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Tivey, J. and Ropkins, K. [orcid.org/0000-0002-0294-6997](https://orcid.org/0000-0002-0294-6997) The Non-Exhaust Particulate Emissions Impact of EURO VI to Battery Electric Bus Fleet Transitions. In: Clean Air Networks Conference 2023, 05-06 Jul 2023, Birmingham, UK.

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

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Jon Tivey<sup>1</sup> and Karl Ropkins<sup>2</sup>

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

5<sup>th</sup> to 6<sup>th</sup> July, 2023

**First**  **Bus**

 Clean Air  
Programme

 UKRI  
Natural  
Environment  
Research Council

 Met Office

  
**TRANSITION**  
CLEAN AIR NETWORK

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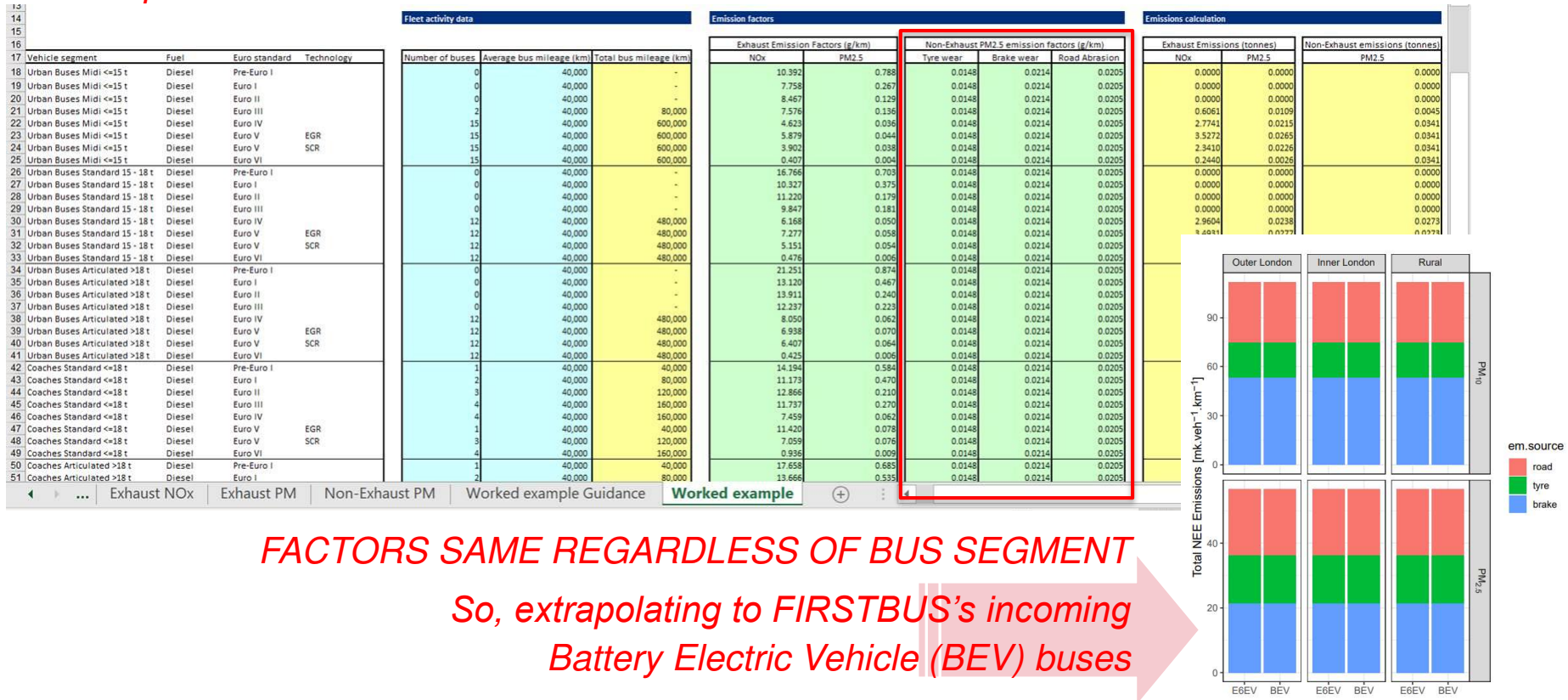


# Situation (pre-project)

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**







# 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*

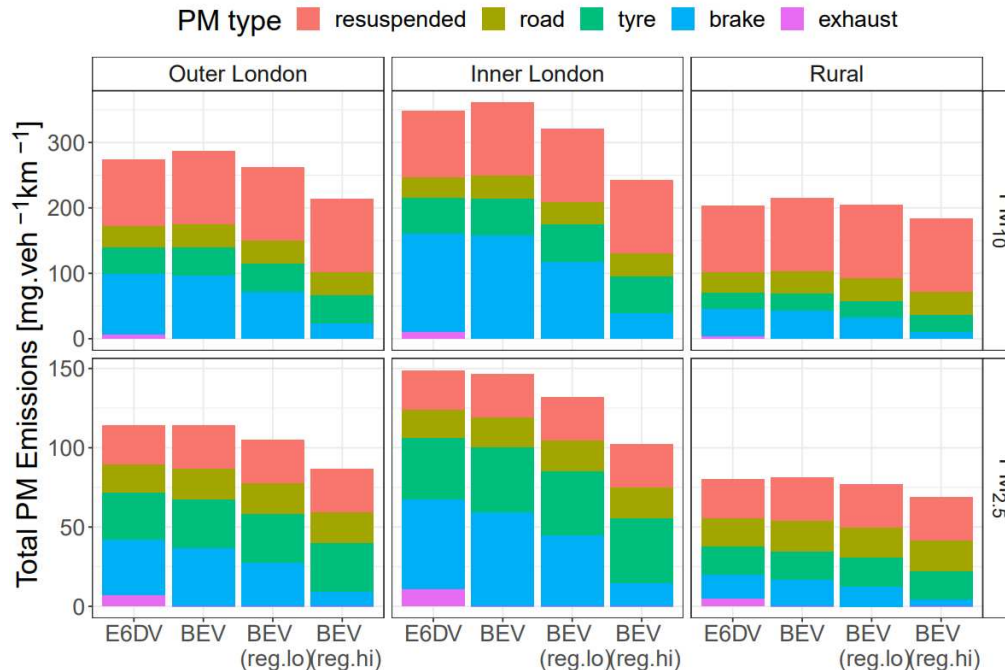
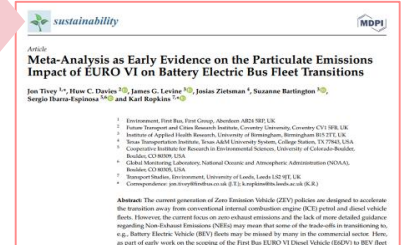
NEE (brake, tyre, road)  
Resuspended PM  
Regenerative Braking  
Exhaust Emissions

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

**REFERENCES:**

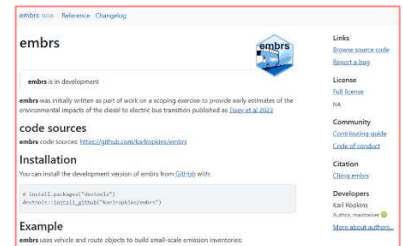
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- US EPA (US Environmental Protection Agency), Emission Factor Documentation for AP-42, Section 13.2.1: Paved Roads. Measurement Policy Group, Office of Air Quality Planning and Standards. U.S. Environmental Protection Agency. 2011. <https://www.epa.gov/chief>
- 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:*



*ALSO thank you ZEMO for UKBC Profile update*

**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.

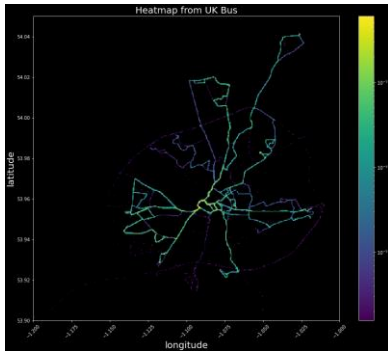


**SOFTWARE:**  
<https://github.com/karloropkins/embrs>  
R software package, freely distributed under public license



# Bus Tests (real-world activity data gathering)

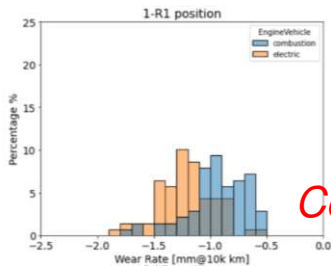
FIRSTBUS, in collaboration with BRIDGESTONE, ALEXANDER DENNIS (ADL) and JURATEK, instrumented 5 Diesel EURO VI and 5 Battery Electrical Buses to collect activity data from routes in and around York.



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

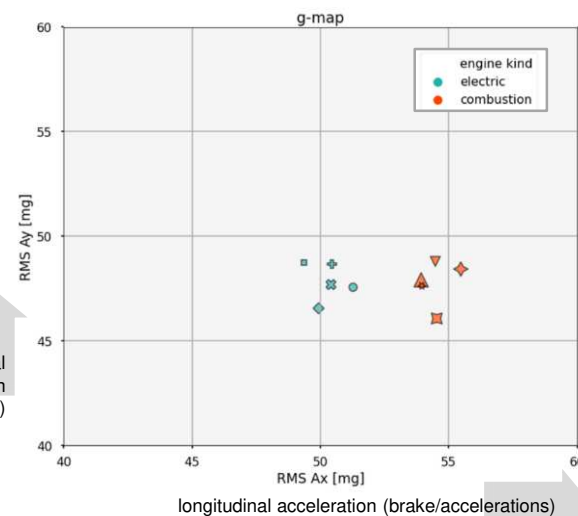
Wear rates consistently higher for BEV compared to EURO VI Diesel...

... 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



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*

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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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Dr Karl Ropkins



## University of York

Dr Sarah Moller





# 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:

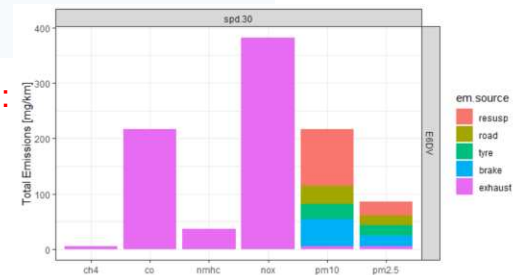
```
# EURO VI diesel versus Battery Electric BUS comparison from Tivey et al (2023)

# 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="BEV\low", veh.wt=17725, brk.regen = 0.25)
# like bus.3 but 75% efficiency
bus.4 <- bus_bev(name="BEV\hi", 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/karlropkins/embrs>

output:

