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The Non-Exhaust Particulate Emissions Impact of EURO VI to Battery Electric Bus Fleet Transitions

Jon Tivey¹ and Karl Ropkins²

Presented at the
Clean Air Networks Conference
(Birmingham, UK)

5th to 6th July, 2023

First  **Bus**




TRANSITION
CLEAN AIR NETWORK

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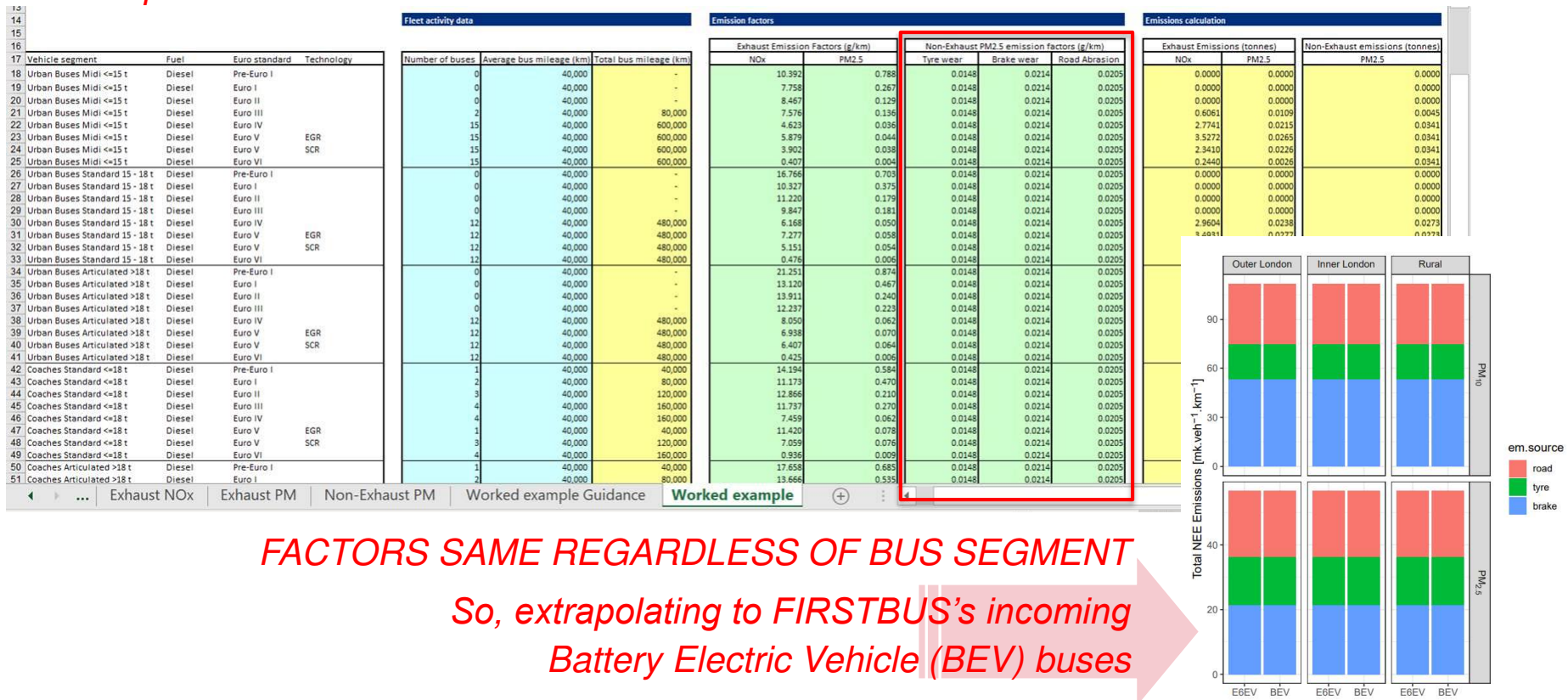


Situation (pre-project)

There was a real need for better evidence on Electric Bus Non-Exhaust Emissions (NEEs) alongside the EURO VI to EV Bus Fleet transition

There was little public evidence on electric vehicles NEES or regenerative braking, and even toolkit factors for conventional internal combustion engine vehicles were very crude

Example: NAEI



FACTORS SAME REGARDLESS OF BUS SEGMENT
 So, extrapolating to FIRSTBUS's incoming
 Battery Electric Vehicle (BEV) buses



Scoping (review and meta analysis)

Initial focus (during lockdown) was on available published evidence, and what could be done in the short-term to fill information-gaps

We focused on

NEE (brake, tyre, road)
Resuspended PM
Regenerative Braking
Exhaust Emissions

Beddows & Harrison (2021)
US EPA (2011)
Hamada & Orphan (2022)
EMEP/EEA Guidebook (2019)

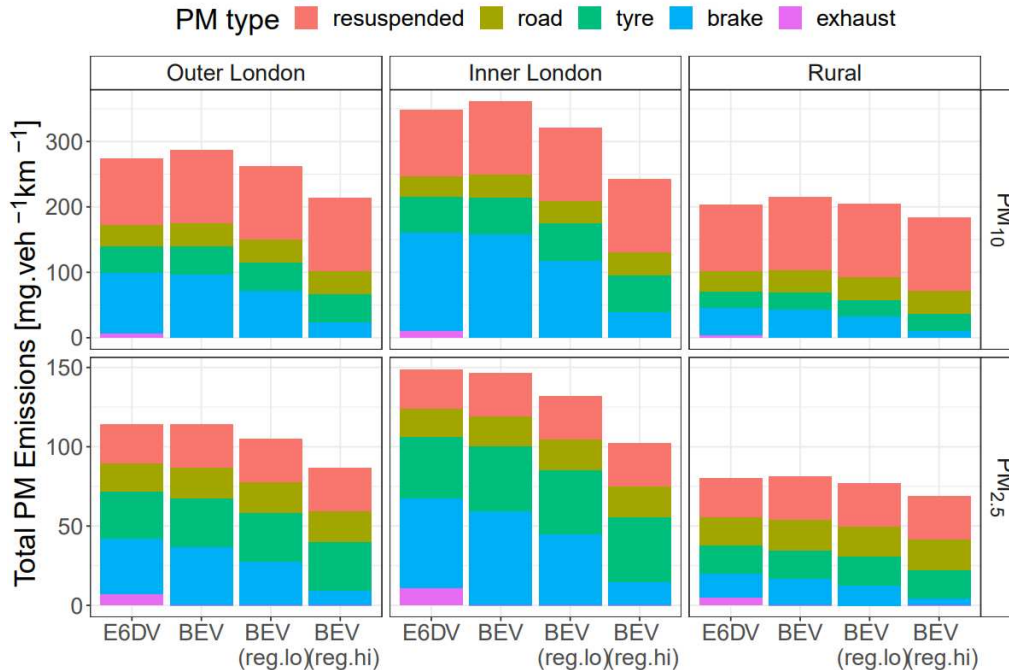
REFERENCES:
Beddows, D.C. & Harrison, R.M. PM10 and PM2.5 emission factors for non-exhaust particles from road vehicles: Dependence upon vehicle mass and implications for battery electric vehicles. Atmospheric Environment, 2021, 244, p.117886. <https://doi.org/10.1016/j.atmosenv.2020.117886>.
US EPA (US Environmental Protection Agency), Emission Factor Documentation for AP-42, Section 13.2.1: Paved Roads. Measurement Policy Group, Office of Air Quality Planning and Standards. U.S. Environmental Protection Agency. 2011. <https://www.epa.gov/chief>
Hamada, A.T. & Orhan, M.F. An overview of regenerative braking systems. Journal of Energy Storage, 2022, 52, p.105033. <https://doi.org/10.1016/j.est.2022.105033>.
EMEP/EEA (European Monitoring and Evaluation Programme/ European Environment Agency) air pollutant emission inventory guidebook, 2019. European Environment Agency. <https://www.eea.europa.eu/publications/emep-eea-guidebook-2019>.

Outputs:

Article
Meta-Analysis as Early Evidence on the Particulate Emissions Impact of EURO VI on Battery Electric Bus Fleet Transitions
 Jon Tivey ^{1*}, Huan C. Davies ^{2,3}, James G. Levine ^{4,5}, Josias Zietsman ⁶, Suzanne Bartington ^{6,7}, Sergio Barone Espinosa ^{8,9} and Karl Ropkins ¹⁰

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Abstract: The current generation of Zero Emission Vehicle (ZEV) policies are designed to accelerate the transition away from conventional internal combustion engine (ICE) petrol and diesel vehicle fleets. However, the current focus on zero-exhaust emissions and the lack of more detailed guidance regarding Non-Exhaust Emissions (NEE) may mean that some of the benefits in transitioning to, e.g. Battery Electric Vehicle (BEV) fleets may be missed by energy on the commercial sector. Here, as part of early work on the scoping of the first bus EURO VI Diesel Vehicle (EDV) to BEV fleet



PAPER:
<https://doi.org/10.3390/su15021522>
 Tivey, J., Davies, H.C., Levine, J.G., Zietsman, J., Bartington, S., Ibarra-Espinosa, S. and Ropkins, K., Meta-Analysis as Early Evidence on the Particulate Emissions Impact of EURO VI on Battery Electric Bus Fleet Transitions. Sustainability, 15(2), p.1522. 2023.

embrs

embrs is in development

embrs was initially written as part of work on a scoping exercise to provide early estimates of the environmental impacts of the diesel to electric bus transition published as [Lacey et al. 2022](#)

code sources <https://github.com/karloropkins/embrs>

Installation

You can install the development version of embrs from GitHub with:

```
# install packages
pip install gitpython
python -c "import git; r = git.Repo('https://github.com/karloropkins/embrs')
```

Example

embrs uses vehicle and route objects to build small-scale emission inventories

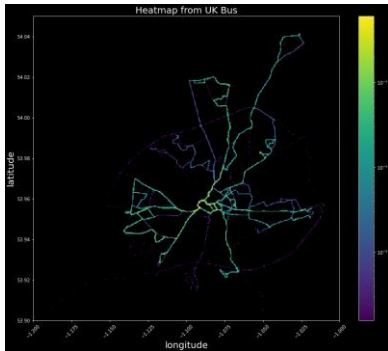
SOFTWARE:
<https://github.com/karloropkins/embrs>
 R software package, freely distributed under public license

ALSO thank you
 ZEMO for UKBC
 Profile update



Bus Tests (real-world activity data gathering)

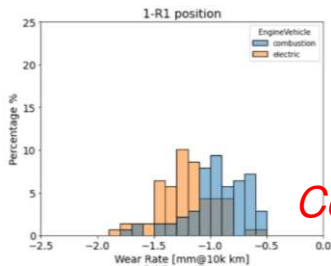
FIRSTBUS, in collaboration with BRIDGESTONE, ALEXANDER DENNIS (ADL) and JURATEK, instrumented 5 Diesel EURO VI and 5 Battery Electrical Buses to collect activity data from routes in and around York.



Axis	Position	EngineVehicle	count	mean	min	max
Drive	2-L1	combustion	60.0	-1.27	-2.01	-0.49
Drive	2-L1	electric	42.0	-1.41	-2.03	-0.82
Drive	2-L2	combustion	51.0	-1.31	-2.01	-0.67
Drive	2-L2	electric	57.0	-1.35	-2.03	-0.58
Drive	2-R1	combustion	76.0	-1.23	-2.03	-0.49
Drive	2-R1	electric	39.0	-1.29	-2.00	-0.64
Drive	2-R2	combustion	71.0	-1.19	-2.03	-0.55
Drive	2-R2	electric	38.0	-1.17	-1.92	-0.68
Steer	1-L1	combustion	50.0	-0.89	-1.43	-0.50
Steer	1-L1	electric	73.0	-1.10	-2.01	-0.59
Steer	1-R1	combustion	69.0	-0.94	-1.72	-0.50
Steer	1-R1	electric	70.0	-1.21	-1.90	-0.59

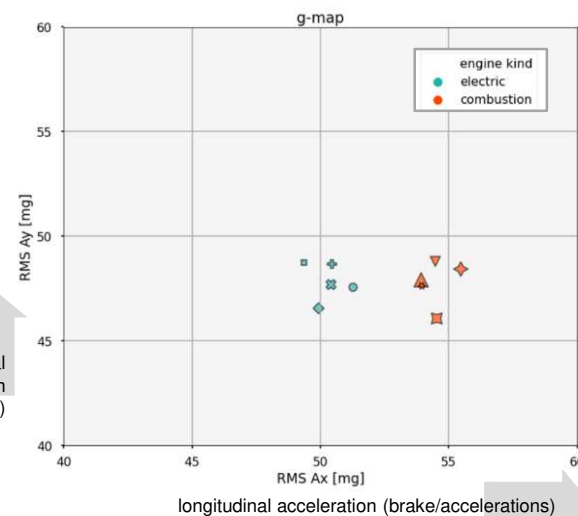
Wear rates consistently higher for BEV compared to EURO VI Diesel...

... and this associates with differences in the acceleration and braking behaviour of different types of buses...



Compare:

... on a wheel-by-wheel basis because individual vehicle analysis shows wear rates



lateral acceleration (turning)

NB: This example is Tyre Wear versus Acceleration/Braking; similar for Tyre Pressures shows 50% and 35% penalties for over- and under-inflation, respectively.



TRANSITION Clean Air Network



The **Clean Air Programme** is jointly delivered by the Natural Environment Research Council (**NERC**) and the **Met Office**, with contributions from the Economic and Social Research Council (**ESRC**), Engineering and Physical Sciences Research Council (**EPSRC**), **Innovate UK**, Medical Research Council (**MRC**), National Physical Laboratory (**NPL**), Science & Technology Facilities Council (**STFC**), Department for Environment, Food and Rural Affairs (**Defra**), Department for Health and Social Care (**DHSC**), Department for Transport (**DfT**), Scottish Government and Welsh Government.

TRANSITION is one of the Networks set up within UK Clean Air Network Programme. led by the **University of Birmingham** in collaboration with nine universities and over 20 cross-sector partners, the network seeks to deliver air quality and health benefits associated with the UK transition to a low-emission transport economy. The academic investigators and policy, public, commercial and not-for-profit sector partners will undertake joint research, to co-define indoor and outdoor air quality challenges and co-deliver innovative, evidence-based solutions.

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TRANSITION Network Partners





FIRSTBUS Test Fleet

Make	Model	Age	Mileage	Fuel/Battery types	Engine Type	Power Output	Emissions standard/status	Other on-board systems	Exhaust Filter	Regen-Braking
Volvo	B9TL	01/09/2008		ULS Diesel	ICE Diesel	260PS / 194KW	Euro VI	SCRT-Adblue	EATS - emission control	N/A
Volvo	B9TL	27/02/2009		ULS Diesel	ICE Diesel	260PS / 194KW	Euro VI	SCRT-Adblue	EATS - emission control	N/A
Volvo	B9TL	27/02/2009		ULS Diesel	ICE Diesel	260PS / 194KW	Euro VI	SCRT-Adblue	EATS - emission control	N/A
Volvo	B9TL	17/03/2009		ULS Diesel	ICE Diesel	260PS / 194KW	Euro VI	SCRT-Adblue	EATS - emission control	N/A
Volvo	B9TL	01/04/2009		ULS Diesel	ICE Diesel	260PS / 194KW	Euro VI	SCRT-Adblue	EATS - emission control	N/A
Optare	Metrodecker M1110EV	01/11/2020		Lithium Ion Battery	Electric Motor	300KW	ZEV	-	N/A	Yes
Optare	Metrodecker M1110EV	01/11/2020		Lithium Ion Battery	Electric Motor	300KW	ZEV	-	N/A	Yes
Optare	Metrodecker M1110EV	01/12/2020		Lithium Ion Battery	Electric Motor	300KW	ZEV	-	N/A	Yes
Optare	Metrodecker M1110EV	01/12/2020		Lithium Ion Battery	Electric Motor	300KW	ZEV	-	N/A	Yes
Optare	Metrodecker M1110EV	01/12/2020		Lithium Ion Battery	Electric Motor	300KW	ZEV	-	N/A	Yes



Existing Fleet Logging:

- Conventional (travel services) telemetry;
- Tyre and brake wear logged by visual inspection as part of routine maintenance

For the 10 Test Vehicles:

- Improved telemetry and additional tyre and brake wear measurement;
- Bridgestone (tyre manufacturer/supplier) proprietary Webfleet 'Wear Dongle' telemetry and tyres fitted with the Bridgestone Tyre Pressure Monitoring System;
- Data analysis by Bridgestone's Digital Garage and Technical Centre (Europe)



embrs software

Objective: to make a simple-to-use vehicle emission modelling syntax for the models and methods used in the First Bus NEEs Study

embrs is written in R, freely distributed by public license and uses vehicle and route objects to build emission models in the classic form:

$$\sum \text{emission}(\text{object}) * \text{activity}(\text{object})$$

R code:

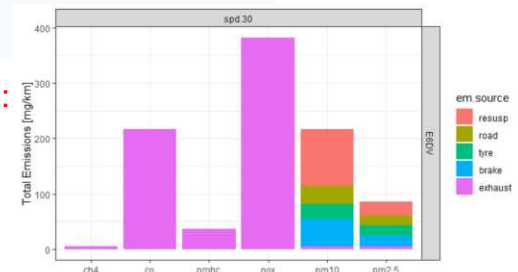
```
# EURO VI diesel versus Battery Electric BUS comparison from Tivey et al (2023)

# a EURO VI ICE diesel bus weighing 15925 kg
bus.1 <- bus_ice(name="E6DV", veh.wt=15925, euro.class="VI", eng.fuel="diesel")
# a battery electric bus weighing 17725 kg (and conventional brakes)
bus.2 <- bus_bev(name="BEV", veh.wt=17725)
# like bus.2 but with regenerative brakes operating at 25% efficiency
bus.3 <- bus_bev(name="BEVnlow", veh.wt=17725, brk.regen = 0.25)
# like bus.3 but 75% efficiency
bus.4 <- bus_bev(name="BEVnhi", veh.wt=17725, brk.regen = 0.75)
# a small fleet
fleet <- bus.1 + bus.2 + bus.3 + bus.4
# some routes
routes <- route_naei_urban() + route_naei_rural() + route_naei_motorway()
# an inventory
inventory <- fleet * routes
# just plotting PM contributions by vehicle (bus.1 to 4)
plot(inventory, plot.type="by.vehicle", em.type="just.pm")
```

R code:

```
library(embrs)
# a EURO VI ICE diesel bus weighing 15925 kg
bus.1 <- bus_ice(name="E6DV", veh.wt=15925, euro.class="VI", eng.fuel="diesel")
# a 30 km/hr route
route.30 <- route_veh_spd(30)
# multiple them
mod <- bus.1 * route.30
# plot that
plot(mod)
```

output:



<https://github.com/karloprokins/embrs>

output:

