AN ASSESSMENT OF THE POTENTIAL REDUCTION OF AIR POLLUTION EMISSIONS FROM BUSES

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ABSTRACT

The Greater Manchester Atmospheric Emissions Inventory (EMIGMA) covers an area of 1552 km^2, encompassing the ten administrative districts of Greater Manchester and Warrington. The database allows the magnitude and spatial distribution of emissions across Greater Manchester and Warrington to be investigated, and enables the relative importance of different sources of air pollution to be examined. The EMIGMA inventory estimates bus emissions to contribute approximately 3% of annual NO_x and 1% of PM_{10} emissions within the whole of the inventory area. However, a recent source apportionment study has indicated that close to the urban centre, buses can contribute as much as 50% of NO_x and up to 11% of total PM_{10} road related emissions. Within the inventory area, air quality standard exceedances are mainly related to road traffic. This has resulted in a greater emphasis being placed upon public transport as a means of reducing urban air pollution, thus the proportion of emissions from buses could become more significant in the future. This paper is based on a study undertaken for the Greater Manchester Passenger Transport Executive (GMPTE), which aims to establish a more accurate estimate of bus emissions, and provide an assessment of the potential reduction of air pollution emissions from buses via end of pipe and replacement vehicle policies. This paper presents the background to the study, the methodology, results and a comparison of the scenarios considered.

INTRODUCTION

ARIC, an air quality research group, within the Dalton Research Institute of Manchester Metropolitan University, were commissioned by the Greater Manchester Passenger Transport Executive (GMPTE) to undertake an assessment of potential reduction of air pollution emissions from buses, as a result of some aspects of its *Air Quality Improvement Programme*. Currently the Greater Manchester Atmospheric Emission Inventory (EMIGMA) does not consider bus emissions separately, though they are calculated as an integral part of road emissions. Further studies carried out on behalf of the local authorities [1,2] have estimated bus emissions to contribute to approximately 3% of annual $NO_{x,}$ emissions and 1% of PM_{10} emissions [1]. However, the contribution of buses to the ground level of NO_x annual average concentration can be much greater [2]. Previous source apportionment work has estimated that close to urban centres buses can contribute as much as 36% to 50% of NO_x road related emissions. For $PM_{10,}$ the contribution can be as much as 2% of the total PM_{10}, and up to 11% of road related concentrations. Air quality dispersion modelling also highlights the contribution of bus related emissions in the main urban centre of Manchester [1]. As more Air Quality Management Areas are declared and emphasis is placed upon public transport as a means of reducing urban air pollution, the emission proportion from buses will become more significant in the future.

METHODOLOGY

The GMPTE *Air Quality Improvement Programme* suggests a number of ways in which the contribution to air pollution from buses can be reduced. In order to assess these schemes, a more accurate baseline estimate of bus emissions was required. Data for speed per link; engine age data; and typical idle times were collated and emission estimates for the base case (2002) calculated. Emissions were determined as a function of the emission factor (EF) for the particular pollutant of interest, the number of buses travelling on a particular trip, and the speed of the trip. Three scenarios were considered, based on three Quality Bus Corridors (QBC) within Greater Manchester (Oxford Road, Bolton-Leigh and Stockport Road). These considered the fitting of particulate traps to pre-Euro II buses; the fitting of particulate traps to post-Euro I buses; and replacing pre-EURO II buses, which travel at least 50% of the length of a QBC, with EURO II buses. Post-EURO I buses are defined as buses with an engine type produced in 1996 and beyond, whilst pre-EURO II buses run on engine type produced before 1996.

RESULTS

Baseline Emissions

Baseline emissions represent total emissions from buses for the base year of 2002/2003. The total emissions for the baseline year of 2002/2003 for each engine type, categorised as pre-pre-88, 88-93, EURO I and EURO II and EURO III for Oxford Road, Stockport Road and the Bolton-Leigh corridor are presented in Tables 1 to 3.

Pollutant	Total emissions (tonnes per annum)							
	Pre-88	88-93	Euro I	Euro II	Euro III	*Total Pre Euro II*	*Total Post Euro I*	Total
NO_x	17.2	5.4	10.2	12.9	10.3	*32.8*	*23.3*	56.1
PM_{10}	2.4	0.4	0.5	0.4	0.3	*3.3*	*0.7*	4.0
HC	8.5	0.8	1.3	1.3	1.1	*10.6*	*2.4*	13.0
CO	20.5	3.6	2.6	3.0	2.4	*26.7*	*5.4*	32.1
CO_2	1223.2	460.4	922.4	1186.2	1371.2	*2606.0*	*2557.4*	5163.4

Table 1 Baseline emissions for Oxford Road (2002/2003)

Pollutant	Total emissions (tonnes per annum)							
	Pre-88	88-93	Euro I	Euro II	Euro III	*Total Pre Euro II*	*Total Post Euro I*	Total
NO_x	14.7	0.0	0.0	6.8	8.2	*14.7*	*15.0*	29.7
PM_{10}	2.2	0.0	0.0	0.2	0.3	*2.2*	*0.5*	2.7
HC	7.9	0.0	0.0	0.7	0.9	*7.9*	*1.6*	9.4
CO	18.4	0.0	0.0	1.6	2.0	*18.4*	*3.6*	22.0
CO_2	1080.6	0.0	0.0	625.2	1080.9	*1080.6*	*1706.1*	2786.6

Table 2. Baseline emissions for Stockport Road (2002/2003)

Pollutant	Total emissions (tonnes per annum)							
	Pre-88	88-93	Euro I	Euro II	Euro III	*Total Pre Euro II*	*Total Post Euro I*	Total
NO_x	2.1	2.5	0.9	5.7	4.0	*5.5*	*9.7*	15.3

PM_{10}	0.2	0.2	0.0	0.2	0.1	*0.4*	*0.3*	0.6
HC	0.8	0.4	0.1	0.6	0.4	*1.3*	*1.0*	2.2
CO	1.9	1.6	0.2	1.4	0.9	*3.7*	*2.3*	6.0
CO_2	116.2	202.1	83.3	541.6	562.5	*401.6*	*1104.1*	1505.7

Table 3. Baseline emissions for the Bolton –Leigh corridor (2002/2003)

Although the proportion of pre-EURO II buses is smaller, they contribute more to the total PM_{10} emissions at all the QBCs under consideration.

<u>Scenario 1 – Fitting particulate traps to pre-EURO II buses</u>

Scenario I provides estimates of PM_{10} emission reductions if particulate traps are fitted onto all pre-EURO II buses. Previous studies [3,4] have found an average 35% PM_{10} reduction on EURO I and pre-EURO I buses. This 35% reduction has been taken as the assumed reduction of PM_{10} after the fitting of particulate traps on pre-EURO II buses at the QBCs. The results of Scenario 1 are presented in Table 4.

Corridor	PM_{10} Tonnes per annum		Percentage %		Total Tonnes per annum (tpa)	
	Pre – EURO II	Post – EURO I	Pre – EURO II	Post – EURO I	Scenario 1	Baseline
Oxford Road	2.182	0.718	75%	25%	2.9	4.1
Stockport Road	1.419	0.469	75%	25%	1.9	2.7
Bolton-Leigh	0.300	0.285	51%	49%	0.6	0.7

Table 4. Results from Scenario 1

Fitting PM traps onto older buses (pre-EURO II buses) would reduce the proportion of PM_{10} emissions from pre-EURO II at all QBCs concerned. More important than the proportions, are the magnitudes of reduction from the total baseline bus emissions. In terms of total PM_{10} emissions, comparison with the baseline total PM_{10} emissions show that emissions would be reduced by 29% (from 4.1 to 2.9 tpa) for Oxford Road, 30% (from 2.7 to 1.9 tpa) for Stockport Road and 14% (from 0.7 to 0.6 tpa) for the Bolton-Leigh corridor

<u>Scenario 2 – Fitting particulate traps to post-EURO I buses</u>

It has been estimated that fitting PM traps to EURO II and EURO III buses can reduce PM_{10} emissions by 85% [5]. For the purpose of this scenario, it was therefore assumed that post-Euro I buses would have a 85% reduction in PM_{10} emissions. It was assumed that emissions from pre-EURO II buses were the same as the baseline emissions. The results for Scenario 2 are presented in Table 5.

Corridor	PM_{10} Tonnes per annum		Percentage %		Total Tonnes per annum (tpa)	
	Pre – EURO II	Post – EURO I	Pre – EURO II	Post – EURO I	Scenario 1	Baseline
Oxford Road	3.357	0.108	92%	8%	3.5	4.1
Stockport Road	2.182	0.070	97%	3%	2.6	2.7
Bolton-Leigh	0.462	0.043	92%	8%	0.5	0.7

Table 5. Results from Scenario 2

Comparison with the baseline PM_{10} emissions shows that fitting PM traps to post-EURO I buses reduced the emissions by 15% (from 4.1. to 3.5 tpa) for Oxford Road, 15% (from 2.7 to 2.6 tpa) for Stockport Road and 29% (from 0.7 to 0.5 tpa) for the Bolton-Leigh corridor. In terms of the Oxford Road and Stockport Road corridors, Scenario 2 reduces less PM_{10} emissions than Scenario 1, however the Bolton-Leigh corridor shows the opposite result as this QBC has the highest proportion of post-Euro I buses. The fitting of PM traps to post-EURO I buses, would result in over 90% of PM_{10} bus emissions along the three QBCs being contributed by pre-EURO II buses.

Scenario 3 – Replacing pre-EURO II using 50% of the QBC with EURO II

In Scenario 3, pre-EURO II buses that are travelling on at least 50% of the length of the QBC would be replaced with EURO II buses. The results are shown in Tables 6 to 8 below.

Pollutant	Emissions					
	Tonnes per annum (tpa)		Percentage		Total (tpa)	Percentage Reduction
	Pre - EURO II	Post – EURO I	Pre - EURO II	Post – EURO I		
NO_x	4.1	43.1	9%	91%	47.2	16%
PM_{10}	0.4	1.3	24%	76%	1.7	57%
HC	1.4	4.4	24%	76%	5.8	55%
CO	3.4	10.1	28%	72%	13.5	58%
CO_2	319.5	4325.1	7%	93%	4644.6	10%

Table 6. Results from Scenario 3 for Oxford Road

Pollutant	Emissions					
	Tonnes per annum (tpa)		Percentage		Total (tpa)	Percentage Reduction
	Pre - EURO II	Post – EURO I	Pre - EURO II	Post - EURO I		
NO_x	8.0	18.9	30%	70%	26.9	10%
PM_{10}	1.2	0.6	67%	33%	1.8	33%
HC	4.2	2.0	68%	32%	6.2	34%
CO	10.0	4.5	69%	31%	14.5	34%
CO_2	584.9	2061.2	22%	78%	2646.1	5%

Table7. Results from Scenario 3 for Stockport Road

Pollutants	Emissions					
	Tonnes per annum (tpa)		Percentage		Total (tpa)	Percentage Reduction
	Pre - EURO II	Post – EURO I	Pre - EURO II	Post - EURO I		
NO_x	1.6	12.3	12%	88%	14.0	8%
PM_{10}	0.1	0.4	20%	80%	0.5	33%
HC	0.4	1.2	25%	75%	1.6	29%
CO	1.1	2.8	28%	72%	4.0	34%
CO_2	119.9	1357.4	8%	92%	1477.4	2%

Table 8. Results from Scenario 3 for the Bolton–Leigh Corridor

The results in Tables 6 to 8 show that Scenario 3 would reduce PM_{10} emissions by 57% for Oxford Road, 33% for Stockport Road and 33% for the Bolton-Leigh corridor. These reductions are higher than those for the other scenarios. Other pollutants also show a reasonable reduction for Scenario 3: 8% to 16% for NO_x; 29% to 54% for HC; 34% to 58%

for CO; and 2% to 10% for CO_2. In general, Scenario 3 increases the proportions of emission contributed by post-EURO I buses as the number of pre-EURO II buses are reduced, except for PM_{10} on Stockport Road. The total emissions on a particular QBC also depend on the fleet composition and the length of the QBC which the buses travel on. The composition of pre-EURO II buses on Stockport Road was dominated by pre-1988 engine type, which has the highest emission factor. If those pre-EURO II buses only travel on less than 50% of the length of the QBC, they were assumed to stay as pre-EURO II buses, hence according to Scenario 3 the emissions would not be reduced.

SUMMARY

The results of scenario testing for PM_{10} reduction are summarised in Figure 1 below. Figure 1 demonstrates that in comparison with Scenario 1 and 2, in general, Scenario 3 would result in the greatest reduction of PM_{10} emissions. Scenario 3 also provides other benefits in terms of reduction of other pollutants, most notably hydrocarbons (HCs) and carbon monoxide (CO) as shown in Figure 10.

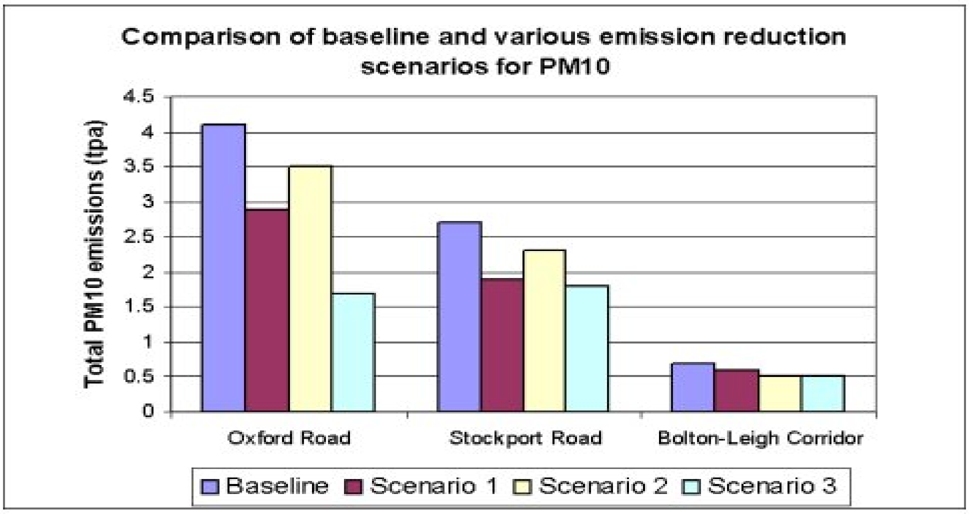
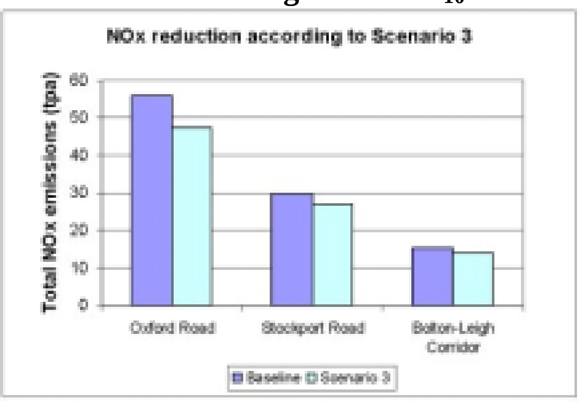
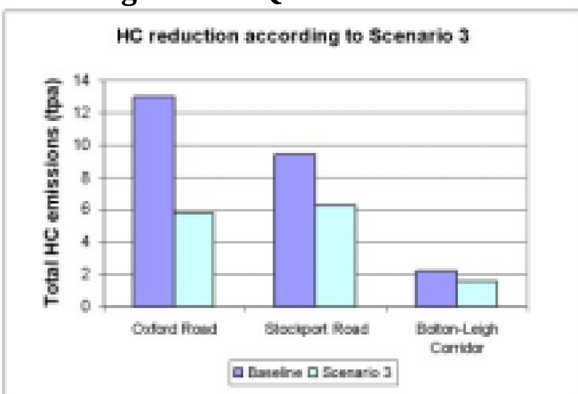


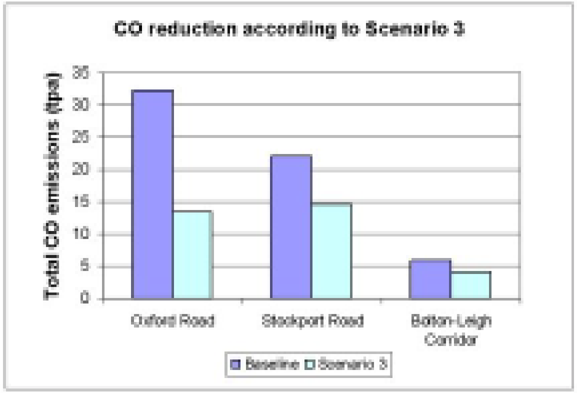
Figure 1. PM_{10} reduction according at each QBC



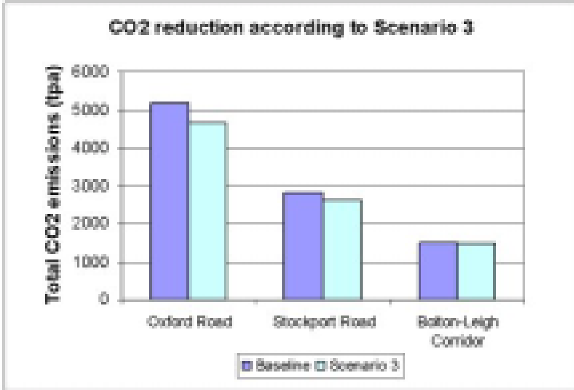
(a) NO_x



(b) HC



(c) CO



(d) CO_2

Figure 4. 9. NO_x , HC, CO and CO_2 reduction according to d Scenario 3 at each QBC

In terms of emissions per bus, fitting PM traps does not necessarily result in a significant reduction of the actual amount of PM_{10} released into the atmosphere. The lowest emissions are obtained by fitting PM traps onto EURO II and EURO III buses. For older buses, the amounts of PM_{10} released per vehicle per km for pre-EURO II buses travelling at 20 kph, which have PM trap fitted, are basically similar to the amount of PM_{10} emitted when the bus travels at 35 kph. Therefore in a QBC where pre-EURO II buses only account for a minor proportion of the fleet, an Express Bus Route might be a more economical option than to fit PM traps.

However, it should be noted that the amounts of PM_{10} emitted by a pre-88 bus, that either has a PM trap fitted or travels at an increase speed, is about 5 times that of the emission of a EURO II bus, which travels at 20 kph without a PM trap fitted. In general, a pre-EURO II bus, which travels at 35 kph, or has PM trap fitted, emits slightly higher emissions than EURO II buses without a fitted PM trap. Accordingly, in a QBC where a significant proportion of the fleet is pre-EURO II buses, replacing those buses with EURO II buses might reduce the most significant amount of $PM_{10.}$ Hence it can be summarised that the option to apply Scenario 1, 2 or 3 or other planning options such as Express Bus Routes or the replacement of fleet with hybrid buses might be unique for each of QBC, and is dependent on the following factors: fleet composition at that particular QBC; the speed at which the buses travel; and the length of the journey within the QBC a bus with a certain engine type travelling

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