Collecting Real-World Evidence on Factors Affecting Bus Fleet Non-Exhaust Emissions

Jon Tivey[1], Huw C. Davies[2],
James Levine[3] Suzanne Bartington[3]
and Karl Ropkins[4]

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1: Head of Environment, First Bus, First Group, UK (jon.tivey@firstbus.co.uk)
2: Future Transport and Cities Research Institute, Coventry University
3: Institute of Applied Health Research, University of Birmingham
4: Transport Studies, Environment, University of Leeds, UK, (k.Ropkins@its.leeds.ac.uk)

Introduction

- Air pollution poses the single greatest environmental risk to human health. As well as human health, air pollution also has implications for the natural environment and for the economy.
- Vehicle non-exhaust PM is emitted from the use of brakes and friction between tyres and road surfaces, so is a result of essential vehicle safety systems.
- There are no robust, publicly available data on brake wear from electric vehicles (EVs) or those with regenerative braking, but anecdotal evidence suggested there would be a reduction in emissions where regenerative braking is used.
- This project aims to better quantify real-world factors affecting Bus Fleet Non-Exhaust Emissions (NEE) in parallel with the proposed transition to a 100% zero emission bus fleet.
- Led by First Bus, and funded by the TRANSITION Clean Air Network, as part of the UK's Natural Environment Research Council's Clean Air Programme, activity data from the bus fleet is being gathered.
- The trial includes 10 doubled decker buses being monitored in York – 5 x ICE, 5 x Electric Vehicles (EVs)

TRANSITION Clean Air Network

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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.

Contact: info@transition-air.org.uk
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Background (1)

There is a need for better quantify real-world factors affecting Bus Fleet Non-Exhaust Emissions (NEE) in parallel with the proposed transition to a 100% Zero Emission Vehicle (ZEV) bus fleet.

					Fleet activity data			Emission factors: Exhaust Emission Factors (g/km)		Non-Exhaust PM2.5 emission factors (g/km)			Emissions calculation: Exhaust Emissions (tonnes)		Non-Exhaust emissions (tonnes)
17	Vehicle segment	Fuel	Euro standard	Technology	Number of buses	Average bus mileage (km)	Total bus mileage (km)	NOx	PM2.5	Tyre wear	Brake wear	Road Abrasion	NOx	PM2.5	PM2.5
18	Urban Buses Midi <=15 t	Diesel	Pre-Euro I		0	40,000	-	10.392	0.788	0.0148	0.0214	0.0205	0.0000	0.0000	0.0000
19	Urban Buses Midi <=15 t	Diesel	Euro I		0	40,000	-	7.758	0.267	0.0148	0.0214	0.0205	0.0000	0.0000	0.0000
20	Urban Buses Midi <=15 t	Diesel	Euro II		0	40,000	-	8.467	0.129	0.0148	0.0214	0.0205	0.0000	0.0000	0.0000
21	Urban Buses Midi <=15 t	Diesel	Euro III		2	40,000	80,000	7.576	0.136	0.0148	0.0214	0.0205	0.6061	0.0109	0.0045
22	Urban Buses Midi <=15 t	Diesel	Euro IV		15	40,000	600,000	4.623	0.036	0.0148	0.0214	0.0205	2.7741	0.0215	0.0341
23	Urban Buses Midi <=15 t	Diesel	Euro V	EGR	15	40,000	600,000	5.879	0.044	0.0148	0.0214	0.0205	3.5272	0.0265	0.0341
24	Urban Buses Midi <=15 t	Diesel	Euro V	SCR	15	40,000	600,000	3.902	0.038	0.0148	0.0214	0.0205	2.3410	0.0226	0.0341
25	Urban Buses Midi <=15 t	Diesel	Euro VI		15	40,000	600,000	0.407	0.004	0.0148	0.0214	0.0205	0.2440	0.0026	0.0341
26	Urban Buses Standard 15 - 18 t	Diesel	Pre-Euro I		0	40,000	-	16.766	0.703	0.0148	0.0214	0.0205	0.0000	0.0000	0.0000
27	Urban Buses Standard 15 - 18 t	Diesel	Euro I		0	40,000	-	10.327	0.375	0.0148	0.0214	0.0205	0.0000	0.0000	0.0000
28	Urban Buses Standard 15 - 18 t	Diesel	Euro II		0	40,000	-	11.220	0.179	0.0148	0.0214	0.0205	0.0000	0.0000	0.0000
29	Urban Buses Standard 15 - 18 t	Diesel	Euro III		0	40,000	-	9.847	0.181	0.0148	0.0214	0.0205	0.0000	0.0000	0.0000
30	Urban Buses Standard 15 - 18 t	Diesel	Euro IV		12	40,000	480,000	6.168	0.050	0.0148	0.0214	0.0205	2.9604	0.0238	0.0273
31	Urban Buses Standard 15 - 18 t	Diesel	Euro V	EGR	12	40,000	480,000	7.277	0.058	0.0148	0.0214	0.0205	3.4931	0.0277	0.0273
32	Urban Buses Standard 15 - 18 t	Diesel	Euro V	SCR	12	40,000	480,000	5.151	0.054	0.0148	0.0214	0.0205	2.4726	0.0259	0.0273
33	Urban Buses Standard 15 - 18 t	Diesel	Euro VI		12	40,000	480,000	0.476	0.006	0.0148	0.0214	0.0205	0.2287	0.0028	0.0273
34	Urban Buses Articulated >18 t	Diesel	Pre-Euro I		0	40,000	-	21.251	0.874	0.0148	0.0214	0.0205	0.0000	0.0000	0.0000
35	Urban Buses Articulated >18 t	Diesel	Euro I		0	40,000	-	13.120	0.467	0.0148	0.0214	0.0205	0.0000	0.0000	0.0000
36	Urban Buses Articulated >18 t	Diesel	Euro II		0	40,000	-	13.911	0.240	0.0148	0.0214	0.0205	0.0000	0.0000	0.0000
37	Urban Buses Articulated >18 t	Diesel	Euro III		0	40,000	-	12.237	0.223	0.0148	0.0214	0.0205	0.0000	0.0000	0.0000
38	Urban Buses Articulated >18 t	Diesel	Euro IV		12	40,000	480,000	8.050	0.062	0.0148	0.0214	0.0205	3.8639	0.0296	0.0273
39	Urban Buses Articulated >18 t	Diesel	Euro V	EGR	12	40,000	480,000	6.938	0.070	0.0148	0.0214	0.0205	3.3302	0.0335	0.0273
40	Urban Buses Articulated >18 t	Diesel	Euro V	SCR	12	40,000	480,000	6.407	0.064	0.0148	0.0214	0.0205	3.0751	0.0305	0.0273
41	Urban Buses Articulated >18 t	Diesel	Euro VI		12	40,000	480,000	0.425	0.006	0.0148	0.0214	0.0205	0.2038	0.0031	0.0273
42	Coaches Standard <=18 t	Diesel	Pre-Euro I		1	40,000	40,000	14.194	0.584	0.0148	0.0214	0.0205	0.5678	0.0233	0.0023
43	Coaches Standard <=18 t	Diesel	Euro I		2	40,000	80,000	11.173	0.470	0.0148	0.0214	0.0205	0.8938	0.0376	0.0045
44	Coaches Standard <=18 t	Diesel	Euro II		3	40,000	120,000	12.866	0.210	0.0148	0.0214	0.0205	1.5439	0.0252	0.0068
45	Coaches Standard <=18 t	Diesel	Euro III		4	40,000	160,000	11.737	0.270	0.0148	0.0214	0.0205	1.8779	0.0432	0.0091
46	Coaches Standard <=18 t	Diesel	Euro IV		4	40,000	160,000	7.459	0.062	0.0148	0.0214	0.0205	1.1935	0.0100	0.0091
47	Coaches Standard <=18 t	Diesel	Euro V	EGR	1	40,000	40,000	11.420	0.078	0.0148	0.0214	0.0205	0.4568	0.0031	0.0023
48	Coaches Standard <=18 t	Diesel	Euro V	SCR	3	40,000	120,000	7.059	0.076	0.0148	0.0214	0.0205	0.8471	0.0091	0.0068
49	Coaches Standard <=18 t	Diesel	Euro VI		4	40,000	160,000	0.936	0.009	0.0148	0.0214	0.0205	0.1497	0.0014	0.0091
50	Coaches Articulated >18 t	Diesel	Pre-Euro I		1	40,000	40,000	17.658	0.685	0.0148	0.0214	0.0205	0.7063	0.0274	0.0023
51	Coaches Articulated >18 t	Diesel	Euro I		2	40,000	80,000	13.666	0.535	0.0148	0.0214	0.0205	1.0933	0.0428	0.0045

... Exhaust NOx | Exhaust PM | Non-Exhaust PM | Worked example Guidance | **Worked example**

The majority of work on NEEs focuses on passenger cars, there is little data on larger vehicles NEEs, and conventional inventorying lacks resolution to characterise trends in an already evolving fleet

Background (2)

There are no robust, publicly available data on brake wear from electric vehicles (EVs) or those with regenerative braking, but anecdotal evidence suggested there would be a reduction in emissions where regenerative braking is used

So, there is a real need for better evidence on Electric Bus NEEs alongside the EURO VI to EV Bus Fleet transition

Study

The trial includes 10 Double Decker buses operated from First's York Bus Depot:

- 5 Conventional ICE Diesel Buses, and
- 5 Battery Electric Vehicles (BEV) Buses

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

Monitoring

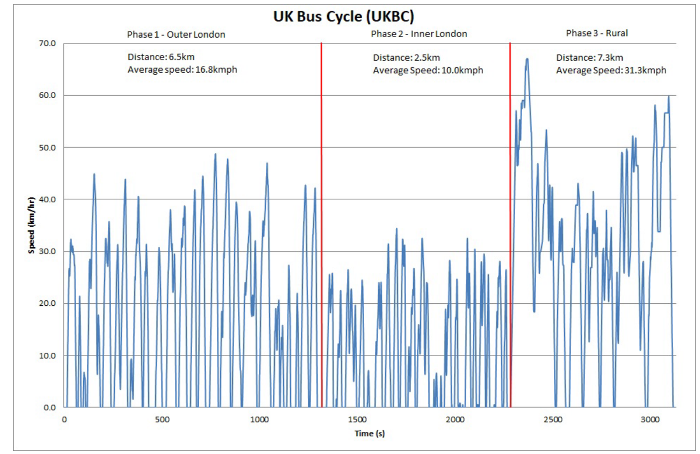
Existing Fleet Logging:

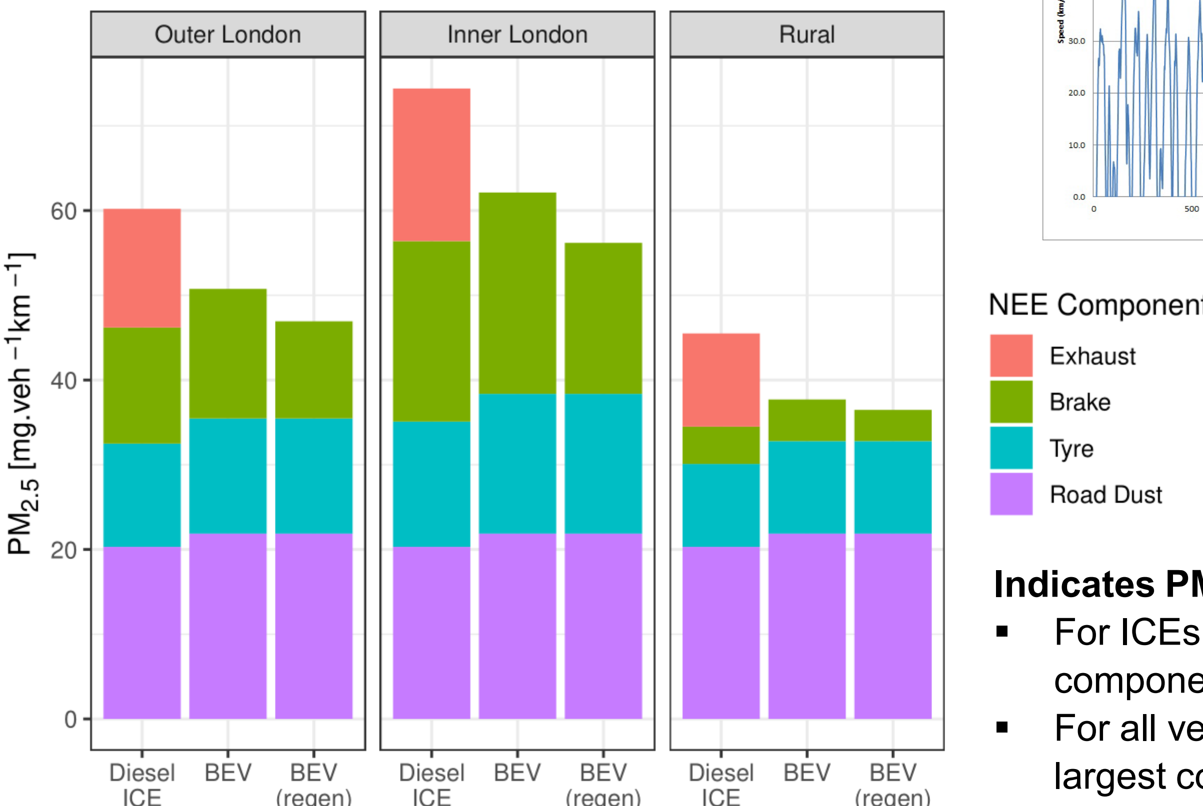
- Conventional telemetry e.g. for travel information services;
- Tyre and brake wear logged using visual/estimated wear rates as part of vehicle inspection cycles.

For the 10 Trial Vehicles:

- Improved telemetry;
- Bridgestone (tyre manufacturer/supplier) installing Webfleet Solution 'Wear Dongle' telemetry and new tyres (including TPMS – Tyre Pressure Monitoring System) to all 10 trial vehicles (with data collection started October 2021);
- Vehicle performance and tyre data (including regular detailed tyre/mileage and tread depth measurements by Bridgestone engineers) are being fed into Bridgestone's 'Toobox' for technical analysis (supported by Bridgestone's Digital Garage and Technical Centre Europe, Rome).

Early indications from preliminary scoping





Indicates $PM_{2.5}$ contributions:

- For ICEs, small but still significant exhaust component;
- For all vehicles, road dust may be biggest largest component;
- Brake $PM_{2.5}$ contribution depends on trade-off vehicle weight (↑) and regenerative braking (↓)

Comments, Challenges and My Question

We are now starting to gather and analysis the activity data (which will help us understand and bridge the expected associated regulatory/real-world gap) but there is still work to do, e.g.:

Brakes

- The Challenge – There are large uncertainties for the early measurements of each of the NEE components, and timely understanding is needed if we want to champion the best mitigations.
  - So, we need to be moving beyond conventional accelerated brake testing and start gathering real-world NEE data;
  - So, we need to reviewing emissions measurement methods.
- Unintended Consequences - Electric vehicles use regenerative braking via the drive motors to do much of the normal braking, however, the friction brake has to be ready to brake the vehicle when the braking demand is outside the scope of the regenerative system. *(When the batteries are fully charged or when higher braking loads are required)*

Additional Slide

Academic Team

University of Birmingham
Dr Suzanne Bartington, Dr James Levine, Dr Stuart Hillmansen, Professor William Bloss, Professor Francis Pope, Katie Youngwood, Harry Williams

University of Sheffield
Professor Martin Mayfield

University of Bath
Professor Sam Akehurst

Coventry University
Dr Huw Davies

University of Surrey
Professor Nigel Gilbert

UCL Energy Institute
Professor Ian Hamilton

UK Health Security Agency
Charlotte Landeg-Cox

University of Oxford
Dr Felix Leach, Kayla Schulte

University of Leeds
Dr Karl Ropkins

University of York
Dr Sarah Moller

Additional Slide

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Network Partners

aimsun.
national express
URBAN DESIGN GROUP
Cambustion
OXFORD STRATEGY
HS2
cenex
Zemo Partnership
Accelerating Transport to Zero Emissions
ORR OFFICE OF RAIL AND ROAD
CREATE streets
global action plan
RED KITE MANAGEMENT CONSULTING
Sheffield City Council
DustScanAQ
oxford bus company
First
apertum
UK:100
www.oxford.gov.uk OXFORD CITY COUNCIL
OXFORDSHIRE COUNTY COUNCIL
Coventry City Council
transport initiatives
local knowledge national expertise

Additional Slide

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Research

TRANSITION Funded Research
(Discovery & Innovation)

(A) Measuring Exposure in Different Transport Modes
Nick Molden (Emissions Analytics Ltd)

(B) Characterising Changing Travel Patterns in the COVID-19 Era
Dr Fiona Crawford (Univ. of West of England)

(C) Progressing Real-Time Source Identification
Gordon Allison (DustScan Ltd)

(D) Minimising Public Exposure at the Roadside
Dr Fabrizio Bonatesta (Oxford Brookes University)