# Integration of Drivers' Routines into Lifecycle Assessment of Electric Vehicles

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# Motivation

- At the end of 2021 more than 16.5 million electric vehicles (EVs) were in use around the world with the Net Zero Emissions Scenario expecting more than 300 million EVs to be in circulation by 2050[1].
- As of March 2023, 735,000 battery EVs (BEVs) and 480,000 plug-in hybrid EVs (PHEVs) were on the UK roads, a number expected to skyrocket in the coming years[2].
- EV manufacturing and recycling is more carbon intensive compared to internal combustion engine vehicles (ICEVs), but the usage of electricity can potentially compensate[1] these increased emissions based on assumption made during the Life Cycle Assessment (LCA) process.
- LCA models tend to be generic and do not take into account actual usage parameters and regional carbon data.

[1] International Energy Agency, 2022. Electric vehicles. URL: https://www.iea.org/reports/electric-vehicles
[2] Society of Motor Manufactures and Traders, 2023. Electric vehicle and alternatively fuelled vehicle registrations. URL: https://www.smmt.co.uk/vehicle-data/evs-and-afvs-registrations/

# Contributions

- Augment existing vehicles' LCA models[1] and enhance their accuracy by integrating country specific usage factors (esp. fuel mix) that result in different user charging patterns and types of chargers.
- Comparative study of three countries in Europe with a high penetration of EVs, viz. United Kingdom, Germany and Norway.
- In-depth study on a per-country (i.e., England, Scotland and Wales) and per-region level (i.e., the 14 regions as defined based on the DNO boundaries[2]) for Great Britain (GB).

[1] Transport & Environment, 2022. Update - t&e's analysis of electric car lifecycle co2 emissions. URL: https://www.transportenvironment.org/wp-content/uploads/2022/05/2022_05_TE_LCA_update-1.pdf
[2] National Grid ESO, 2023. Carbon intensity api. URL: https://carbonintensity.org.uk

# Literature review

- LCA is a standardised methodology based on the ISO 14040:2006 Standard[1].
- Recent review papers compared different available LCA models for estimating the total carbon footprint of different vehicular technologies including EVs and ICEVs[2, 3].

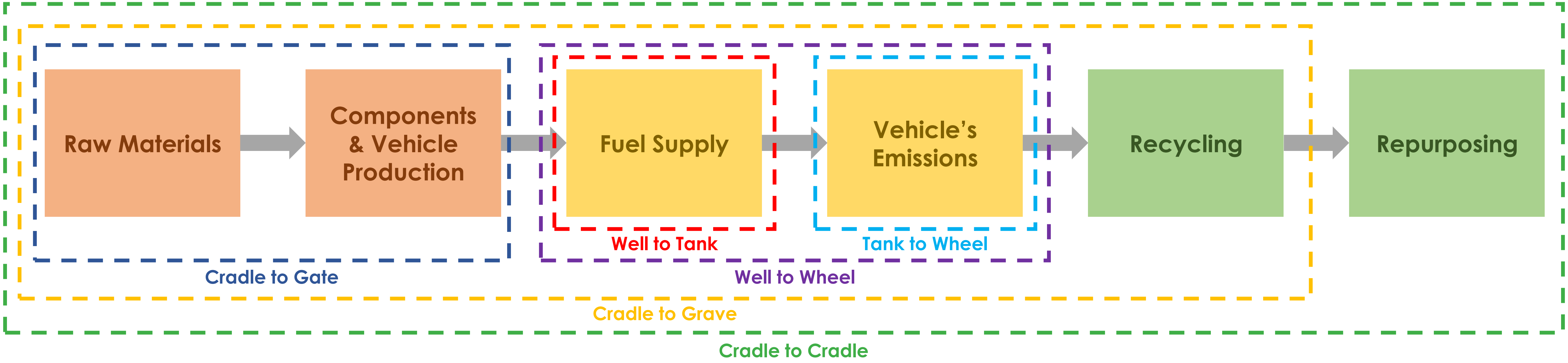


*Figure 1* – LCA models approaches


[1] International Organization for Standardization (ISO), 2009. Iso 14040: 2006 environmental management–life cycle assessment–principles and framework (2).
[2] Xia, X., Li, P., 2022. A review of the life cycle assessment of electric vehicles: Considering the influence of batteries. Science of the Total Environment , 152870doi:10.1016/j.scitotenv.2021.152870.
[3] Verma, S., Dwivedi, G., Verma, P., 2022. Life cycle assessment of electric vehicles in comparison to combustion engine vehicles: A review.Materials Today: Proceedings 49, 217–222. doi:10.1016/j.matpr.2021.01.666.

# Methodology

- Adaptation of Transport & Environment model[1].
- Integration of end-users' routines based on quantitative and qualitative data collected from three countries, viz. United Kingdom, Germany and Norway.
- National specific energy production data: generation mixture obtained through the European Network of Transmission System Operators for Electricity[2], which was translated to an approximate carbon footprint.
- GB regional specific generation mixture data obtained through the National Grid ESO[3].
- Fossil fuels carbon footprint → considering the Indirect Land-Use Change (ILUC) on a per-country level.

| Source | gCO2eq/kWh |
|---|---|
| Coal | 997 |
| Gas | 434 |
| Solar | 34 |
| Offshore wind | 14 |
| Onshore wind | 12 |
| Hydro | 11 |
| Nuclear | 5 |

*Table 1* – Generation footprint

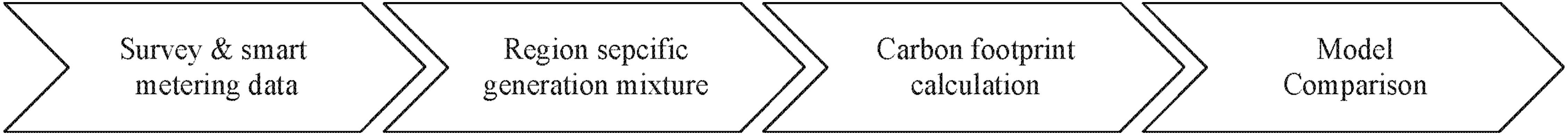


*Figure 2* – Methodology summary

[1] Transport & Environment, 2022. Update - t&e's analysis of electric car lifecycle co2 emissions. URL: https://www.transportenvironment.org/wp-content/uploads/2022/05/2022_05_TE_LCA_update-1.pdf
[2] European Network of Transmission System Operators for Electricity, 2023. ENTSOE Transparency Platform. URL: https://transparency.entsoe.eu/dashboard/show.
[3] National Grid ESO, 2023. Carbon intensity api. URL: https://carbonintensity.org.uk..

# Methodology – users' routines

- **UK:** Smart chargepoint survey[1] & EV charging research[2] with 1,000 EV driver participants; 93% of participants have access to a charging installation at home and select to do so. The vast majority of people with a dedicated chargepoint charge overnight. People with a 3-pin system charge directly after normal working hours. As UK comprises of the GB and the NI (where a different ESO exists) assessment was carried out only for the GB. Two charging profiles were created:
  - **1st profile:** dedicated chargepoint (@11kW), charging for a period of 3 hours, starting at 01:00;
  - **2nd profile:** 3-pin system(3kW) , charging for a period of 11 hours, starting at 18:00.
- **Germany:** Based on actual EV load data[3] of a household in Germany monitored for 1 year (2021), with a fast EV charger (11kW), a user profile was created.
- **Norway:** A field study was performed by the GECKO project[4]. Based on smart metering data, questionnaires and interviews in the area of Frederikstad, two profiles were created:
  - **1st profile:** dedicated chargepoint (@11kW), charging for a period of 3 hours, starting at 01:00;
  - **2nd profile:** 3-pin system (@3kW), charging for a period of 11 hours, starting at 17:00.

[1] Department for Business, Energy and Industrial Strategy, 2022. Electric Vehicle Smart Chargepoint Survey. Technical Report. URL: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1129104/electric-vehicle-smart-charging-survey-2022.pdf. .
[2] Department for Transport, 2022a. Electric Vehicle Charging Research. Technical Report. URL: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1078871/dft-ev-driver-survey-summary-report.pdf .
[3] Vavouris, A., Stankovic, L., Stankovic, V., 2022a. Smart meter electricity of a household in germany with electric vehicle charging annotation.doi:10.15129/c41a6a02-5df5-4ed7-b8e6-6488895d43f7. .
[4] GECKO MSCA ITN, 2023. Gecko project. URL: https://gecko-project.eu.

# Methodology – LCA

- A one-year calculation of the actual footprint based on the charging time and the actual electricity consumption of different households was performed.
- Results were then extrapolated to a vehicle's lifetime – i.e., total expected mileage before withdrawal from circulation.
- A medium-sized vehicle was simulated with an expected lifetime mileage of 225,000km. Powertrain parameters used for the LCA are presented in Table 2.

| Fuel | Medium-sized vehicle |
|---|---|
| **Petrol** | 7.5 l/km |
| **Diesel** | 6.2 l/km |
| **BEV (consumption)** | 17.5kWh/100km |
| **BEV (capacity)** | 60 kWh |

*Table 2 – Powertrain parameters[1]*



[1] Transport & Environment, 2022. Update - t&e's analysis of electric car lifecycle co2 emissions. URL: https://www.transportenvironment.org/wp-content/uploads/2022/05/2022_05_TE_LCA_update-1.pdf

# Findings across Europe

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- **GB:** 5.8% increase (~0.8 tCO2) with a slow charger and 13.3% decrease (~1.9 tCO2) with a  fast charger.
- **Germany:** 12.9% decrease (~2.7 tCO2) with a  fast charger.
- **Norway:** 1.5% increase (~0.2 tCO2) with a slow charger and 0.6% decrease (~0.1 tCO2) with a fast charger.
- The increase/decrease in the CO2 emissions was a result of the charge duration in relation to fuel mix at these times; a full charge is assumed.

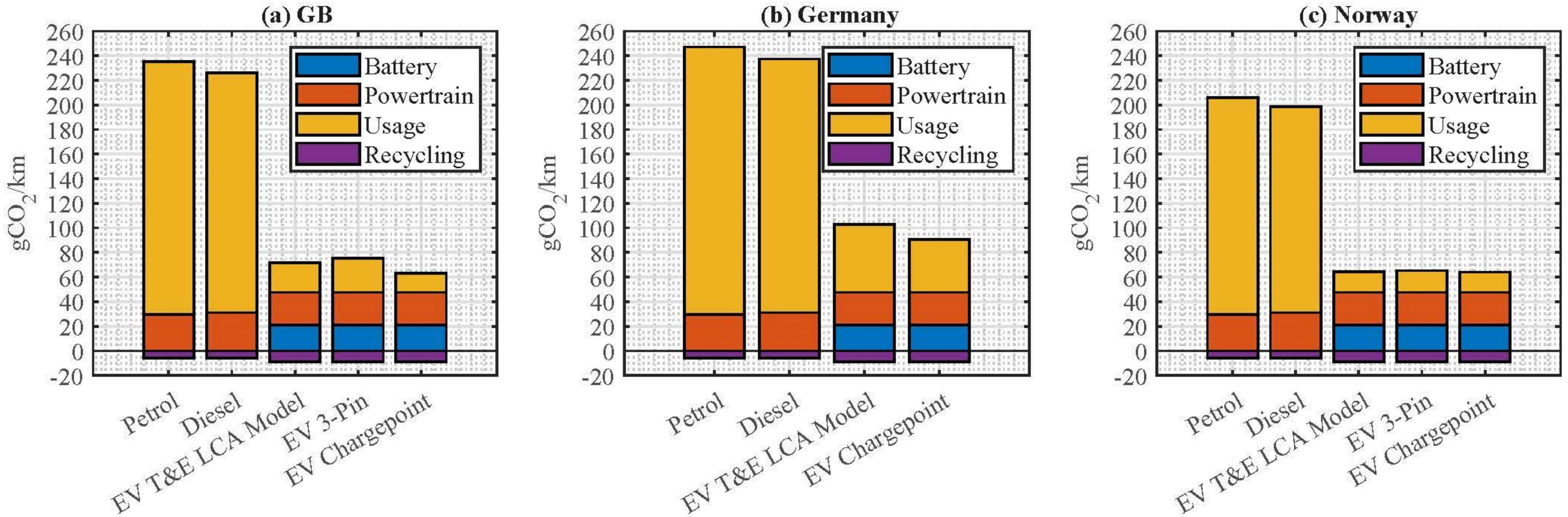


*Figure 3* – LCA assessment comparison

# GB regional findings

- **Scotland** is the only country in GB that exhibits a better than GB average footprint.
- **England** falls slightly above average.
- **Wales** exhibits the highest footprint, mainly due to increased usage of fossil fuels in electricity generation[1].
- **Northern Britain** exhibits higher levels of CO2 savings due to RES penetration[1].
- **South** and **South-East Britain** exhibit the worst performance.


*Figure 4* – GB regional carbon footprint, from dark green (lower) to dark red (higher)

| Region | Slow charger (18:00 – 05:00) [gCO2/km] | Fast charger (01:00 – 04:00) [gCO2/km] |
|---|---|---|
| **Great Britain** | 66.279 | 54.327 |
| **England** | 67.944 | 54.969 |
| **Scotland** | 48.464 | 45.400 |
| **Wales** | 75.946 | 61.181 |
| **South-East England** | 71.947 | 58.423 |
| **London** | 69.434 | 55.887 |
| **South England** | 80.018 | 62.526 |
| **South-West England** | 74.265 | 57.924 |
| **East England** | 65.217 | 52.866 |
| **East Midlands** | 82.851 | 62.321 |
| **West Midlands** | 67.118 | 53.526 |
| **South Wales** | 86.849 | 67.373 |
| **North Wales & Merseyside** | 56.865 | 49.500 |
| **Yorkshire** | 66.555 | 54.438 |
| **Nort-East England** | 43.657 | 41.874 |
| **North-West England** | 49.470 | 44.300 |
| **South Scotland** | 46.315 | 44.467 |
| **North Scotland** | 49.679 | 47.402 |

*Table 3* – Carbon footprint estimation for the regions of the GB, based on the users' routines (see Methodology users' routines)

[1] National Grid ESO, 2023. Carbon intensity api. URL: https://carbonintensity.org.uk..

# GB regional findings

- **Scotland** exhibits ~16% and 27% reduced emissions in the 1st and 2nd profile, respectively.
- **England** exhibits almost the same level of carbon footprint as GB average.
- **Wales** exhibit an increased carbon footprint of ~15% and ~13% in the 1st and 2nd profile, respectively.

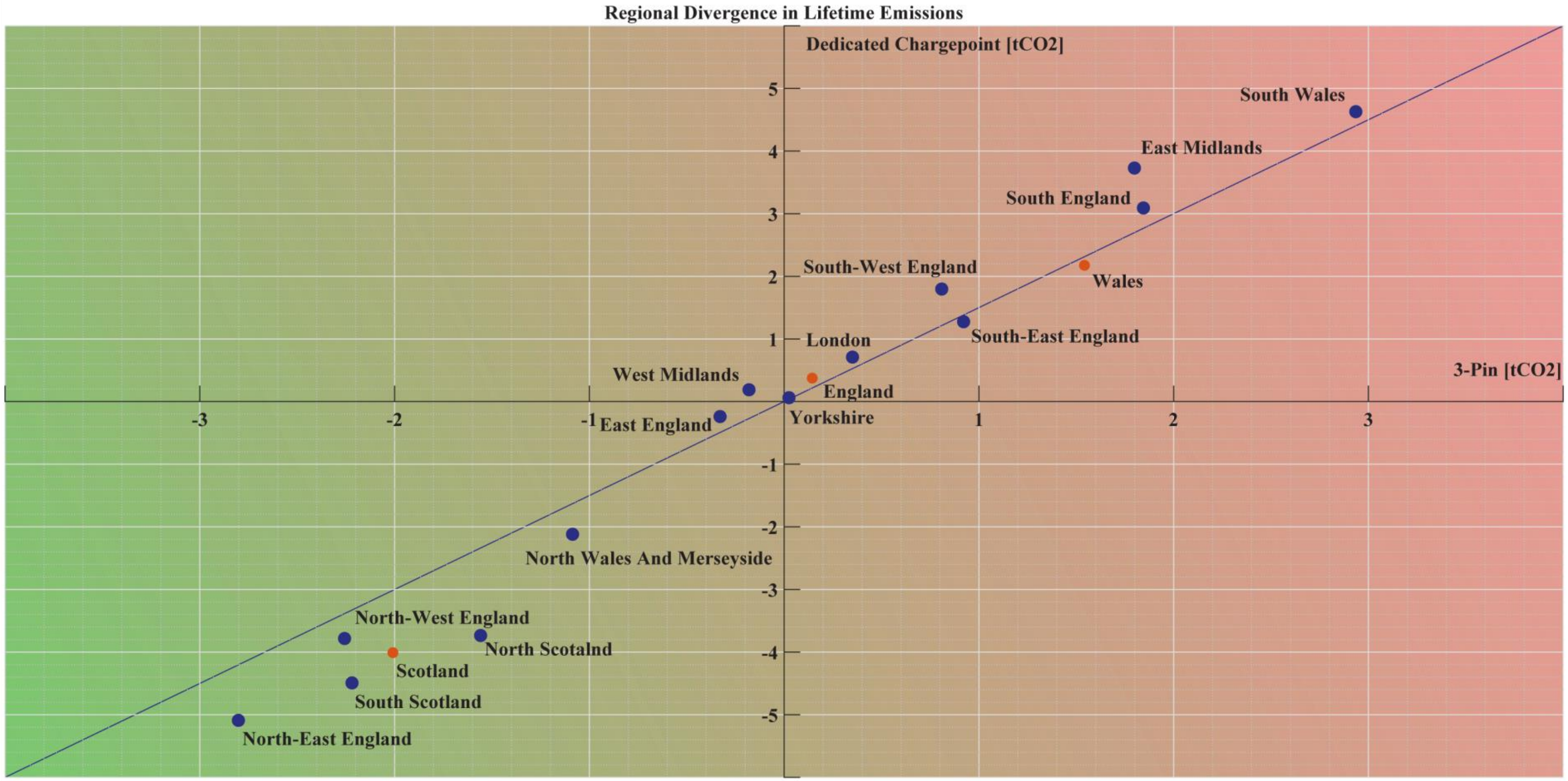


*Figure 5* – Great Britain regional divergence in lifetime emissions

# Conclusions

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- Infrastructure, charging routines and different users' location – both on national and regional level – can affect the LCA of an EV.
- Lifecycle emissions per vehicle type can vary from -12.9% up to +3.8% considering the different users' charging routines.
- Regions that demonstrate the lowest carbon footprint per produced kWh of electricity should be prioritised for EV deployment, as the reduction of the GHGs will be faster as well as the compensation of the increased carbon unleashed during the production of an EV.
- Further research should be carried out, across different countries on a regional level.

# Thank you!
# Questions?

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