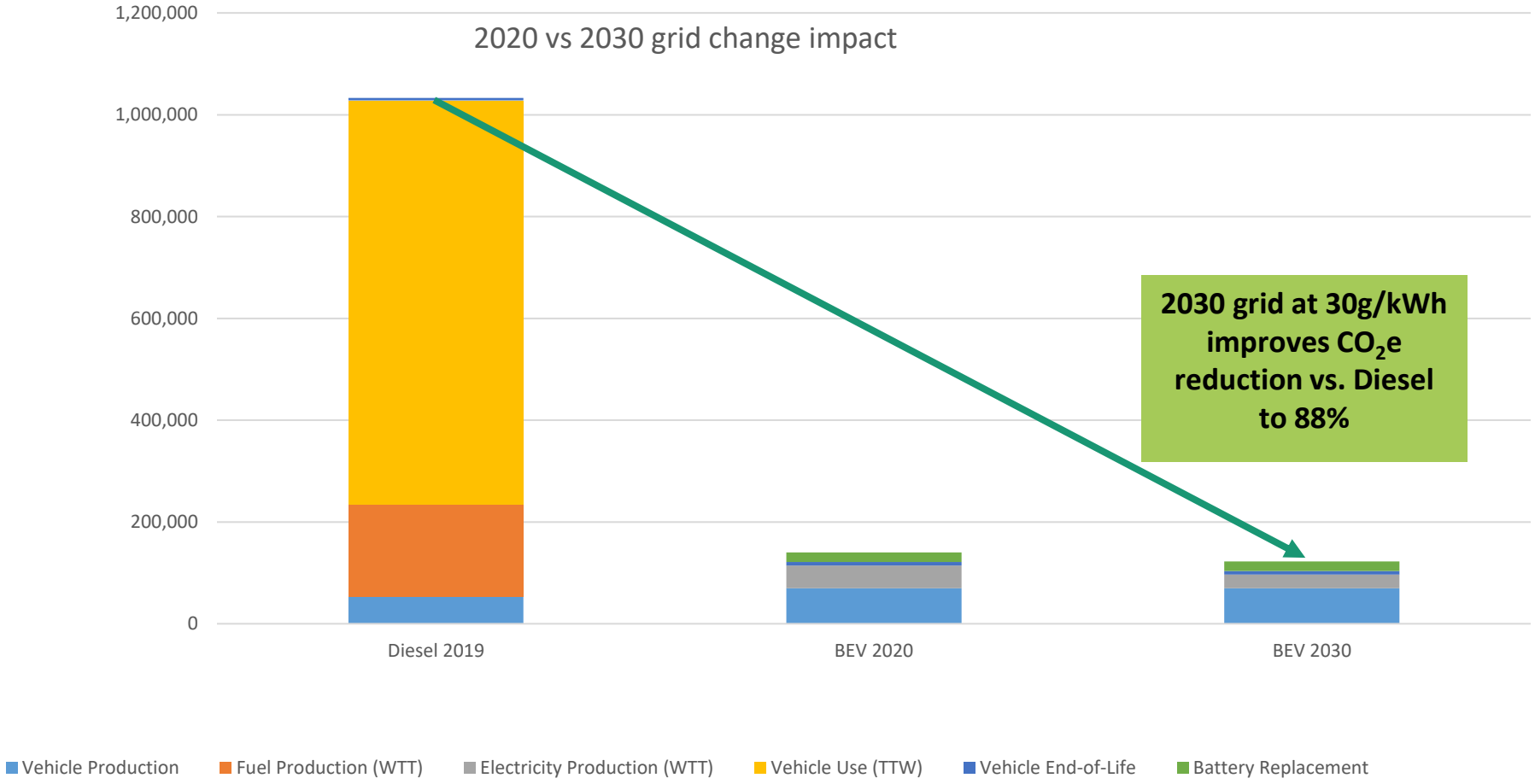


4: Single Deck Bus: Impact of Improvement in Scottish Grid Carbon Intensity on Vehicle Lifecycle CO_2e Emissions

The Scottish grid is already so clean that there is little change in the GHG emissions in 2030 vs 2020.

A move from 50 g CO_2e/kWh in 2020 to 30g CO_2e/kWh in 2030 only results in a 2% reduction in total LCA saving over 15 years.

An EV bus operating on the Scottish grid in 2030 saves around 88% Lifetime GHG vs diesel.



Bus LCA – Key Points

- A battery-electric bus operating on current UK grid offers a lifetime CO_2e saving of approximately **65%** vs. current market diesel.
- With the lower carbon intensity of the Scottish grid, the BEV bus offers an improvement of **86%** vs. market diesel, growing to **88% in 2030,** as grid improves further.
- Although vehicle operating emissions dominate, embedded manufacturing CO_2e is significant, ranging from c. **57-74 tons** per vehicle, depending on production location and grid intensity. Other actions will be required to offset this in order to achieve net-zero*.
- Local battery manufacture, taking advantage of Scotland's low-carbon grid, would give a significant CO_2e benefit of c. **10.6 tons**. (Equivalent to one complete passenger car BEV). This benefit will further increase if batteries are replaced in service.

* Building 1000 BEV buses per year will create embedded CO_2e emissions of approximately 60-70,000 tons per year. For comparison, operation of a large HGV fleet (e.g. Diageo, c. 200 vehicles), produces c. 30,000 tons CO_2e per year.

Medium Passenger Car Technology & Scenarios

- Due to the rapid trend away from diesel propulsion as a choice for new vehicles in the medium car segment, LCA comparison is made for three different technologies:
  - Conventional petrol
  - Petrol plug-in hybrid
  - Battery electric

- All are modelled as operating in Scotland (2020 grid 50 gCO_2e/kWh), however the manufacturing location & hence grid carbon intensity is also assessed for:

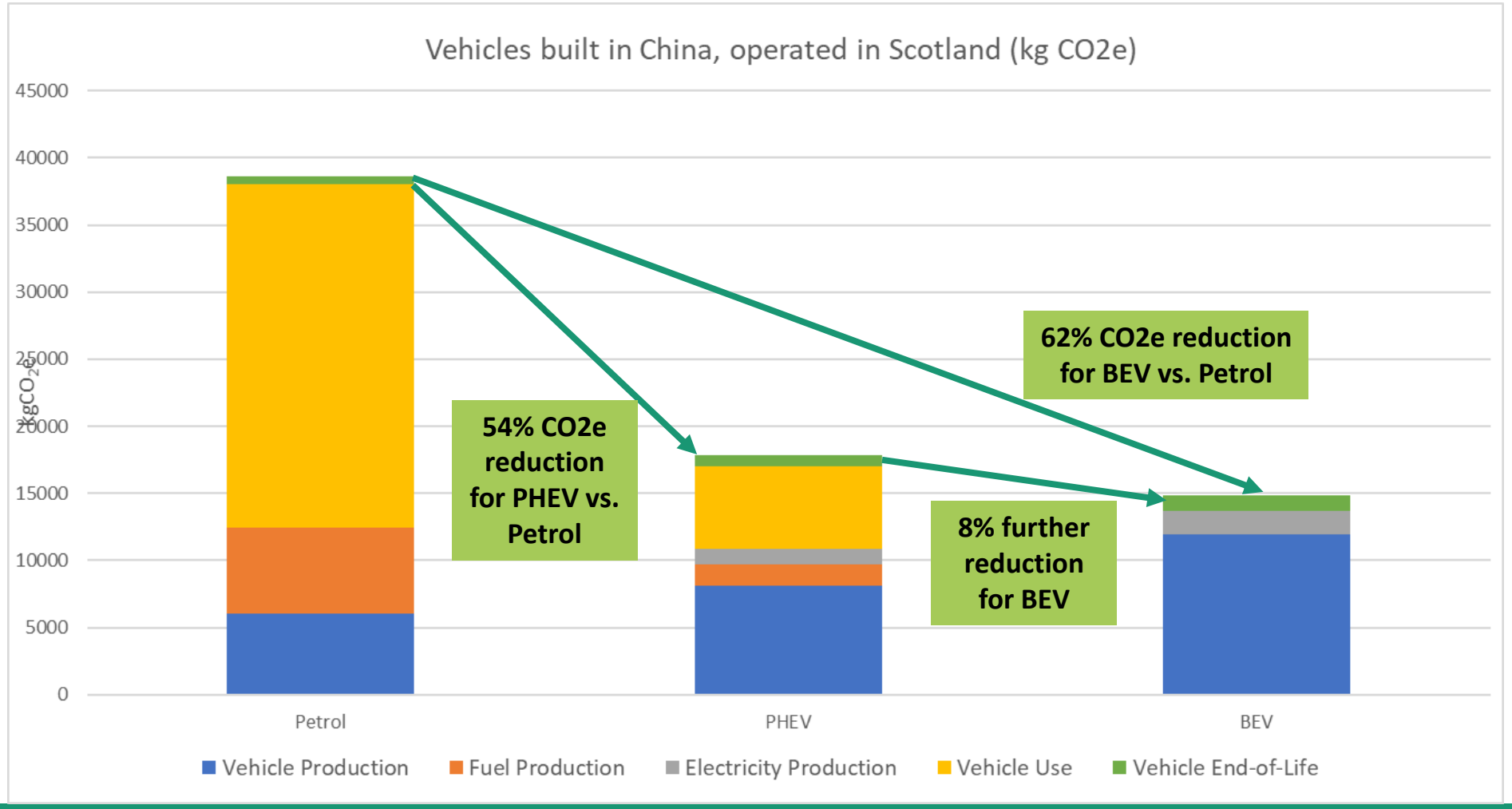
  - Poland (846 g/kWh) currently location of Europe's largest battery plant, LGChem.
  - China (624 g/kWh) currently source of batteries for many passenger cars, as well as ADL buses via BYD.
  - UK (278 g/kWh)

Grid CO_2e data from carbonfootprint.org for China and Poland, BEIS 2020 for UK.

Medium Passenger Car LCA Comparison – China Manufacture

Relatively high CO_2e grid increases embedded CO_2e, especially in battery manufacture, and limits benefit of BEV over PHEV

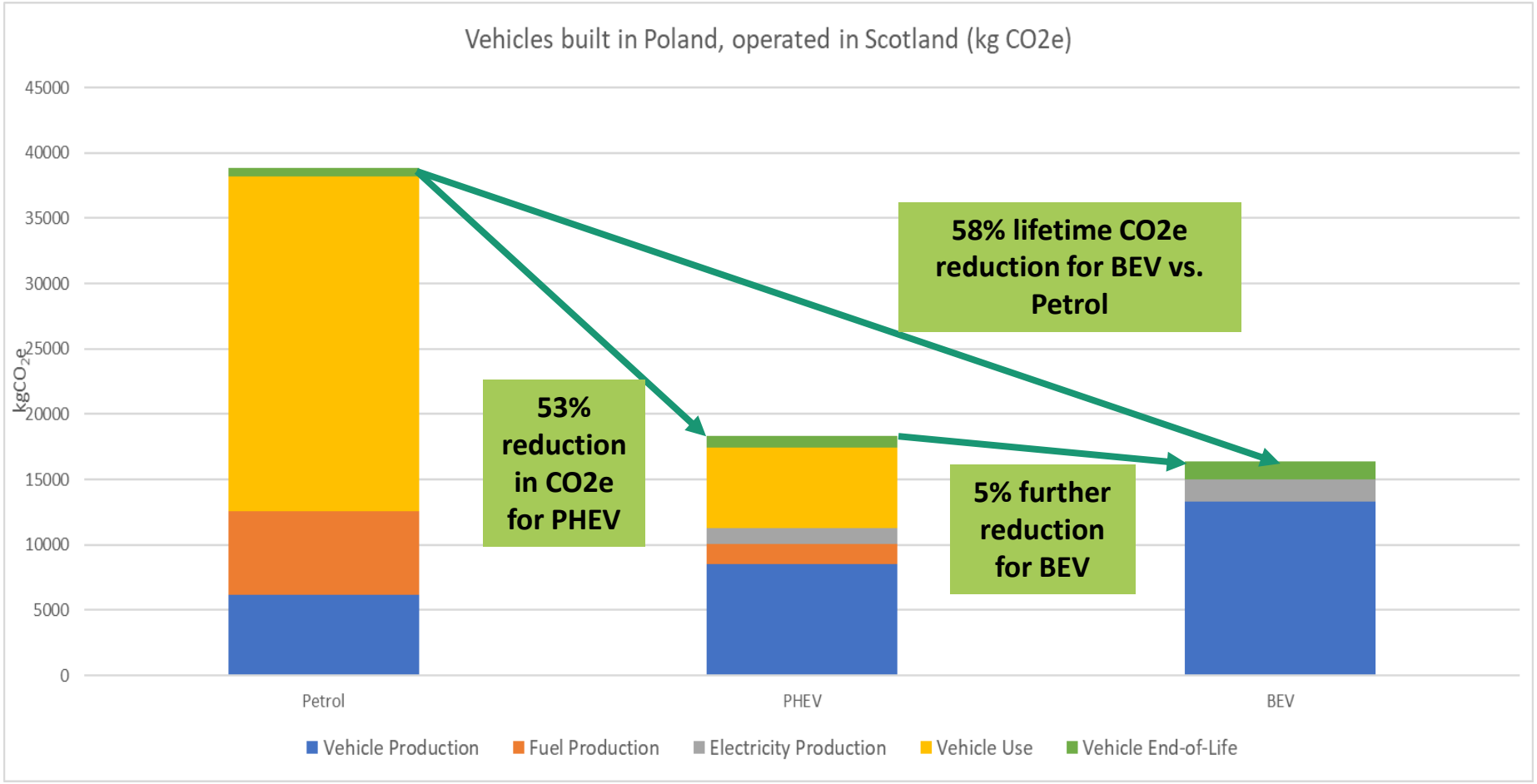
(PHEV assessed as 70% electric miles, 30% fuelled)



Medium Passenger Car LCA Comparison – Poland Manufacture

Very high CO_2e grid erodes benefit for BEV, showing overall only 5% CO_2e reduction vs. PHEV

(PHEV assessed as 70% electric miles, 30% fuelled)

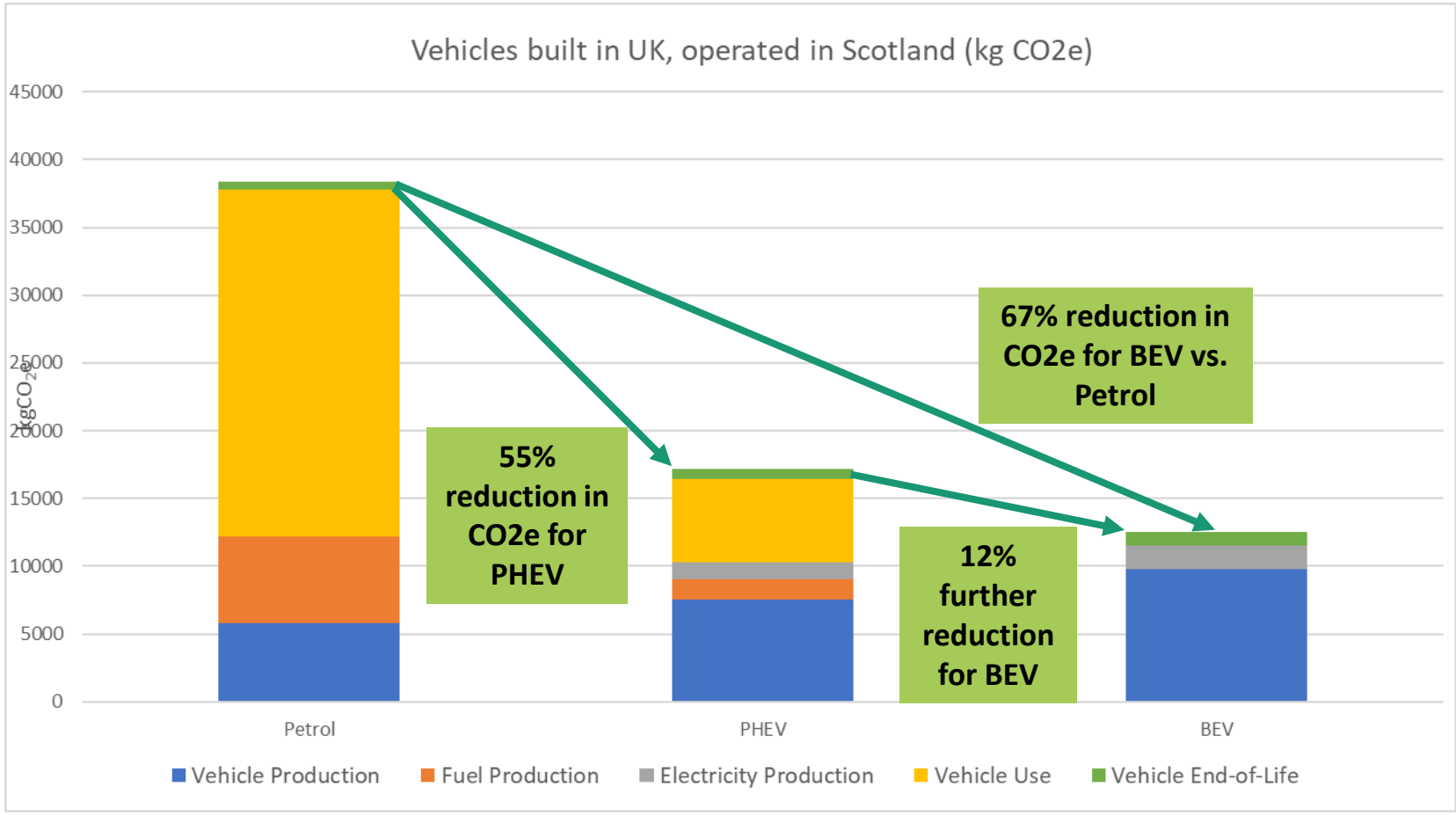


Medium Passenger Car LCA Comparison – UK Manufacture

Significantly lower CO_2e grid enhances both PHEV and BEV benefit by reducing embedded CO_2e.

Manufacture of battery using Scottish grid or futured UK grid will further improve BEV advantage vs. petrol. and PHEV.

(PHEV assessed as 70% electric miles, 30% fuelled)



Medium Car LCA – Key Points

- Vehicle manufacturing CO_2e is a larger proportion of total lifecycle CO_2e for a car than a bus, due to significantly lower propulsion energy over lifetime.
- The larger battery required for a BEV vs. a PHEV narrows the gap in lifecycle CO_2e, especially where manufacturing grid CO_2 intensity is higher, such as in Poland.
- The best-case BEV, built with UK grid, offers a lifetime CO_2e benefit of **67%** vs. a baseline petrol car. Built in China or Poland the figures are **62** and **58%** respectively.
- Embedded manufacturing CO_2e for BEVs varies from c. **9.8 – 11.9 tons**, depending on manufacturing location, which will require other offsetting actions to achieve net-zero.

Passenger Modal Comparison – Bus vs. Medium Car

- There is a strong desire to increase trips made by both public transport and active travel in future net-zero GHG passenger transport proposals.
- In order to provide compelling data to help encourage this modal shift, it is helpful to analyse lifecycle CO_2e emissions on a passenger-km basis, to provide direct comparison of the respective trip efficiencies.
- Having established lifecycle CO_2e for vehicles, it is necessary to estimate lifetime passenger-km in order to get a per-km figure.

Passenger Distance Calculation - Buses

- DfT data (see backup table 3) shows bus occupancy data ranging from a high of 20 in London, to a low of only 8 in Scotland, with a Great Britain average of 11.7.
- For a bus covering 80,000km/year over 15 years, a total distance of 1.2M km lifetime, these figures give passenger-km totals of:

  - London (best case): 24M Pax-km
  - GB average 14M
  - Scotland (worst case) 9.6M

Passenger Distance Calculation – Medium Car

- A medium car has a minimum occupancy of one by definition, a DfT average of 1.6, and a typical maximum of 4.
- Over a 15 year, 125,000 mile, 200,000km life these yield passenger-km figures of:
  - Minimum: 200,000 Pax-km
  - Average: 320,000
  - Maximum 800,000

(RAC Foundation average vehicle mileage = 8300 miles, 13,300km)

Absolute Passenger-km Results

- Using the lifetime passenger km calculation, combined with lifecycle CO2e, gives the following results for ranges of passenger-km CO_2e:

- Existing diesel SD bus: 43 – 108 gCO_2e/PAX-km
- UK built EV SD bus: 4.3 – 11
- Petrol passenger car: 48 - 192
- BEV passenger car made in PL: 21 - 82
- BEV passenger car made in UK: 16 - 63

These figures are shown graphically on the next page.

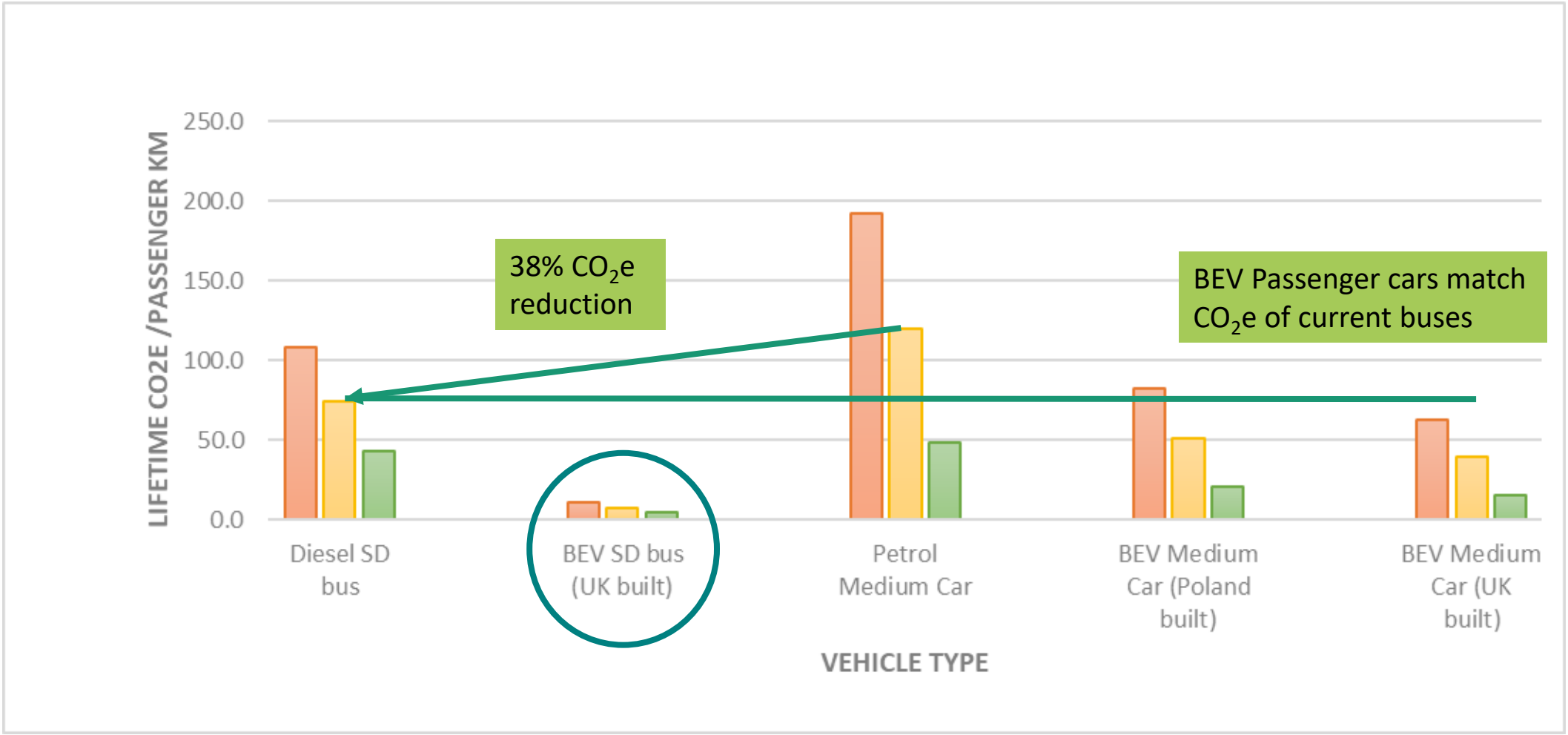
Comparison of Passenger-km CO_2e vs. Occupancy

Worst Case, Average, Best

Moving passenger travel out of petrol cars to a Diesel bus has a 38% CO_2e reduction potential.

However, electric cars can match the CO_2e of current diesel buses.

Electric (or equivalent) buses are required to support low CO_2e benefit for bus vs. car travel.



Overall Passenger - km CO_2e: Key Points

- There is a strong case for CO_2e reduction by moving passenger travel from current typical petrol cars to diesel buses.
- At average passenger occupancy, travel in a BEV passenger car (39-51g/PAX-km CO_2e) is generally better than the CO_2e intensity of a current diesel bus (74g) .
- Migrating bus fleets to EV, or other equally low CO_2e technology, in parallel with electrification of light-vehicle parc, maintains a compelling case for encouraging bus travel in place of some BEV usage, with **81% CO_2e** reduction on an average passenger-km basis.

Appendix
Table 1: Medium Car – Key Model Parameters

	Petrol	Hybrid	Plug-in Hybrid	Battery Electric
Vehicle Mass (kg)	1300	1331	1412	1546
Engine Type	1.4L turbo, 100kW	1.8L, 72kW	1.4L turbo, 100kW	
Transmission	6 spd manual	CVT	7 spd DCT	Single speed
E-Motor			70kW	90kW
Battery size & type		1.3 kWh NiMH	14kWh Li-Ion	60kWh Li-Ion
PHEV Electric Utility			70%	
WLTP CO_2	131	105	39	
Energy Consumption	5.5L/100km	4.4L/100km	1.7L/100km	20kWh/100km
Annual distance (km)	13,300	13,300	13,300	13,300

Appendix
Table 2: Bus – Key Model Parameters
Based on ADL ENV 200, 11.6m, 40 seats

	Diesel	Battery Electric
Mass (kg)	10,700	11,235
Engine	8L, 210 kW	180kW
Transmission	6 speed	Single Speed
Battery Size & type		310kWh, Li-Ion
Real-world tailpipe CO_2	1102g/km	
Energy consumption	40.8L/100km	123kWh/100km
Annual Distance (km)	80,000	80,000

Appendix
Table 3: DfT Bus Occupancy Data

Table BUS0304

Average bus occupancy[1] on local bus services by metropolitan area status and country: Great Britain, annual from 2004/05

Number

Year	London	English metropolitan areas	English non-metropolitan areas	England	Scotland	Wales	Great Britain	England outside London
2004/05	16.6	9.8	7.5	10.1	9.0	7.6	9.8	8.3
2005/06	18.3	9.7	7.3	10.4	9.2	7.3	10.0	8.2
2006/07	18.8	9.9	7.9	10.8	9.2	7.6	10.4	8.6
2007/08	20.3	10.3	8.5	11.6	9.1	7.8	11.0	9.1
2008/09	19.9	10.7	8.8	11.8	9.8	8.2	11.3	9.5
2009/10	19.6	11.0	8.6	11.7	10.0	7.6	11.3	9.4
2010/11	19.5	10.5	8.5	11.5	10.0	8.1	11.1	9.2
2011/12	19.7	10.1	8.6	11.6	9.5	8.9	11.2	9.2
2012/13	19.9	10.1	9.1	11.9	9.0	8.3	11.3	9.4
2013/14	20.6	10.2	9.4	12.3	8.9	8.4	11.6	9.7
2014/15	20.5	10.4	9.3	12.2	8.6	8.4	11.6	9.7
2015/16	19.8	10.2	9.0	11.9	8.4	8.5	11.3	9.4
2016/17	19.3	10.7	8.9	11.9	8.2	8.9	11.3	9.5
2017/18	20.2	10.5	9.0	12.2	8.1	8.8	11.5	9.5
2018/19	**20.0**	10.5	9.8	12.5	**8.0**	8.9	**11.7**	10.0

Appendix

Carbon emissions by vehicle type and occupancy (g CO2 equivalent)[2]

	Vehicle emissions per km	Per head at (existing average vehicle occupancy)	Per head at (achievable increased average vehicle occupancy)
Medium-sized petrol car 2020 (whole life emissions/km)	253	158 (1.6)	127 (2)
2019 fleet average petrol car (fuel consumption only)	174	109 (1.6)	87 (2)
2019 fleet average diesel car (fuel consumption only)	168	105 (1.6)	84 (2)
2019 fleet average diesel bus (fuel consumption only)	1,282	105 (12.2)	53 (24)
Medium-sized electric car in 2020 eg Nissan Leaf (whole life emissions/km, EU average CO2/ kWh electricity)	91	57 (1.6)	46 (2)
Dennis Enviro200 battery electric bus, currently in service in London, capacity 65 passengers (power consumption only)	438	36 (12.2)	18 (24)

6 **Decarbonising transport** The role of busses