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RESEARCH ARTICLE OPEN ACCESS

The Mitigation Importance of Nitrogen Dioxide Emissions from Road Vehicle Exhaust

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ABSTRACT
Many European towns have seen an increase in near-road ambient concentrations of nitrogen dioxide (NO_2) due to the direct emission of NO_2 from road vehicle exhaust. In terms of NO_2 emissions from roads, diesel vehicles and their associated emission control technologies, such as Diesel Oxidation Catalysts, have been the most prominent contributors. As a result of recent remote sensing measurements in the UK, we now have precise data on NO_2 and total NOx (NO_2+NO). The current study was based on extensive observations using a spectroscopic remote sensing (RS) equipment created by the University of Denver. The Fuel Efficiency Automobile Test (FEAT) instrument has been utilized. Remote sensing data showed that there were significant variations in total NOx emissions between LNT and SCR diesel passenger automobiles on average. While the NO_2/NOx ratios of LNT and SCR cars are similar on average, in terms of absolute NO_2 emissions, SCR-equipped vehicles release around 60% less NO2 than LNT-equipped vehicles. With the complete adoption of RDE Regulations and Euro 6d-temp and Euro 6d cars, NOx and NO_2 emissions were predicted to be considerably decreased, with the majority of vehicles adopting SCR or SCR LNT.

***Keywords* -** Fuel Efficiency, NOx and NO_2 emissions, Road vehicle exhaust, SCR-equipped vehicles, Spectroscopic remote sensing (RS),

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I. INTRODUCTION

Road transport generates considerable amounts of greenhouse gases and other gases, not to mention other air pollutants. Even if car efficiency has increased over the years, transportation still accounts for over 20% of Europe's GHG emissions today. Many European towns have air pollution levels that are well over EU guidelines because of car emissions [1].

Transportation, especially road transportation, provides numerous advantages for modern society. It promotes economic growth and job creation by facilitating the free flow of people and things. The road transport industry, however, is a major contributor to Europe's emissions of greenhouse gases (GHGs) and air pollutants, despite these benefits and the many technological and efficiency gains achieved over the last decades. Both bad air quality and climate change are harmful to people and the environment, but in different ways. The negative effects from pollution from roads cost society money [2].

One of the most common urban air pollutants is nitrogen dioxide (NO_2). Transportation, electricity generating, industry, and residential activities all contribute significantly due to their reliance on fuel combustion as a primary source of air pollution in metropolitan areas. From a public health standpoint, NO_2 has been linked to a host of respiratory issues, the worst of which is an asthma exacerbation. Ground-level ozone (O_3) concentrations are another public health issue, and NO_2 is a major contributor to their formation. In this policy brief, we examine the connections between traffic, climate change mitigation, and ambient levels of air pollutants like NO_2 [3].

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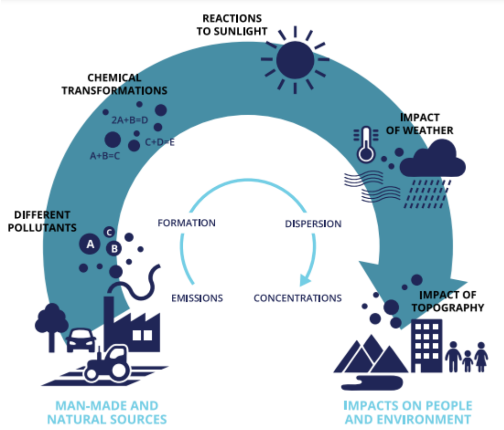

Fig. 1. Effects of air pollution, from emissions to exposure [4]

The purpose of this research was to better comprehend the latest findings from comprehensive vehicle emission remote sensing measurements pertaining to the emissions of NOx and NO_2. Consideration was given to how NO_2 emissions have changed over time as Euro regulations have been stricter, as well as the date a vehicle was constructed. The present effort focused on determining the emissions from light duty vehicles, especially diesel passenger cars and light commercial vehicles (LCV, N1 Type Approval category). For the first time, we took into account vehicle mileage at the time of assessment to better evaluate potential degradation impacts.

The first chapter provided a description of how vehicle emissions occur and how they are tested, and the reasons for the differences observed between tested and real-world driving emissions. The next chapter presented a more detailed description on the effects of vehicle emissions. Chapter three provided a summary of the testing procedures used for estimating vehicle emissions, as well as the technologies that were currently in place for their reduction. The final chapter provided the conclusion.

II. LITERATURE REVIEW

The emission of nitrogen dioxide (NO_2) is a major environmental risk in cities all around the globe. Transport and stationary fuel burning are the main contributors to NO_2 levels in the atmosphere. It is predicted that the largest levels of nitrogen dioxide (NO_2) can be found in highly travelled locations, places with a high concentration of buildings that burn fuel for heating and running water boilers, and areas with a high concentration of industrial land uses. U.S. EPA reported that during the past few decades, ambient NO_2 concentrations have decreased thanks to increased fuel economy and stricter limits on vehicle pollution emissions [5,6]. Between 2009 and 2018, NO_2 concentrations dropped by 29%. These concentration readings are gathered from various sites across the world [7].

It might be challenging to characterize NO_2 concentrations in a city since NO_2 concentrations can vary greatly depending on traffic loads. In addition, there is data suggesting that the elevation of monitoring stations affects the accuracy with which this pollutant is measured. Concentrations were found to vary significantly between 4 and 15 m above ground in one investigation [8].

NO_2 ground level concentration estimates have lately become available across large areas, even in places with no monitoring stations, thanks to satellite measurements. It appears that NO_2 levels are rising in East Asia while falling in North America and Europe. The demand for transportation and energy services, as well as transportation and energy policy initiatives that aim to reduce the use of fossil fuels and associated emissions, are all factors in these variations [9].

NOx and other pollution emissions from automobiles are continually changing as new technologies join vehicle fleets and older vehicles retire. As improved diesel NOx management technologies have been introduced in recent years, there have been significant advances in this regard. Lean NOx Traps (LNT) and Selective Catalytic Reduction (SCR) are two main technologies that are now widely used (SCR). Both of these technologies have the potential to considerably cut NOx and NO_2 emissions [10].

LNT and SCR are currently the major NOx control technologies used on light duty cars, and it is critical to evaluate their efficacy under real-world operating circumstances in terms of total NOx reduction and their impact on direct NO_2 emissions. During lean engine running, NOx is adsorbed onto a catalyst by LNT. When the catalyst becomes saturated, the system is regenerated by brief bursts of fuel-rich operation in which NOx is catalytically reduced. In the presence of ammonia, a catalyst in SCR converts NOx to gaseous nitrogen and water.

The source of ammonia in light-duty cars is aqueous urea solution (AdBlueTM) [10].

The number of laboratory and on-road emission measurements from automobiles has increased significantly in recent years. This rise reflects worry that pollutants from automobiles released under real-world driving circumstances are several times higher than those detected under laboratory settings. The widespread use of LNT and SCR on light duty Euro 6 cars has resulted in an increase in the volume of emissions data from these vehicles. While these measures give much-needed information on NOx emissions, most studies failed to distinguish between NO and NO_2. While such speciation was unimportant in terms of Type Approval, it is critical in terms of urban air pollution [11-13].

In the last quarter of a century, significant strides have been made toward reducing the harmful effects of vehicle emissions on the environment. These successes are the result of a number of policies and measures, including technological standards for vehicle emissions and fuel quality, legislation establishing air quality limits, and measures implemented at the local level to manage transportation use, such as improved transport planning and public transportation incentive programs. Although emission reductions over the past few decades have generally been larger than first expected, this is not always the case due to the overall increases in passenger and freight demand as well as the under-performance of certain vehicle standards under real-world operating conditions [14].

III. METHODOLOGY

3.1. Research Design

The current study was based on extensive observations using a spectroscopic remote sensing (RS) equipment created by the University of Denver. The Fuel Efficiency Automobile Test (FEAT) instrument has been utilized in several projects throughout the world and is thoroughly detailed elsewhere [15-18].

3.2. Research Instrument

The instrument was made up of a source and a detector that are placed on opposite side of a single lane road. A collinear beam of non-dispersive infrared (IR) and dispersive ultraviolet (UV) light was directed over the single lane and into the detecting unit as the source. When the collinear beam entered the detector, it was directed onto a dichroic beam splitter, which separated the IR and UV components. The infrared component was directed at a rotating polygon mirror, which distributed the beam evenly over four infrared detectors in order to measure CO, CO_2, hydrocarbons (HCs), and a background reference.

The UV component was reflected off the dichroic mirror and was sent to two independent UV spectrometers through a quartz fiber bundle. The first monitors were SO_2, NH_3, and NO, while the second monitor was NO_2. When a vehicle passed through the FEAT setup, the control computer initiated an assessment of the exhaust plume when it detected the vehicle's rear obstructing the first speed bar laser. At this stage, the ratios of CO, HCs, SO_2, NH_3, NO, and NO_2 to CO_2 were calculated using the above-mentioned approach.

Because a vehicle exhaust plume varied substantially in terms of density, route length, and emission position, all species were evaluated as a ratio to CO_2. The speed bar lasers measured the vehicle's speed and acceleration. Finally, a video camera was utilized to picture the car registration plate, which may subsequently be used to collect technical information about the vehicle.

3.3. Site Details & Measurement Conditions

In 2017 and early 2018, remote sensing studies were conducted in two UK cities: York and London. York and London were chosen as two different locales, with the latter giving the possibility of 2012/2013 follow-up measures [15]. A total of 7413 vehicle emission measurements were taken at three sites in York between July 12th and September 20th, 2017, over a 12-day period, while 34,055 cars were measured at three locations in London between November 14th and April 12th, 2018, during a 15-day period. The measurements were aggregated into a single data set of 41,468. Except for rainy days, the polls were conducted on weekdays during daylight hours (between 0900 and 1700 h).

Table (1)

Detailed location data for York's potential measuring sites.

	University Rd	A59/A1237	Clifton Moor
Latitude	53°56'57.5"N	53°58'21.2"N	53°59'15.0"N
Longitude	1°03'15.0"W	1°08'38.1"W	1°05'36.5"W
Ambient temperature range (°C)	16–22	17–21	15–16
Gradient (%)	0.4	0.0	0.0
Mean speed (km h^{-1})	28.8	36.4	42.1
Mean VSP (kW t^{-1})	6.1	9.0	13.1
Car (M1)	3648	2609	48
Bus (M2 + M3)	161	9	0
LCV (N1)	551	324	6
HGV (N2 + N3)	20	34	0

Table (2)

Detailed location data for London's potential measuring sites.

	Greenford Rd	West End Rd	Putney Hill
Latitude	51°31'11.4"N	51°34'06.7"N	51°27'19.7"N
Longitude	0°21'16.7"W	0°25'20.8"W	0°13'10.1"W
Ambient temperature range (°C)	12–15	3–7	5–14
Gradient (%)	0.7	0.0	3.0
Mean speed (km h^{-1})	35.1	32.7	33.3
Mean VSP (kW t^{-1})	5.3	8.0	8.6
Car (M1)	2506	2519	16659
Bus (M2 + M3)	121	51	1445
LCV (N1)	552	438	5582
HGV (N2 + N3)	24	25	355

3.4. Vehicle technical information

A commercial provider provided individual car details (CDL Vehicle Information Services Limited). Data gathered as part of the UK vehicle taxation system (DVLA) and data requested from the Society of Motor Manufacturers and Traders (SMMT) Motor Vehicle Registration Information System are the two major sources of data provided by CDL (MVRIS). These statistics include information on various physical features of road cars, such as engine size, fuel type, kerb weight, date a vehicle was constructed and first registered, and the vehicle's Euro Standard.

3.5. Model fitting:

Generalized Additive Models (GAMs) were used to develop correlations between emissions and other factors such as vehicle miles or date of production. GAMs are a highly adaptable 'data-driven' modelling method that is well suited for analyzing vehicle emission remote sensing data (Wood, 2004). The capacity to explore non-linear interactions between independent and dependent variables while making no a priori assumptions about the nature of the relationship is the primary advantage of the GAM technique in the current situation. We use the thin-plate regression spline approach from the R package mgcv [19].

The emission is considered to be a smooth function of either the date of manufacturing of a vehicle or the vehicle miles in the basic models employed in the current study. The default choices of the mgcv package's gam function were utilized without modification, resulting in interpretable models with smooth connections between the dependent and independent variables. Instead of the year of manufacturing, the date of manufacture has been represented to the nearest month.

IV. RESULTS AND DISCUSSION

In this chapter, we examined how the introduction of Euro 6 after treatment technology for diesel passenger cars and LCVs has impacted NOx and NO_2 emissions. From what can be seen in Fig. 2, NOx emissions dropped between the years 2000 and 2007, then were rather stable until around 2014. There has been a significant reduction in NOx emissions across the board since 2014 for all cars (the black line). However, as seen in Fig. 2, there is a significant performance gap between LNT- and SCR-equipped vehicles. NOx emissions from vehicles equipped with SCR technology, for instance, are reduced by a factor of around three when compared to those from vehicles employing LNT. The noticeable shift in 2014 depicted in Fig. 2 coincides with the launch of Euro 6 passenger automobiles, with the September 2014 deadline for all new model vehicles to meet Euro 6 standards. Some automakers did release Euro 6 models before to September 2014, however there were relatively few of them on the road at the time.

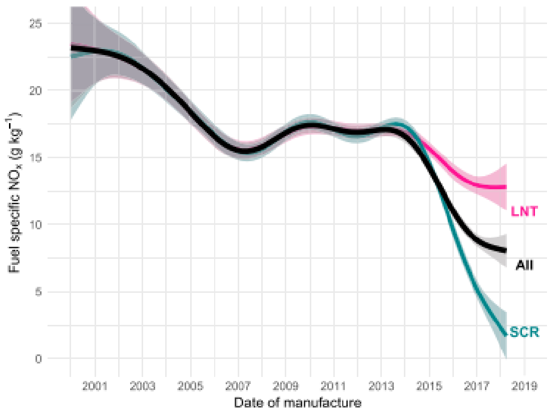

Fig. 2. Diesel passenger car NOx emissions (g kg-1 fuel) by year of manufacture. Emissions for all vehicles, independent of after treatment technology, are depicted by the black line. A GAM was used to determine if there was a correlation between the date of manufacture and the level of NOx emissions.

As can be seen in Fig. 3, the trajectory of NO_2 emissions is very unlike to that of NOx. Between the years of 2000 and 2007, emissions rose steadily until peaking in that year and falling steadily ever since. Some indicators point to a sharp decline in car numbers beginning around 2015. When comparing the actions of cars with LNTs versus those with SCRs, striking differences emerge. Though there has been a marked decline in NO_2 emissions from SCR-equipped vehicles since 2014, there is reason to believe that NO_2 emissions have increased due to the use of LNT vehicles. The introduction of Euro 6 automobiles, however, has resulted in overall lower NO_2 emissions.

From 2000-2007, LCV NO_2 emissions followed the same upward trend as diesel-powered automobiles (Fig. 4). Emissions of NO_2 in model year 2017/2018 are around half those of vehicles made in 2007, but the evidence is much more convincing for LCVs, which were first introduced in 2010–2011. Diesel passenger vehicle NO_2 emissions, on the other hand, have decreased by around a third over the same time period.

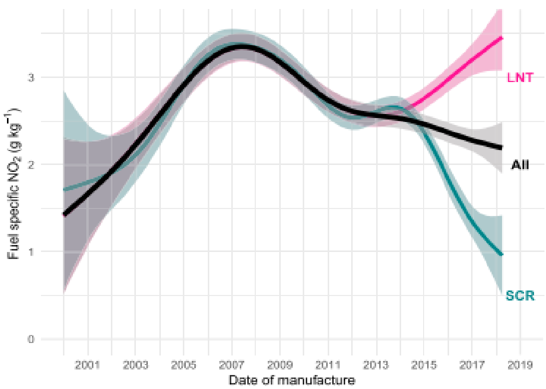

Fig. 3. Diesel passenger car NO_2 emissions (g kg-1 fuel) by year of manufacture. A GAM was used to determine if there was a correlation between the date of manufacture and the level of NO_2 emissions

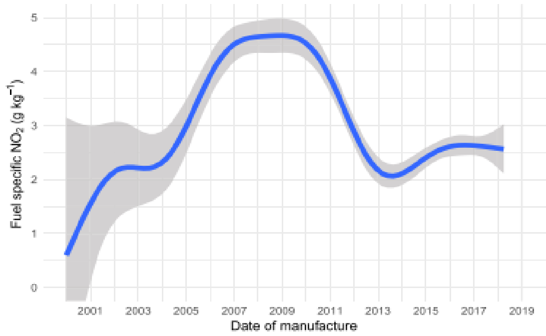

Fig. 4. Diesel LCV's NO_2 emissions (g kg-1 fuel) by year of manufacture. A GAM was used to determine if there was a correlation between the date of manufacture and the level of NO_2 emissions

Table 3 provides a brief overview of the fuel-specific emission factors for passenger cars and LCVs. As we move from Euro 5 to Euro 6, we see a significant drop in NOx emissions from both vehicle classes. A 62% decrease in NOx production is seen in LCVs, whereas a 47% decrease is seen in PCs. The decrease in NO_2 is approximately 10-18% for PC and LCV.

Table (3)
Diesel vehicle NOx and NO2 emissions categorized by vehicle type and Euro norm. LCV stands for Light Commercial Vehicle while PC is for Passenger Car.

Vehicle class	Euro status	NO_x (g kg^{-1})	NO_2 g kg^{-1}	Sample number
PC	2	20.9 ± 3.2	1.5 ± 0.5	42
PC	3	19.8 ± 0.6	2.7 ± 0.2	1028
PC	4	16.1 ± 0.4	3.2 ± 0.1	2639
PC	5	17.2 ± 0.4	2.7 ± 0.1	5255
PC	6	9.1 ± 0.3	2.2 ± 0.1	3735
LCV	0	19.7 ± 3.4	1.5 ± 0.5	53
LCV	2	23.3 ± 2.9	2.0 ± 0.7	66
LCV	3	21.9 ± 1.3	3.1 ± 0.3	462
LCV	4	20.4 ± 0.7	4.6 ± 0.3	1584
LCV	5	24.5 ± 0.5	2.5 ± 0.1	3890
LCV	6	9.3 ± 0.6	2.3 ± 0.2	1306

Some preliminary research on diesel vehicle NO2 emissions has revealed that the amount of NO2 produced by older vehicles declines [20]. Age of the vehicle is not likely to be the most telling factor in after treatment system failure. The number of miles driven is a more accurate indicator of how often a car is driven. The recent effort allows for the first time to correlate remote sensing data of vehicle emissions with a given vehicle's mileage. By combining them, we gain rich information on the consequences of vehicle deterioration thanks to the large sample sizes and wide ranges of mileages.

About half of the diesel automobile fleet, or about 7,000 vehicles, have available mileage data. The fact that passenger cars in the UK only need to undergo an annual MOT examination after they are over 3 years old is the primary reason why there is not a bigger proportion of vehicles for which mileage is available. Therefore, there is less data accessible for Euro 6 vehicles, such as their mileage. In addition, due to the recent release of Euro 6 vehicles, there are a comparably small number that have high mileage.

A correlation between diesel passenger car mileage and NO_2 emissions as measured by the Euro Standard is depicted in Fig. 5. As the vehicle's mileage grows, there is evidence that the amount of NO_2 emitted reduces, and this holds true across the board (from Euro 3 to Euro 6). Evidence of a decline in NO_2 levels is strongest for Euro 5 vehicles, likely because of the greater sample sizes of these vehicles.

Because overall NOx emissions from diesel vehicles remain relatively constant with mileage, the NO2/NOx ratio tends to fall as the mileage of the vehicle rises. The findings also caution against making inferences about the 'missing' NO_2 when analyzing remote sensing data for which only NO measurements are available [21].

For Euro 4 and 5 vehicles with large enough sample sizes, the statistics demonstrate that NOx emissions are constant across all mileages, but the ratio of NO to NO_2 shifts as the vehicle ages. The prior analysis took into account data collected in 2017 and 2018. Nonetheless, contrasting the NO_2/NOx ratios with past study at the same west London on Putney Hill site is also instructive [20].

In June and July of 2013, 4358 Euro 5 diesel PC were analyzed as part of the 2013 program. In 2013, the average NO_2/NOx ratio for Euro 5 diesel PC was 25.5%. After 5 years, the percentage has gone down to 15.6%. As the ratio of NO_2 to NOx declines with increased mileage in diesel personal computers, a 10% absolute drop over 5 years is significant.

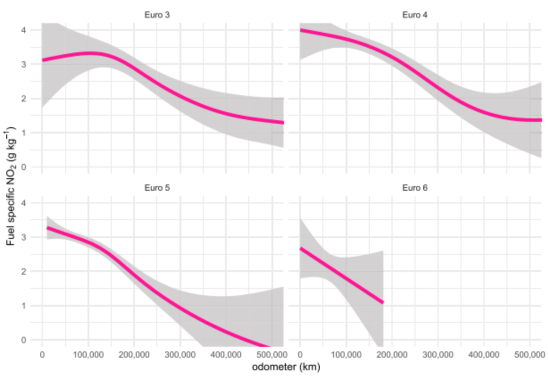

Fig. 5. NO_2 emissions (g kg-1fuel) for diesel passenger automobiles as a function of annual mileage, broken down by fuel type and Euro standard. Using a GAM, we were able to determine the correlation between NO_2 emissions and mileage.

These findings demonstrate a significant variation in NO_2 emissions (and overall NOx emissions, with a factor of 17 separating the lowest and highest emitting vehicles) among vehicle types, makes, and models. Higher and lower NO_2 emissions are not necessarily linked to the vehicles with the greatest total NOx emissions, and vice versa. Diesel passenger vehicles with good NOx and NO_2 performance are technically feasible, as some of the lowest NOx emitters also emit low proportions of NO_2. The data also shows that the composition of the fleet will have a significant impact on the future significance of NOx and NO_2 emissions. Further, the vehicles measured here are not RDE-compliant (i.e. Euro 6d-temp or Euro 6d), so further emission reductions are to be anticipated in the near future.

V. CONCLUSION

The direct emission of NO_2 from diesel cars has had a significant impact on near-road concentrations of ambient NO_2 throughout Europe. The future impact of NOx emissions from road vehicles was determined by both the absolute amount of NOx released and the amount of NOx emitted as NO_2. According to the present research, the relevance of primary NO_2 from cars has been decreasing in recent years.

There were two major elements that operate to diminish the significance of direct NO_2 emissions. First, the recent introduction of Euro 6 automobiles has resulted in a significant reduction in absolute NOx emissions from vehicles. Despite the fact that remote sensing data revealed that new vehicles with little mileage have relatively significant NO_2 emissions (with NO_2 accounting for 30% of NOx), absolute NO_2 emissions from diesel automobiles and LCV have been decreasing since roughly 2007.

Second, the new data published in the current study revealed that NO_2 emissions tend to decrease as vehicle mileage increases. The reduction in NO_2 emissions with age can be significant. This was a significant result since existing emission factors and inventories did not account for changes in NO_2 assumptions as cars age. Importantly, there was no indication of a change in overall NOx emissions.

The current study's trend of decreasing NO_2/NOx ratios and absolute NO_2 emissions was consistent with a comprehensive examination of ambient data at various sites throughout Europe. According to [22], the NO_2/NOx ratio at most roadside sites across Europe began to decline around 2010.

Remote sensing data showed that there were significant variations in total NOx emissions between LNT and SCR diesel passenger automobiles on average. While the NO_2/NOx ratios of LNT and SCR cars were similar on average, in terms of absolute NO_2 emissions, SCR-equipped vehicles released around 60% less NO_2 than LNT-equipped vehicles. With the complete adoption of RDE

Regulations and Euro 6d-temp and Euro 6d cars, NOx and NO_2 emissions were predicted to be considerably decreased, with the majority of vehicles adopting SCR or SCR LNT. As a result, the importance of primary NO_2 emissions in the urban environment will continue to decline.

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An acknowledgement section may be presented after the conclusion, if desired.

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