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

¹: Head of Environment, FirstBus, First Group, UK (jon.tivey@firstbus.co.uk) ²: Transport Studies, Environment, University of Leeds, UK, (k.Ropkins@its.leeds.ac.uk)
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)

PAPER:
https://doi.org/10.3390/su15021522

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

REFERENCES:

We focused on

ALSO thank you ZEMO for UKBC Profile update

Outputs:
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.

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

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.
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  
**Visit:** www.transition-air.org.uk  
**Follow:** @TRANSITION_Air
**FIRSTBUS Test Fleet**

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

**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)
**embru software**

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

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

\[ \sum \text{emission(object)} \times \text{activity(object)} \]

R code:

```r
# EURO VI ICE diesel bus weighing 15925 kg
bus.1 <- bus_ice(name="ET00", veh.wt=15925, euro.class="VI", eng.fuel="diesel")
# a battery electric bus weighing 17725 kg (and conventional brakes)
bus.2 <- bus_beve(name="BEV", veh.wt=17725)
# like bus.2 but with regenerative brakes operating at 25% efficiency
bus.3 <- bus_beve(name="BEV(low)", veh.wt=17725, brk.regen = 0.25)
# like bus.3 but 25% efficiency
bus.4 <- bus_beve(name="BEV(hi)", veh.wt=17725, brk.regen = 0.75)
# a small fleet
fleet <- c(bus.1, bus.2, bus.3, bus.4)
# some routes
routes <- route_road_urban() + route_road_rural() + route_road_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")
```

Output:

[Image of R code execution output]

https://github.com/karlropkins/embru