Electronic Supplementary Material (ESI) for RSC Sustainability.
This journal is © The Royal Society of Chemistry 2024

Title

Future Material Demand and Greenhouse Gas Emissions Implications for Electrification of the UK Light-Duty Vehicle Fleet

Authors

Ben Davies[1, *]

Jorge A. Llamas-Orozco[1]

Fanran Meng[2, **]

I. Daniel Posen[3]

Heather L. MacLean[3]

Amir F. N. Abdul-Manan[4]

Jon McKechnie[1]

Affiliations

1. Low Carbon Energy and Resource Technologies, University of Nottingham, Nottingham, United Kingdom

2. Department of Chemical & Biological Engineering, University of Sheffield, Sheffield, United Kingdom

3. Department of Civil & Mineral Engineering, University of Toronto, Toronto, Ontario, Canada

4. Strategic Transport Analysis Team, Transport Technologies R&D, Research & Development Center (R&D), Saudi Aramco, Dhahran, Saudi Arabia

Correspondence

* Ben.Davies@nottingham.ac.uk, +44(0)115 951 4002

** F.Meng@sheffield.ac.uk, +44(0)114 222 7510

Supplementary model information

Vehicles module

Table S1: Kerb weight by vehicle technology [1].

Vehicle technology	Fixed kerb weight, less traction battery, kg	Kerb weight including 2020 market battery, kg
P-ICEV	1369	1369
D-ICEV	1796	1796
HEV	2032	2090
PHEV	2032	2090
BEV	1830	2158

Table S2: Materials composition by vehicle technology, adopted from [2].

Material	P-ICEV	D-ICEV	HEV	PHEV	BEV
Steel	59.9%	59.9%	59.3%	58.8%	58.4%
Wrought Aluminium	4.6%	4.6%	2.7%	2.6%	3.0%
Cast Aluminium	8.2%	8.2%	9.7%	10.3%	10.7%
Copper	2.4%	2.4%	4.0%	4.6%	6.3%
Automotive Plastics	15.3%	15.3%	12.6%	12.2%	14.3%
Rubber	3.9%	3.9%	3.3%	3.2%	3.3%
Platinum	0.0%	0.0%	0.0%	0.0%	0.0%

Table S3: Fuel and energy consumption by vehicle technology, adapted from [3].

Vehicle technology	Fuel consumption, l/100 km		Vehicle technology	Electricity consumption, kWh/100 km
P-ICEV	6.15		PHEV	17.3
D-ICEV	5.87		BEV	17.7
HEV	5.17			
PHEV	1.94			

PHEV fleet-class average utility factor = 0.818

Table S4: Vehicle battery capacity for electrified powertrains, adopted from [2].

Vehicle technology	Battery capacity, kWh
HEV	15.0
PHEV	15.0
BEV	84.0

Table S5: Materials composition by battery chemistry, adopted from [4]

Material	NMC111	NMC532	NMC622	NMC811	NMC955	NCA	LFP
$LiCO_3$	14.6%	14.7%	13.8%	0.0%	0.0%	0.0%	8.4%
$NiSO_4$	20.4%	31.6%	34.6%	40.1%	45.1%	44.7%	0.0%
$MnSO_4$	19.9%	18.0%	11.2%	4.9%	2.5%	0.0%	0.0%
$CoSO_4$	20.4%	12.8%	11.5%	5.0%	2.5%	8.5%	0.0%
LiOH	0.0%	0.0%	0.0%	7.8%	7.8%	8.6%	9.7%
Graphite	20.2%	20.6%	22.1%	24.4%	24.4%	23.4%	19.1%
Copper	7.2%	7.2%	7.1%	7.2%	7.2%	6.8%	8.3%
Aluminium	17.3%	17.3%	17.8%	18.4%	18.4%	18.0%	17.5%

Fleet module

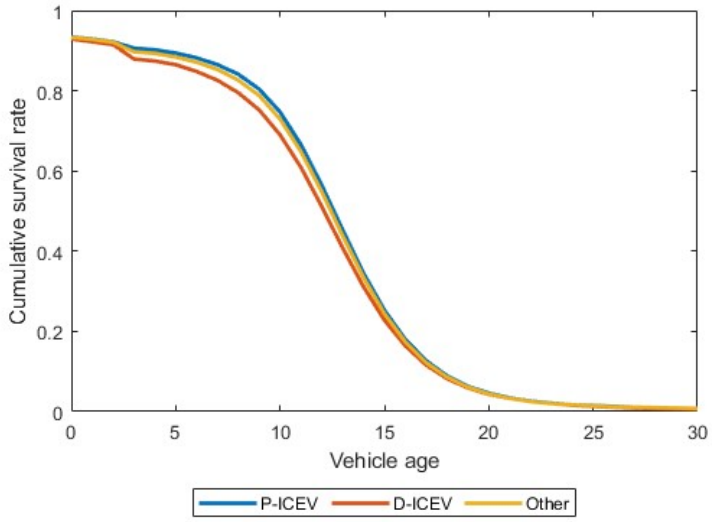

Figure S1: Cumulative vehicle survival rate by age for fleet-average vehicle technologies, calculated from [5]. *Due to insufficient data, HEV, PHEV, and BEV follow the fleet average for "Other" technologies.*

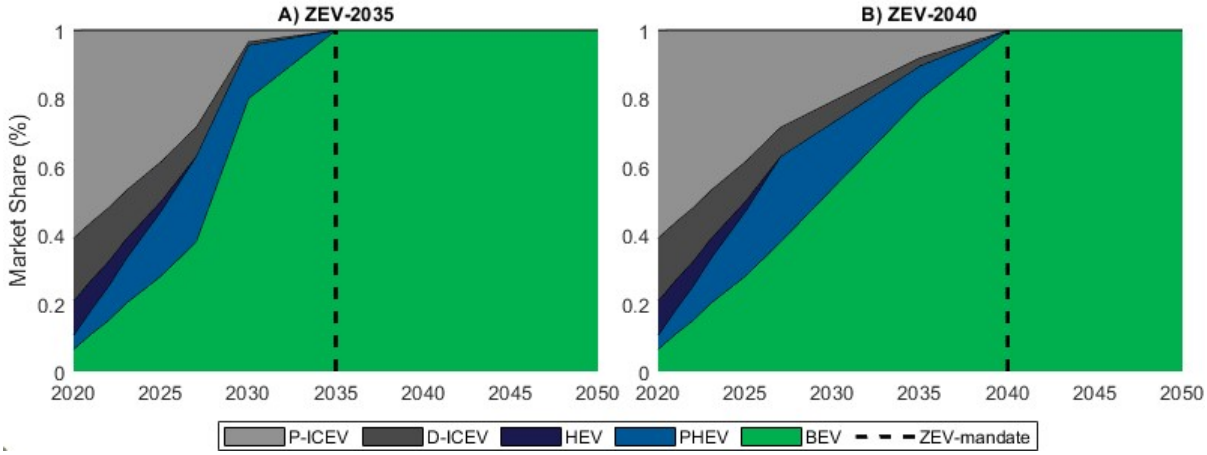

Figure S2: Fleet vehicle market scenarios, adapted from [6].

Materials and manufacturing module

Table S6: Primary and secondary materials production emissions factor for bulk vehicle materials.

Material	Primary production, kg CO_2 eq./kg	Secondary production, kg CO_2 eq./kg
Steel	1.978	1.225
Wrought Aluminium	13.840	0.813
Cast Aluminium	5.685	0.813
Copper	7.199	0.017
Plastic	4.149	0.000
Rubber	4.777	0.000
Platinum	120290	35737

Batteries module scenarios

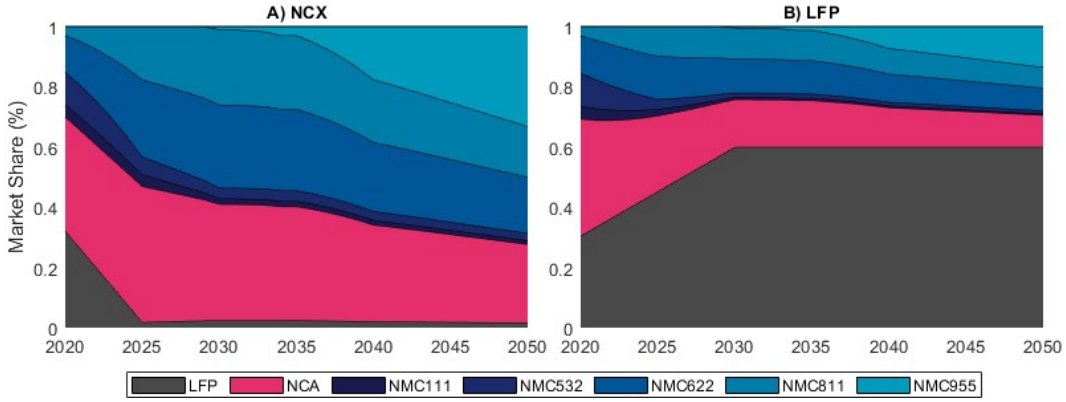

Figure S3: Battery chemistry market scenarios, adopted from[7].

Fuel and energy module scenarios

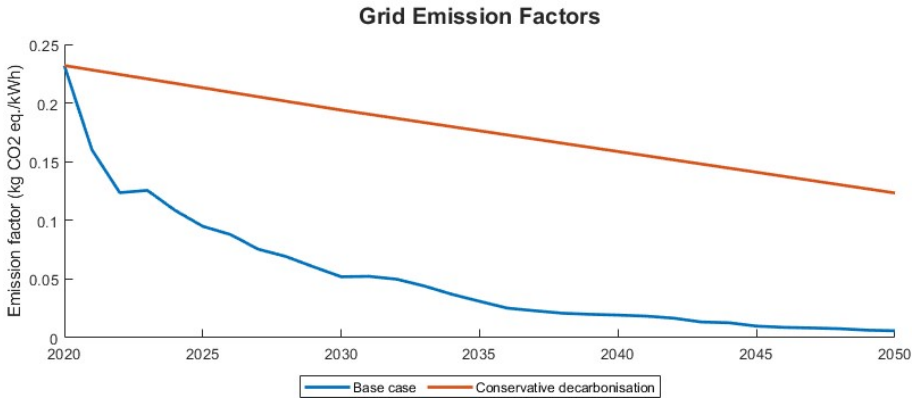

Figure S4: Grid generation emissions factor scenarios.

Life cycle assessment emissions factors

Table S7: Summary of life cycle inventory datasets consulted from the ecoinvent database [8].

ecoinvent dataset
steel production, low-alloyed, hot rolled_RER_2020_Allocation, cut-off
steel production, chromium steel 18_8, hot rolled_RER_2020_Allocation, cut-off
aluminium production, primary, ingot_IAI Area, EU27 & EFTA_2020_Allocation, cut-off
aluminium ingot, primary, to aluminium, wrought alloy market_GLO_2020_Allocation, cut-off
aluminium ingot, primary, to aluminium, cast alloy market_GLO_2020_Allocation, cut-off
sheet rolling, aluminium_RER_2020_Allocation, cut-off
copper production, cathode, solvent extraction and electrowinning process_GLO_2020_Allocation, cut-off
wire drawing, copper_RER_2020_Allocation, cut-off
acrylonitrile-butadiene-styrene copolymer production_RER_2020_Allocation, cut-off
epoxy resin, liquid_RER_2020_Allocation, cut-off
fibre, viscose_GLO_2020_Allocation, cut-off
polyethylene production, high density, granulate_RER_2020_Allocation, cut-off
polypropylene, granulate_GLO_2020_Allocation, cut-off
polyphenylene sulfide_GLO_2020_Allocation, cut-off
polyurethane, flexible foam_RER_2020_Allocation, cut-off
printed wiring board, mounted mainboard, desktop computer, Pb free_GLO_2020_Allocation, cut-off
carbon fibre reinforced plastic, injection moulded_GLO_2020_Allocation, cut-off
synthetic rubber production_RER_2020_Allocation, cut-off
platinum group metal, extraction and refinery operations_ZA_2020_Allocation, cut-off
road vehicle factory_GLO_2020_Allocation, cut-off
petrol production, low-sulfur_Europe without Switzerland_2020_Allocation, cut-off
diesel production, low-sulfur, petroleum refinery operation_Europe without Switzerland_2020_Allocation, cut-off
manual dismantling of used passenger car with internal combustion engine_GLO_2020_Allocation, cut-off
treatment of used glider, passenger car, shredding_GLO_2020_Allocation, cut-off
treatment of used internal combustion engine, shredding_GLO_2020_Allocation, cut-off
treatment of used powertrain for electric passenger car, manual dismantling_GLO_2020_Allocation, cut-off
treatment of automobile catalyst_RER_2020_Allocation, cut-off

Supplementary model results

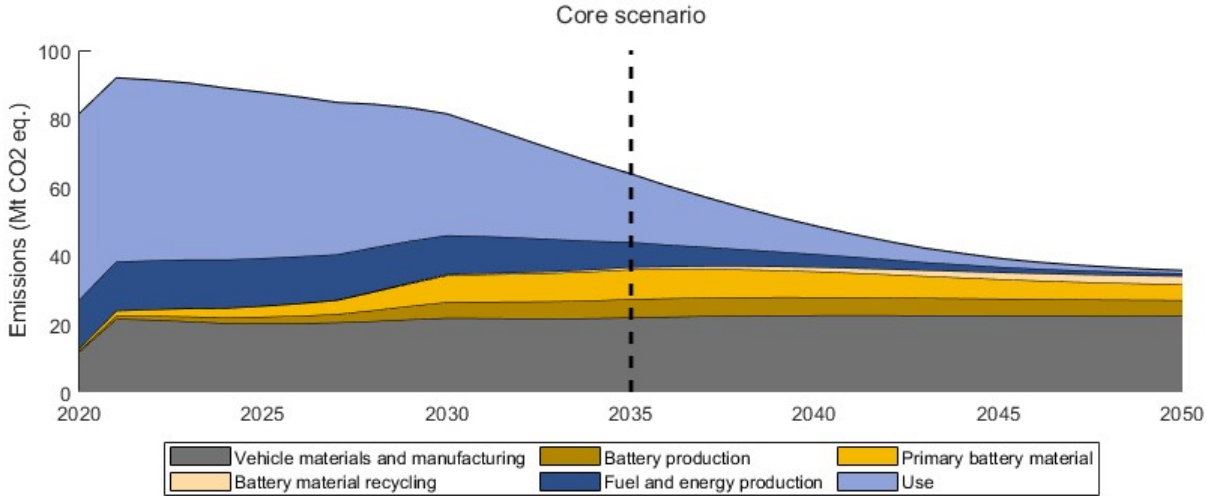

Figure S5: Annual GHG emission results for the Core scenario.

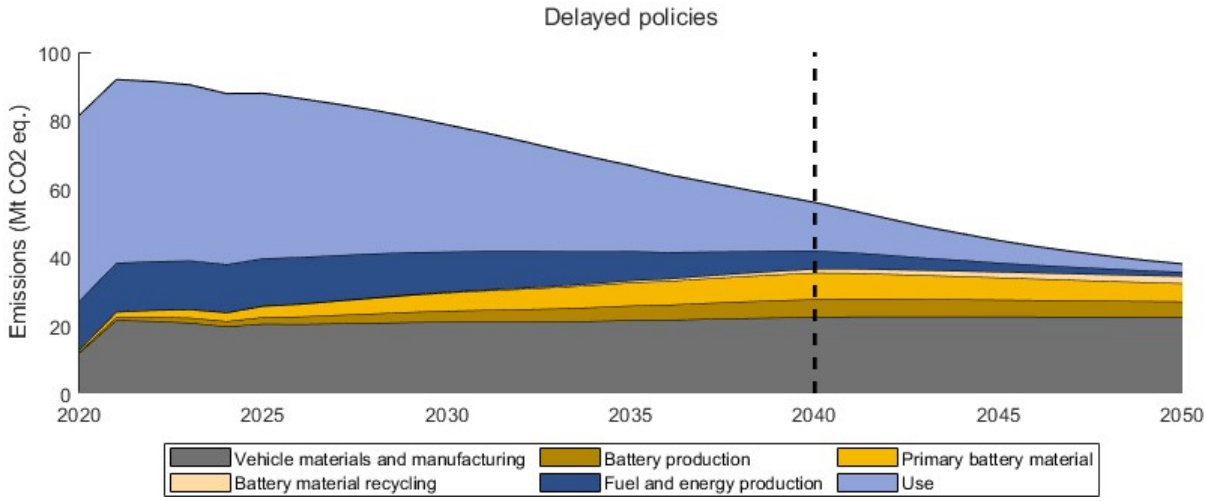

Figure S6: Annual GHG emission results for the Delayed policies scenario.

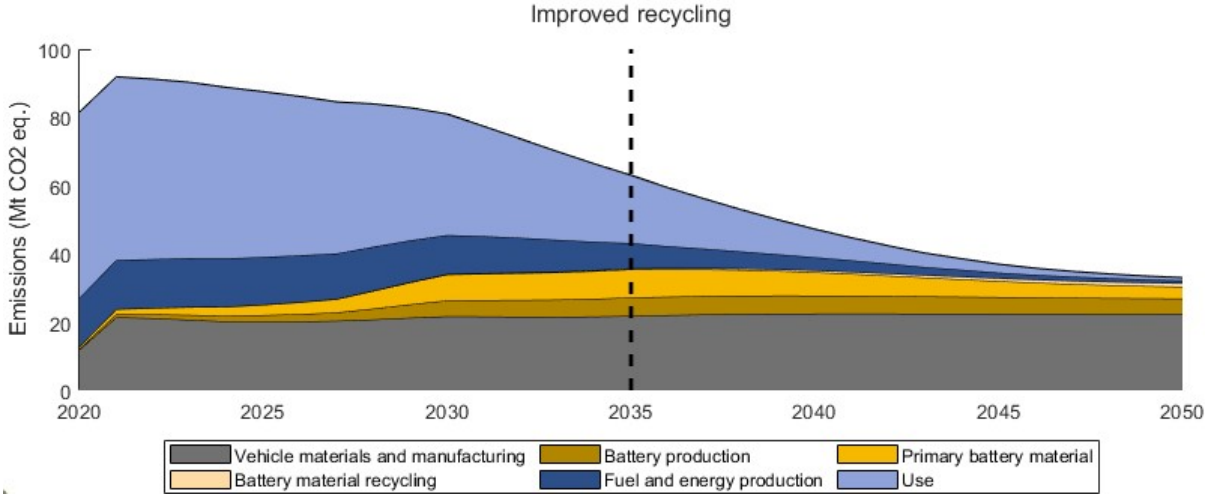

Figure S7: Annual GHG emission results for the Improved recycling scenario.

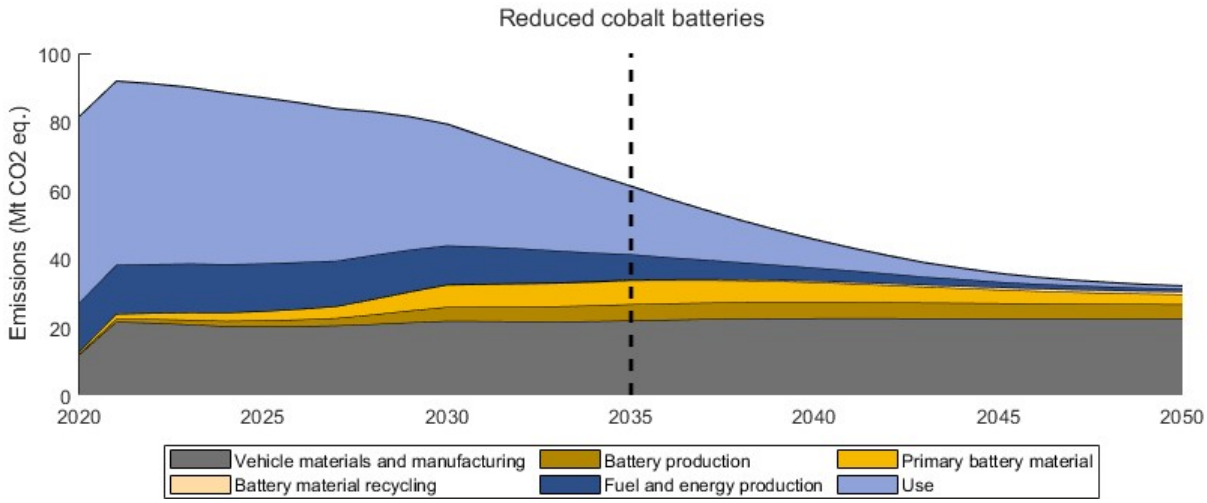

Figure S8: Annual GHG emission results for the Reduced cobalt batteries scenario.

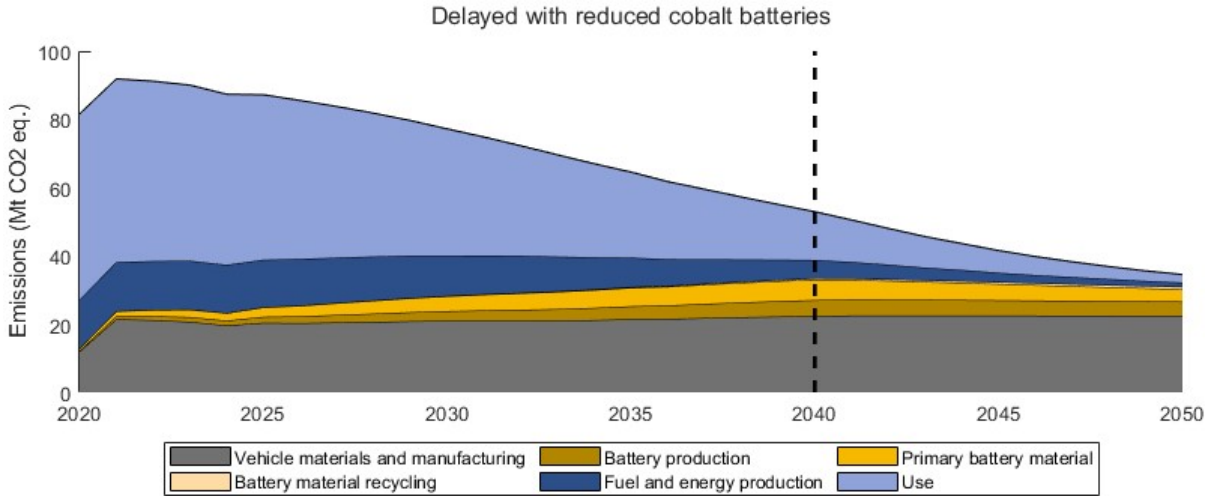

Figure S9: Annual GHG emission results for the Delayed with reduced cobalt batteries scenario.

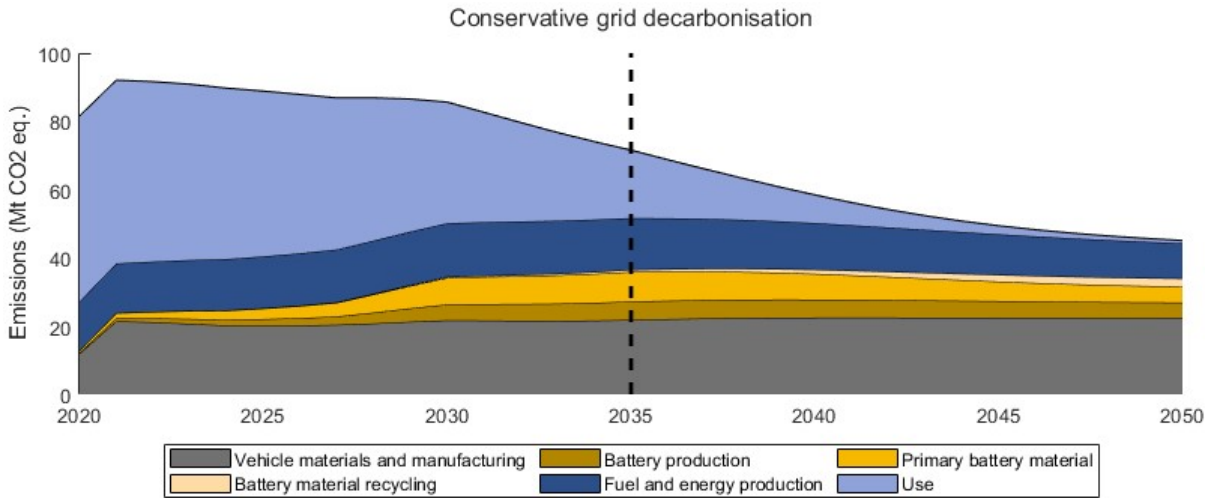

Figure S10: Annual GHG emission results for the Conservative gird decarbonisation scenario.

References

[1] European Environment Agency, “Monitoring of CO2 emissions from passenger cars Regulation (EU) 2019/631,” 2023. [Online]. Available: co2cars.apps.eea.europa.eu

[2] GREET, “GREET Life Cycle Model User Guide,” *Argonne National Labratory*, pp. 169–232, 2020, [Online]. Available: www.impact-test.co.uk

[3] Vehicle Certification Agency, “Fuel Consumption & CO2 Databases.” Accessed: Jun. 05, 2023. [Online]. Available: https://www.vehicle-certification-agency.gov.uk/fuel-consumption-co2/

[4] J. A. Llamas-Orozco *et al.*, “Estimating the Environmental Impacts of Global Lithium-Ion Battery Supply Chain: A Temporal, Geographical, and Technological Perspective,” *PNAS Nexus*, vol. 2, no. 11, pp. 1–16, 2023, doi: 10.1093/pnasnexus/pgad361.

[5] Department for Transport and Driver and Vehicle Licensing Agency, “Vehicle licensing statistics: 2022,” National statistics. [Online]. Available: https://www.gov.uk/government/statistics/vehicle-licensing-statistics-2022

[6] Department for Transport, “Zero emission vehicle (ZEV) mandate consultation: Summary of responses and joint government response,” 2023.

[7] C. Xu, Q. Dai, L. Gaines, M. Hu, A. Tukker, and B. Steubing, “Future material demand for automotive lithium-based batteries,” *Commun Mater*, vol. 1, no. 1, p. 99, Dec. 2020, doi: 10.1038/s43246-020-00095-x.

[8] ecoInvent, “ecoinvent database V3.7.” Accessed: May 25, 2022. [Online]. Available: https://ecoinvent.org/