

**The potential health, financial & environmental impacts of *dieselgate*  
in Ireland**

Shreya Dey, Brian Caulfield and Bidisha Ghosh\*

Department of Civil, Structural & Environmental Engineering, Trinity College Dublin,  
Dublin, Ireland

\*Corresponding Author Email: [bghosh@tcd.ie](mailto:bghosh@tcd.ie)

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The transportation sector is the greatest contributor to air pollution. With the booming demand for transportation, reducing the pollution has become one of the main concerns of researchers. EPA emission standards are designed to protect air quality and human health. Diesel Euro 5 NO<sub>x</sub> has become a matter of disquiet since it has been found that NO<sub>x</sub> emissions are significantly exceeding the standard limit. This paper presents a study to estimate the disparity in real world NO<sub>x</sub> emission levels resulted from all diesel Euro 5 passenger cars (PC) and light commercial vehicles (LCV) that are present in Ireland. NO<sub>x</sub> emission levels calculated based on laboratory test results, on-road measurements and COPERT 4 model were compared. Additionally, NO<sub>x</sub> emission levels from the defective Volkswagen models have been calculated to quantify the effect of the Volkswagen scandal on Ireland. Impacts of excess NO<sub>x</sub> emissions on health and cost have also been presented.

Keywords: *dieselgate*; Volkswagen scandal; COPERT 4; euro 5 light duty vehicles; NO<sub>x</sub> emissions; health impact of NO<sub>x</sub>

## **Introduction**

Air pollution is associated with 7 million premature deaths annually (WHO, 2014) and Nitrogen Oxides (NO<sub>x</sub>) are classic air pollutants which are responsible for a wide variety of environmental, health and financial damages. NO<sub>x</sub> pollution contributes to atmospheric levels of NO<sub>x</sub>, fine particulate matter, and ground-level ozone. Exposure to these pollutants has been linked with a range of serious health effects, including increased asthma attacks and other respiratory diseases (USEPA, 2016). The impact handbook (Korzhenevych et al., 2014) reported that one tonne of NO<sub>x</sub> causes 5688 euros of financial damage which includes damage cost of health, crop, material and biodiversity, in Ireland.

Ireland has relatively good air quality compared to other European Union (EU) Member States and meets the EU specified guidelines (EPA, 2017). However, while ambient NO<sub>x</sub> levels are within limit in Ireland at the monitoring locations, the NO<sub>x</sub> emission levels failed meet the national emission ceilings (NEC) in 2010 and continue to be above the NEC target (EPA, 2016). Diesel engines tend to emit a higher percentage of NO<sub>2</sub> (EPA, 2015) and it is expected that the NO<sub>x</sub> emission levels in Ireland will increase due to a significant increase in the number of diesel vehicles in the fleet since 2008 and due to the *dieseltgate* where certain diesel Euro 5 PC models were found to be cheating the emission test with the help of a defeat device fitted with a software which turns the full emissions controls for NO<sub>x</sub> on only during the test and at other times the 2.0 litre and 3.0 litre engines emit NO<sub>x</sub> up to 40 times and up to nine times the standard, respectively (USEPA, 2016). These Euro 5 engines were originally planned to reduce the ambient NO<sub>x</sub> concentration due to better vehicular technologies producing less NO<sub>x</sub> emission than their predecessors which may not be the reality. The rise in the number of

diesel passenger vehicles can be linked to the Irish Carbon-based vehicle tax system whereby vehicles purchased from 2008 onwards would be taxed based on their CO<sub>2</sub> emissions intensity rather than their engine capacity (the previous approach) (Giblin & McNabola, 2009). This resulted in a shift in new vehicle purchasing patterns from petrol to diesel. Figure 1 shows the new car registration pattern over the period 2007-2015 (SIMI, 2016).

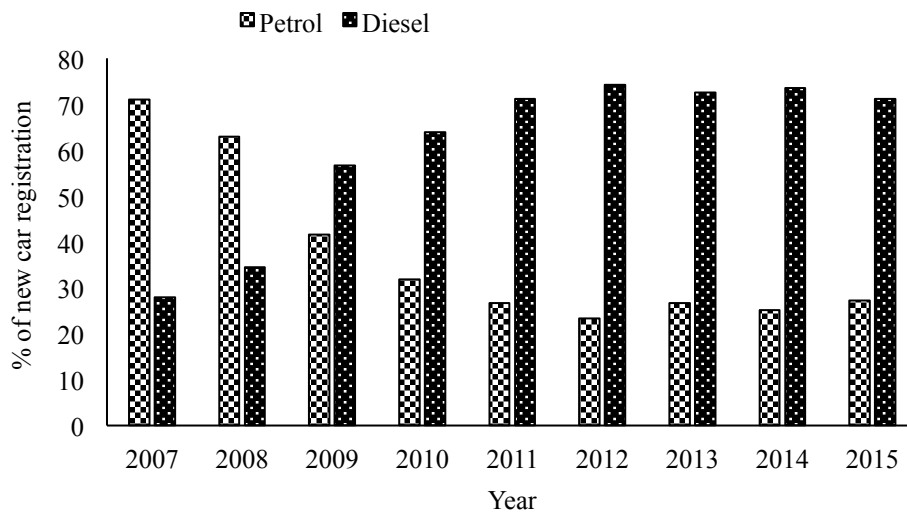


Figure 1. New car registration pattern over 2007-2015

In Volkswagen (VW) scandal, VW and Audi passenger cars have been found to violate Euro 5 emission standards resulting in higher NO<sub>x</sub> emission levels from these vehicles than from vehicles with properly operating emission control systems. Even though emission standards became stringent with every progressive emission standard directive, in reality, in-service emissions from diesel vehicles have not reduced at all through the Euro 1-5 emission standards (Moody and Tate, 2017). Transport & Environment (2016) has reported that Volkswagen Euro 5 LCVs produce cleanest vans when empty but exceeds the limit by 225% when full. Also, it has been suspected that a total of 21.4 million Euro 5 PCs and 2.2 million Euro 5 LCVs across Europe are faulty (Transport & Environment, 2016). It is important to investigate whether the

discrepancies between the real-world emission levels and the lab tested levels are adjusted in assessing the environmental impacts of NO<sub>x</sub> in Ireland. However, this study only focuses on the impact of excess NO<sub>x</sub> from Euro 5 LDVs. The NO<sub>x</sub> emissions behaviour of in service Euro 6 vehicles under real driving was explored by Moody and Tate (2017) who reported that Euro 6 diesel cars show a significant improvement over Euro 5 diesel cars.

COPERT 4 is one of the most widely used models in Europe for calculating emissions from road transportation which are used for national inventories as well as for target setting for future. Thus, it is important for the model to reflect the real world emissions well. COPERT 4 is a recommended model by European Environmental Agency (EEA) to calculate emission for more than 30 European countries (EMISIA, 2014). It is developed based on a large database which includes information on vehicle fleet, speed related emission factors (EF), fuel related information, annual mileage and average speed for each vehicle category and capable of calculating emissions from a wide range of pollutants (Ong et al., 2011). COPERT is also used in Ireland to estimate emission levels of air pollutants (Caulfield, 2009; Brady and O'Mahony, 2011; Doorley et al., 2015; Alam et al., 2015). It has been identified that the model developed EFs do not comply well with real world emission values as measured in lab test or PEMS and it is not only Volkswagen but all the other Euro 5 vehicles that might be emitting more NO<sub>x</sub> than the standard limit (Ntziachristos et al., 2016).

Achour et al. (2011) used a portable Gas Analyzer to validate COPERT 4 EFs and found that COPERT 4 underestimates the NO<sub>x</sub> emissions. Berkowicz et al. (2006) used Operational Street Pollution Model (OSPM) and Kousoulidou et al. (2011) used Portable Emissions Measurement Systems (PEMS) to verify COPERT EFs and both have reported significant underestimation of NO<sub>x</sub> concentration by COPERT. From the

aforementioned studies, it can be concluded that COPERT always has a tendency to underestimate NO<sub>x</sub> and this might be because of COPERT considers average speed whereas in real driving scenario there are many other factors involved that affects the emission profile such as, driving behaviour and frequent speed changes which affect the emission levels.

In tests conducted by TNO (2016) on wide range of Euro 5 makes and models, it was observed that the NO<sub>x</sub> values obtained in real world conditions in a lab or on the road are significantly higher than that obtained from the type approval test or Euro 5 limit. It has also been pointed out that, earlier, the model EFs could partially be linked to the real-world emissions considering the difference in them with respect to driving behaviour under real-world condition. But now the difference in emissions are much higher even when the vehicles are driven under such conditions that are comparable to the type approval test condition (TNO, 2016). Weiss et al. (2011) found the NO<sub>x</sub> values for diesel Euro 5 cars to be in the range 0.4-1 g/km which is 3-5 times more than the European driving cycle values.

This paper intends to study the environmental impact in terms of excess emission by Euro 5 light duty vehicles (LDV) i.e. PCs and LCVs in Ireland based on all the reported facts on *dieseldate*. The first objective of this paper is to study the NO<sub>x</sub> emission levels from all the Euro 5 PCs and LCVs in Ireland. This situation is considered and studied based on researches where it has been found that the real world EFs are lot higher than the euro standard limit. But exactly which models or if all the models are faulty or fitted with defeat device are not known. Thus, the emission levels are tested considering all the Euro 5 PCs and LCVs to see the overall quantity of excess emission.

As the VW scandal came in light, it has been identified that specific VW and Audi models (USEPA, 2016) are cheating the emission standard. The second objective of this

study is to see the effect of VW scandal in Ireland by quantifying the extra emission by reported VW and Audi models. Transport & Environment (2016) has reported that not only specific VW and Audi PCs but many other LDVs are suspected to be cheating the emission standards. The third objective has been designed to study the NO<sub>x</sub> emission levels resulted from all PC and LCV models of VW and Audi. This will give an idea how much a single brand of vehicle which has been proved to be cheating, is contributing. Additionally, this paper also studies the health and financial impacts of the excess NO<sub>x</sub> discharged from all the Euro 5 PCs and LCVs.

The next section describes the methodology, followed by presentation and discussion of the results and conclusion.

## **Methodology**

The potential effect of *dieseldgate* in Ireland has been investigated in this study. The discrepancy between the on-road emissions and the modelled emissions obtained using COPERT 4 is also explored along with the health & cost implications of the hidden NO<sub>x</sub>.

The investigation was carried by designing different actual and hypothetical scenarios. This section presents the methodology followed to find out the NO<sub>x</sub> emission levels from all diesel Euro 5 LDVs using COPERT 4 (v11.3), lab test results, PEMS measurements and also based on euro standards. PEMS records the emissions when vehicle is driven on road and the measurements reflect the on-road emission levels. In order to achieve the objectives of the paper, different emission scenarios were designed and they are summarised in table 1. The scenarios are also described in details in this section.

Table 1. Summary of the designed scenarios.

<b>Scenarios</b>	<b>Description</b>
Scenario 0- Euro standard scenario	NOx emission levels as per euro standard specification for euro 5 PCs and LCVs
Scenario 1A- COPERT base scenario	NOx emission levels from Euro 5 PCs and LCVs calculated using COPERT
Scenario 1B-PEMS base scenario	NOx emission levels based on the PEMS measurements and includes all the Euro 5 PCs and LCVs in the fleet in Ireland
Scenario 1C- lab test base scenario	NOx emissions based on lab test measurements for all the euro 5 PCs and LCVs present in the fleet in Ireland
Scenario 2A- VW COPERT base scenario	NOx emissions resulted from reportedly (USEPA, 2016) faulty VW and Audi models present in the Irish PC fleet and calculated using COPERT
Scenario 2B- VW PEMS base scenario	NOx emissions from the reportedly faulty PC models based on PEMS measurements
Scenario 2C- VW lab test base scenario	NOx emission levels from the reportedly faulty PC models based on lab test results



Scenario 3A- VW PC hypothetical scenario	NOx emissions considering if all the VW and Audi PCs present in the Irish PC fleet are faulty
Scenario 3B- VW LCV hypothetical scenario	NOx emissions considering if all the VW and Audi LCVs present in the Irish LCV fleet are faulty

***Scenario 0- Euro standard scenario***

This section describes the expected emission levels following the Euro standard specifications for Euro 5 PCs and LCVs. The standard emission levels for all the vehicles were calculated using the following equation,

$$E_{istd} = N_i * M_i * EF_{euro} * 10^{-6} \quad (1)$$

$E_{istd}$  is the NOx emissions (ton) in the year  $i$  following the euro standard specification;  $N_i$  is the number of PCs or LCVs in year  $i$ ;  $M_i$  is the average annual mileage (km) in year  $i$ ;  $EF_{euro}$  is the standard NOx emission factor (g/km) for Euro 5 PC or LCV.

Euro standard NOx concentration is taken as 0.18g/km for PCs (EEA, 2007) and 0.28g/km for LCVs (TNO, 2015).

***Scenario 1A- COPERT base scenario***

In this scenario the vehicular NOx emission levels resulted from the existing Euro 5 and LCV fleet in Ireland were calculated by COPERT 4 (v11.3) using the default emission factors. Depending on the extent of data availability, three different approaches namely, Tier 1, Tier 2 and Tier 3 can be used to calculate emissions (EEA, 2016). COPERT uses the Tier 3 approach which is most accurate among them and uses detailed activity data

(average speed and kilometres travelled) corresponding to each technology class as well as mode. In COPERT, the following set of equations are used to calculate the total emissions (Ntziachristos and Zissis, 2014),

$$E_{\text{Total}} = E_{\text{Hot}} + E_{\text{Cold}} \quad (2)$$

where,  $E_{\text{Total}}$  is the total emissions of a pollutant;  $E_{\text{Hot}}$  is the emissions during stabilised engine operation (hot exhaust emissions) and  $E_{\text{Cold}}$  is the cold start emissions that is the emissions during transient thermal engine operation. The hot exhaust emission is calculated using the following equation,

$$E_{\text{Hot}; i, k, r} = N_k * M_{k,r} * EF_{\text{Hot}; i, k, r} \quad (3)$$

where,  $E_{\text{Hot}; i, k, r}$  is the hot exhaust emissions of the pollutant  $i$  (g), produced in the period concerned by vehicles of technology  $k$  driven on roads of type  $r$ ;  $N_k$  is the number of vehicles (veh) of technology  $k$  in the period concerned;  $M_{k,r}$  is the mileage per vehicle (km/veh) driven on roads of type  $r$  by vehicles of technology  $k$ ;  $EF_{\text{Hot}; i, k, r}$  is the emission factor (g/km) for pollutant  $i$ , relevant for the vehicle technology  $k$ , operated on roads of type  $r$ . Cold-start emissions are introduced into the calculation as additional emissions per km using the following formula,

$$E_{\text{Cold}; i, k} = \beta_{i, k} * N_k * M_k * EF_{\text{Hot}; i, k} * (e^{\text{Cold}} / e^{\text{Hot}}_{|i, k} - 1) \quad (4)$$

where,  $E_{\text{Cold}; i, k}$  is the cold-start emissions of pollutant  $i$  (for the reference year), produced by vehicle technology  $k$ ;  $\beta_{i, k}$  is the fraction of mileage driven with a cold engine or the catalyst operated below the light-off temperature for pollutant  $i$  and vehicle technology  $k$ ;  $N_k$  = number of vehicles (veh) of technology  $k$  in circulation;  $M_k$  = total mileage per vehicle (km/veh) in vehicle technology  $k$ ;  $e^{\text{Cold}} / e^{\text{Hot}}_{|i, k}$  = cold/hot emission quotient for pollutant  $i$  and vehicles of  $k$  technology.

For this study, overall Euro 5 fleet data were obtained from Department of Transport, Tourism and Sport (DTTAS) by considering total number of newly registered vehicle

since the introduction of Euro 5 vehicles (i.e. over the period of 2011-2015, RSA). Average annual mileages were calculated for each year and mileage shares were assumed to be 15%, 9% and 76% for urban, rural and highway driving respectively (Brady and O'Mahony, 2011). The NO<sub>x</sub> emissions were then calculated for each year separately (2011-2015) for PCs as well as LCVs and added up to obtain the overall NO<sub>x</sub> emissions from Euro 5 PCs and LCVs.

### ***Scenario 1B- PEMS base scenario***

PEMS base scenario calculates the actual quantity of the NO<sub>x</sub> emissions from Euro 5 LDVs to show how much the Euro 5 LDVs possibly be emitting while on-road compared to the euro standard emission levels as calculated in Scenario 0 and also, to show the quantity of overestimated (for Euro 5 PC) and ignored (for Euro 5 LCV) emissions by COPERT 4. In order to estimate the on-road emissions, urban, rural and highway emissions were calculated separately using COPERT and then modified to reflect the real-world NO<sub>x</sub> emissions. NO<sub>x</sub> emissions for urban driving condition were found by keeping Urban driving share as 100% and the same for rural and highway as zero. The similar approaches were followed while calculating emissions for rural and highway driving. Annual mileage values were disaggregated by their respective percentage of driving mode shares. To get the on-road emission values, NO<sub>x</sub> concentrations (g/km) which are based on significant number of on-road measurements and lab tests (Ntziachristos et al., 2016) were taken as reference, the values have been presented in table 2 and table 3. EFs from real-world lab tests were found to be very close to that of COPERT 4. But the differences between emission values obtained from COPERT 4 and

Table 2. NO<sub>x</sub> EFs (g/km) from the graph (Annexure) for urban, rural and highway for passenger cars.

Driving mode	Euro 5 Standard EFs	COPERT EFs	PEMS EFs	Difference between COPERT and PEMS EFs (%)
Urban	0.18	0.76	0.88	-14
Rural	0.18	0.49	0.22	+123
Highway	0.18	0.61	0.35	+74

on-road measurements are quite significant and both are much higher than the Euro 5 NO<sub>x</sub> limit. The percentage differences between the COPERT and PEMS estimated concentration values (g/km) were calculated. These percentage differences were used to estimate the on-road emission levels.

Table 3. NO<sub>x</sub> EFs (g/km) from the graph (Annexure) for urban, rural and highway for light commercial vehicles.

Driving mode	Euro 5 Standard EFs*	COPERT EFs	PEMS EFs	Difference between COPERT and PEMS EFs (%)	Lab test EFs	Difference between COPERT and lab test EFs (%)
Urban	0.28	0.78	1.55	-50	0.90	-13
Rural	0.28	0.64	1.52	+58	0.72	-11
Highway	0.28	1.25	1.64	+24	1.16	+8

\*varies with respect to the weight, the highest among them is presented here.

Concentration values from real-world lab cycle tests were found to be higher than model estimated emission factors for urban and rural roads, but on-road measurements were even higher in all the driving conditions and all the estimated values were significantly higher than the standard Euro 5 NO<sub>x</sub> limit.

Real-world emission levels were calculated by multiplying the separate emissions by a factor equal to the percentage differences (see table 2 and table 3) between COPERT EFs and PEMS EFs to assess the real-world NO<sub>x</sub> emission levels. These individual emission levels calculated under urban, rural and highway driving conditions were then summed up to represent the total on-road NO<sub>x</sub> emission level. The same methodology was followed to acquire emission for each year from 2011-2015. Similarly, real world emission levels for Euro 5 LCVs were calculated.

#### ***Scenario 1C- lab test base scenario***

Lab test base scenario presents the quantity of Euro 5 NO<sub>x</sub> emissions based on lab test results. Similar procedure, as was followed to obtain NO<sub>x</sub> emissions based on PEMS measurements, was also followed to achieve lab test emissions from Euro 5 PCs and LCVs. In this case the percentage differences (see table 2 and table 3) found between COPERT 4 emission factors and lab test emission factors were used to modify emission values calculated by COPERT 4. It can be observed in table 2 that for Euro 5 PCs, the PEMS and lab test emission factors are very close. Thus, it is considered that NO<sub>x</sub> emission levels estimated by COPERT 4 are consistent with those resulted from lab tests. Therefore, PC NO<sub>x</sub> emissions have not been calculated separately and lab test base scenario only presents results for Euro 5 LCVs.

#### ***Scenario 2A- VW COPERT base scenario***

VW base scenario conveys the NO<sub>x</sub> emitted by the fleet of vehicles fitted with defeat devices as reported by USEPA. Table 4. presents the VW and Audi passenger car models that have been reportedly found to be cheating the NO<sub>x</sub> emissions,

Table 4. Affected VW and Audi passenger car models (USEPA, 2016).

Affected 2.0 litre diesel models	Affected 3.0 litre diesel models
Jetta	Volkswagen Touareg
Jetta Sportswagen	Porsche Cayenne
Beetle	Audi A6 Quattro
Beetle Convertible	Audi A7 Quattro
Audi A3	Audi A8
Golf Sportswagen	Audi A8L
Golf	Audi Q5
Passat	Audi Q7

Specific models (Table 4) of VW and Audi passenger cars with 2.0L and 3.0 L were extracted from the overall database of Irish Motor Industry (SIMI, 2016) and NO<sub>x</sub> emissions were then calculated using COPERT 4. Input parameters such as speed, mileage share, average annual mileage etc. were considered to be same as those in base scenario.

***Scenario 2B- VW PEMS base scenario***

This section presents the actual quantity of NO<sub>x</sub> discharged from USEPA reported VW and Audi models based on PEMS measurements. To calculate emissions measured by PEMS, similar approach was followed as PEMS base scenario i.e. emissions were calculated separately for different driving modes using COPERT and revised to calculate real-world emission levels as recorded using PEMS.

***Scenario 2C- VW lab test base scenario***

This section presents the NO<sub>x</sub> emission levels exhausted by faulty VW and Audi models as per lab test results. The similar procedure, as followed in case of lab test base scenario to estimate emission for overall Euro 5 fleet, was also used to obtain NO<sub>x</sub> emission levels from VW and Audi PCs in lab tests.

### ***Scenario 3A- VW PC hypothetical scenario***

Hypothetical Scenarios are designed to explore the effect of circumstances if all 59527 VW and Audi Euro 5 PCs (SIMI, 2016) and 12337 VW Euro 5 LCVs in Ireland are faulty. Based on the reports (Transport & Environment, 2016; Ntziachristos et al., 2016), it would be worth assuming that it is not only the USEPA reported VW and Audi models but all the VW Euro 5 PCs are equipped with defeat devices. Hence, the following hypothetical situations were tested to measure the excess amount of NO<sub>x</sub>. This section presents NO<sub>x</sub> emission levels from all the aforementioned VW scenarios i.e. VW COPERT base scenario, VW PEMS base scenario and VW lab test base scenario, but for overall VW and Audi Euro 5 car fleet in Ireland. Total number of all VW and Audi models in Ireland were extracted from the overall dataset of Irish Motor Industry (SIMI, 2016). NO<sub>x</sub> emissions for all VW and Audi models were then estimated using the similar methodology as used to calculate the same for reported VW and Audi models.

### ***Scenario 3B- VW LCV hypothetical scenario***

In this section NO<sub>x</sub> emissions of all VW Euro 5 LCVs are presented. Number of VW LCVs present in Ireland were obtained from Irish Motor Industry (SIMI, 2016) database. Number of Audi LCVs are negligible, hence ignored. Emissions were calculated by all three methods, i.e. COPERT 4, Lab test and PEMS following the similar approach as mentioned in real-world base scenario and lab test base scenario.

### ***Impacts of NO<sub>x</sub>***

The health and financial impact of the hidden NO<sub>x</sub> caused due to *dieselpgate* in Ireland has been calculated following the methods described in this subsection. The health impact of NO<sub>x</sub> emission has been calculated using Burden of disease (BOD) approach (WHO, 2013). Burden of Disease (BOD) is a measure of the sum of Years of Life Lost (YLLs) and Years of healthy Life lost due to Disability (YLDs) and is referred as Disability Adjusted Life Years (DALYs). In this study, the unit DALY value reported by Tang et al. (2015) for European countries has been multiplied by total extra NO<sub>x</sub> emissions in order to obtain the extra number of DALYs resulted due to the hidden NO<sub>x</sub> from Euro 5 LDVs. Tang et al. (2015) have found that 1 kg of NO<sub>x</sub> is responsible for  $0.9 \times 10^{-4}$  Disability Adjusted Life Years (DALYs).

The damage costs for NO<sub>x</sub> from transport in Ireland have been calculated based on updated Handbook on External Costs of Transport (Korzhenevych et al., 2014). This damage cost includes not only health effects of NO<sub>x</sub> but also its effect on crops, material (e.g. buildings) and biodiversity. Also, mortality incidences per kiloton (kt) of NO<sub>x</sub> and their corresponding value of statistical life were calculated based on a study by Oldenkamp et al. (2016).

To study the spatial variation of the impact, total excess NO<sub>x</sub> emissions were distributed over all the counties in Ireland. County-wise population (CSO, 2011) and LDV count (SIMI, 2016) were extracted and plotted as shown in Figure 1. It can be observed from the graph that the R<sup>2</sup> value is significantly high, therefore, a linear relationship was assumed between population and vehicle count.



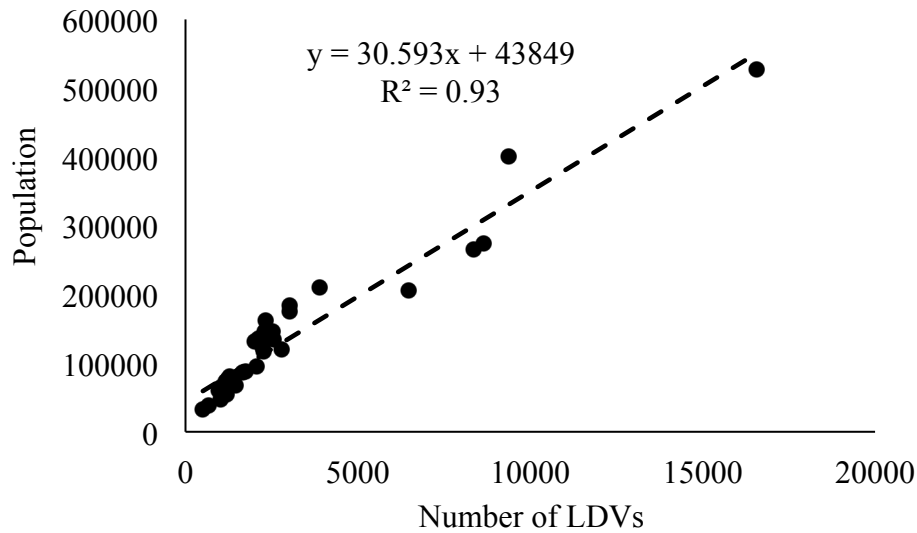


Figure 1. County specific total number of vehicles (PCs+LCVs) vs population

The total excess NOx emission was distributed using the following the equation,

$$\Delta E_{ij} = \Delta E_i * k_{ij} \quad (5)$$

Where,  $\Delta E_i$  is the total excess NOx emissions in Ireland in the years  $i$ ;  $\Delta E_{ij}$  is the excess NOx emissions in year  $i$  and county  $j$ ;  $k_{ij}$  is spatial emissions distribution factor for county  $j$  in year  $i$ , introduced to observe the county specific impacts based on automobile density (Wang et al., 2016). Health and cost impacts were then calculated using this the county specific extra NOx emission.

### Data description

Major input data that were required to calculate emissions from COPERT were, meteorological data (e.g. mean monthly maximum and minimum temperature, humidity), engine size, fuel information, speed (kmph), mileage (km), travel share (%) and vehicle population. Table 5 shows the main input data and their respective sources. Speeds for urban roads, rural roads and highways were taken as 50kmph, 80kmph and 100kmph respectively (RSA, 2013; RSA, 2015). The data availability on driving mode share in Ireland is very limited, therefore, the mileage shares assumed by Brady and O'Mahony (2011) for Greater Dublin Area (GDA) have been extended to overall

Ireland. Thus, driving shares have been assumed to be 15%, 9% and 76% for urban, rural and highway respectively.

Table 5. Input data and their sources.

<b>Input data</b>	<b>Source of data</b>
Meteorological data	MET Eireann: The Irish Meteorological Service Online
Fleet data	Department of Transport, Tourism and Sport
Speed	Road Safety Authority
Mileage data	Central statistics office (Kilometres travelled by road traffic)
Volkswagen Euro 5 cars and fleet configuration	Motorstats: The official statistics of the Irish Motor Industry

The total kilometre travelled by passenger cars were obtained from CSO (2014) and divided by total number of vehicles to get average annual mileage. Information on overall kilometres travelled were available till the year 2014, thus mileage for 2015 was calculated by extrapolating the 2004-2014 data. Figure 2 and Figure 3 show the number of diesel Euro 5 LDVs and average annual mileage respectively. It is perceptible

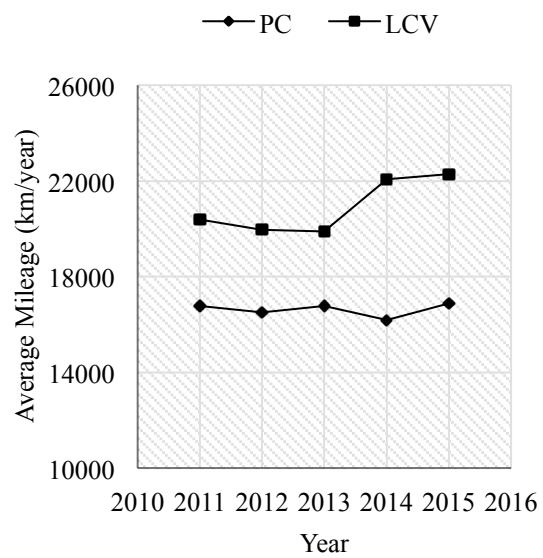
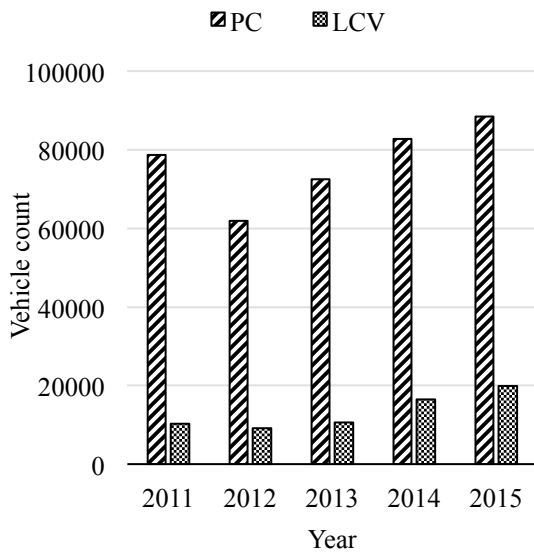


Figure 2. Total number of diesel Euro 5 LDVs. Figure 3. Annual average mileage (km/year).

that there is a significant increase in vehicle numbers every year while the kilometre travelled per year is quite consistent. The LCVs have increased at a higher rate with every year until 2014 while there is a sudden increase in average annual kilometre travelled after 2013. The number of affected diesel Euro 5 VW and Audi passenger cars those are present in Ireland are summarized in Table 6.

Table 6. Number of affected Volkswagen and Audi vehicles.

Year	Volkswagen		Audi		Total	Percentage of total fleet
	<=2.0L	>2.0L	<=2.0L	>2.0L		
2011	3499	20	353	36	3908	5
2012	3543	21	351	38	3953	6
2013	3312	3	602	33	3950	5
2014	4088	2	1939	247	6276	8

2015	4455	18	2377	290	7140	8
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It can be observed from table 5 that there is a significant increase in overall number after 2013.

## Results and Discussion

The results in terms of total and hidden NOx emissions discharged from potential defective Euro 5 LDVs are presented and discussed in the following subsections.

### *Existing NOx emission levels in Ireland*

This section presents the emission levels for diesel Euro 5 LDVs in Ireland as calculated using COPERT 4 (v11.3) following the methodologies described in scenario 1A, 1B and 1C. Table 7 presents the overall quantity of NOx emissions (tonnes) estimated by COPERT and PEMS and the last column in table 7 shows the euro standard NOx values in ideal case, i.e. NOx emissions if all the Euro 5 diesel passenger cars had followed the emission standard. A new version (11.4) of COPERT 4 has been released with modified emission factors for Euro 5 LCVs and Euro 6 PCs. The emissions of Euro 5 LCVs have been calculated with the new version of COPERT 4 as well.

Table 7. Vehicle statistics and NOx emission values for passenger cars.

Year	Vehicle count	COPERT 4 (v11.3/ v11.4)/ lab test	On-road	Euro Standard
In Tonnes				
2011	78710	738	485	237
2012	61910	572	376	184
2013	72558	680	447	219
2014	82777	746	491	241
2015	88485	835	550	269

Total	384440	3571	2349	1150
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From table 7, it can be observed that the differences between the model estimated values and PEMS estimates are significant (52%). The differences between these estimates might mislead the policymakers. There is huge gap between the euro standard and actual emissions. The emissions obtained via COPERT 4 and on-road measurements are 100-220% in excess than the euro standard NOx emission levels from diesel Euro 5 PC fleet. The proportion of excess emissions burden on urban, rural and highway is 29%, 9% and 62% respectively. Table 8 summarizes the overall model estimated and real world emissions from Euro 5 LCVs along with the expected values, i.e. the total NOx emission from Euro 5 diesel LCVs if the standard emission specification was followed.

Table 8. COPERT, On-road and lab test emission values (in tonnes) for LCVs.

Year	Vehicle count	COPERT 4 (v11.3) In Tonnes	COPERT 4 (v11.4) In Tonnes	On-road In Tonnes	Lab test In Tonnes	Euro standard In Tonnes
2011	10355	194	344	252	187	59
2012	9159	168	297	218	162	51
2013	10536	192	340	249	185	59
2014	16457	332	588	431	320	102
2015	19942	408	723	529	393	124
Total	66449	1293	2293	1678	1247	395

From Table 8, it can be noticed that the real world as calculated using PEMS measurements and model estimated emission quantities are about 200-500% higher than the anticipated values. Even though model estimated urban and rural NOx emission

factors were observed to be more in lab test outcomes, combined emission amounts calculated by COPERT were estimated to be more than lab test results. On the other hand, the opposite pattern was observed when compared with on-road measurements. Emission values obtained from PEMS measurements were significantly higher than that estimated with COPERT. COPERT 4 (v11.3) underestimates and COPERT 4 (v11.4) overestimates the real-world emission by 23% and 37% respectively. COPERT4 (v11.3) was used in Ireland for National Emission Inventory preparation as well as in scientific researches until September, 2016 when COPERT 4 (v 11.4) became available with modified emission factors after the research results (such as, Ntziachristos et al., 2016) pointed out the necessary modification in NO<sub>x</sub> estimates by previous version of COPERT 4. Thus, all the policy decisions have been made based on the COPERT 4 (v 11.3) emission values as the real -world values in the country. The results from both the versions have been shown to present the difference in estimates between the previous version which has been extensively used in Ireland for calculating road transport emissions and the recent modified version. The discrepancy between the actual NO<sub>x</sub> discharge and model estimates should be accounted by the researchers and the policymakers, as it might affect many areas given COPERT's extensive application in air quality and impact assessments, projections (energy, CO<sub>2</sub>, pollutants), urban/regional inventories, new road (road section) construction etc. (Kouridis et al., 2014).

### ***NO<sub>x</sub> emission levels from affected VW-Audi vehicles***

In this subsection, the NO<sub>x</sub> emission levels calculated based on the methodology described in scenario 2A, 2B and 2C for the defective VW and Audi models in Ireland, are shown. NO<sub>x</sub> emissions were calculated for those PCs using COPERT 4. Emissions in scenario 2B and scenario 2C were estimated in the similar way as estimated for overall Euro 5 LDV fleet. The expected NO<sub>x</sub> emissions as per euro specification were



	fleet				LCV fleet	
2011	8299	3037	11336	14	1858	18
2012	7540	3373	10913	18	2326	25
2013	6792	3432	10224	14	2084	20
2014	8368	3967	12335	15	2852	17
2015	10284	4435	14719	17	3217	16
Total	41283	18244	59527	15	12337	19

Figure 5. shows the NOx emission levels for all 59527 VW and Audi Euro 5 PCs considering if all Euro 5 VW-Audi PCs in Ireland are faulty. The PEMS estimated as well as modelled emission levels are significantly higher than that calculated by following the

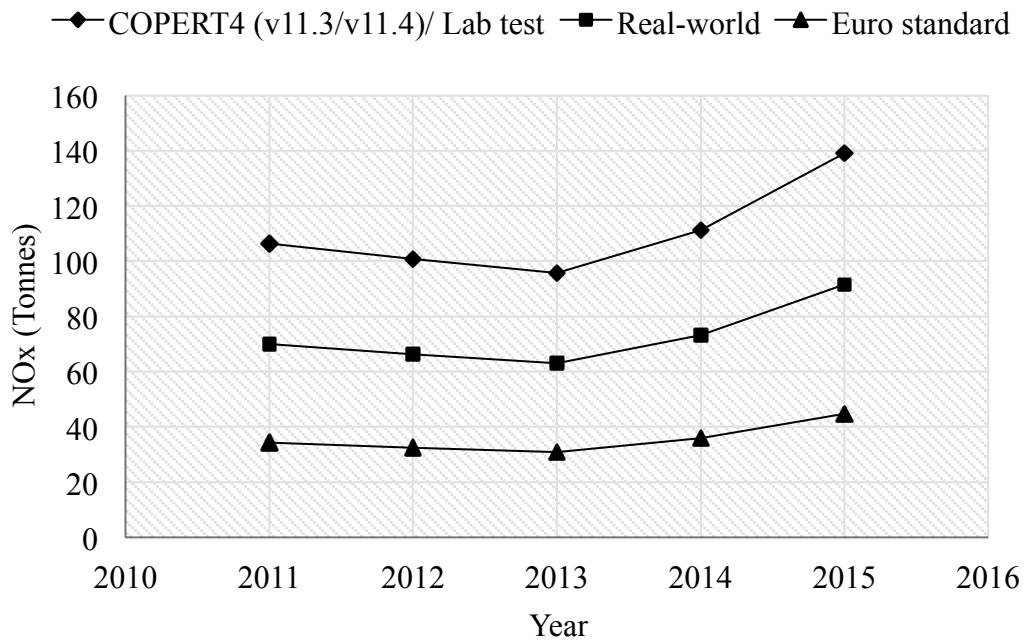


Figure 5. COPERT, PEMS and euro standard emission values (in Tonnes) of VW and Audi PCs.



Euro standard emission factor for Euro 5 PC. It was observed that PCs of VW and Audi alone produce 15% of overall extra NOx emissions from diesel Euro 5 PCs. Figure 6 presents the NOx emission levels from 12337 VW Euro 5 LCVs in Ireland assuming if

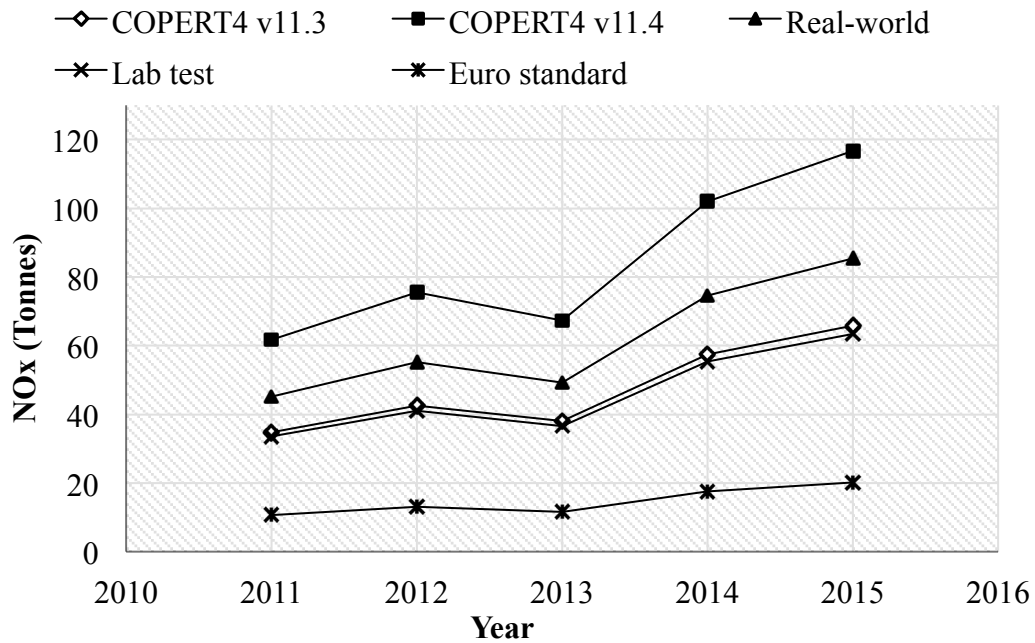


Figure 6. COPERT, PEMS, lab tests and euro standard emission values (in Tonnes) of VW LCVs.

all Euro 5 VW LCVs in Ireland are faulty. It can be observed that VW LCVs solely contribute to significantly large amount of NOx emissions which is 18% of the excess emissions produced by overall LCV fleet.

***Potential health and financial impact***

This section presents the potential health and cost impact of the hidden NOx from Euro 5 PCs and LCVs. It has been assumed that all the vehicles that were newly registered over the period 2011-2015, remained in the market till 2015. Figure 7 shows the total excess NOx exhausted by the Euro 5 PCs and LCVs annually compared to the expected euro standard emission.

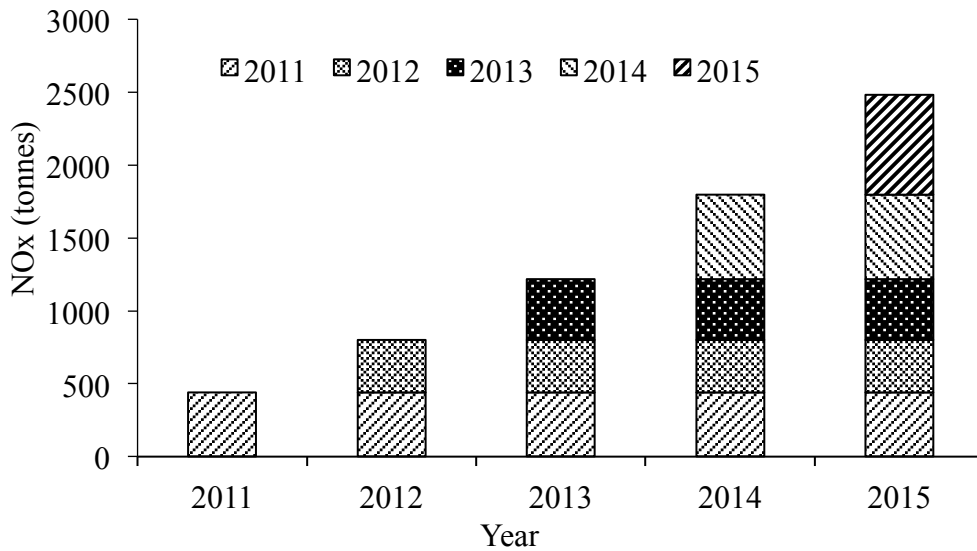


Figure 7. Total excess NOx (tonnes) from all Euro 5 LDVs.

About 451,000 (Figure 2) of allegedly faulty vehicles have emitted 6735.6 tonnes of extra NOx to the atmosphere over the 5 year period. In table 10 the annual extra NOx and their corresponding potential DALYs, mortality incidences and damage costs of the hidden NOx from Euro 5 LDVs are listed. The unit values used to access the BOD and mortality incidences are 90 DALYs/kt (Tang et al., 2014) and 10.23 incidences/kt (Oldenkamp et al., 2016) respectively. The value of statistical life (VSL) was taken as 7.2 million (approximated) euro/death incident (Robinson & Hammitt, 2015) and the damage cost as 5688 euro/tonne (Handbook, 2014) of extra NOx.

Table 10. Potential health and cost damages due to extra NOx from faulty vehicles.

Year	Extra NOx (kt)	Additional DALYs	Mortality incidences	Additional VSL (Million Euro)	Additional Damage cost (Million Euro)
2011	0.44	39.64	5	32.44	2.51
2012	0.80	71.91	8	58.85	4.54

2013	1.22	109.59	12	89.69	6.93
2014	1.80	161.67	18	132.31	10.22
2015	2.48	223.40	25	182.83	14.12

It can be observed from the above table that the potential faulty vehicles might have caused damage worth of approximately 540 million euros. The automobile density for a specific county has been calculated by dividing the number of vehicles (SIMI, 2016) in that county by its population (CSO, 2011) and presented in Figure 8. The spatial variations of health and cost impacts due to the excess NOx have been shown in Figure 9 and Figure 10.

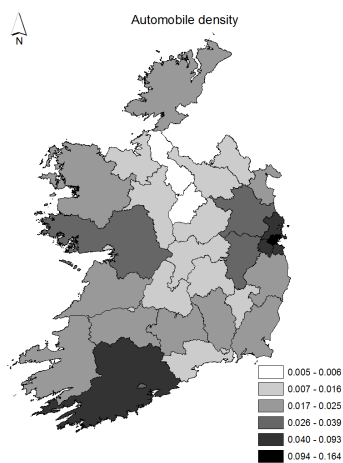


Figure 8. Spatial

distribution of automobile density in Ireland

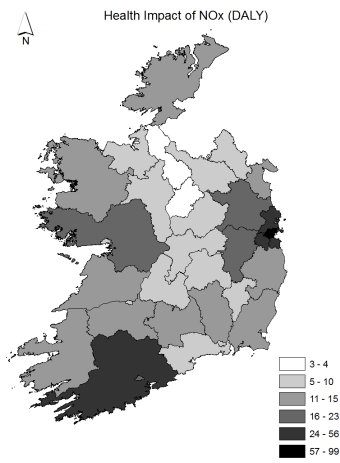


Figure 9. Spatial

distribution of health impact due to excess NOx

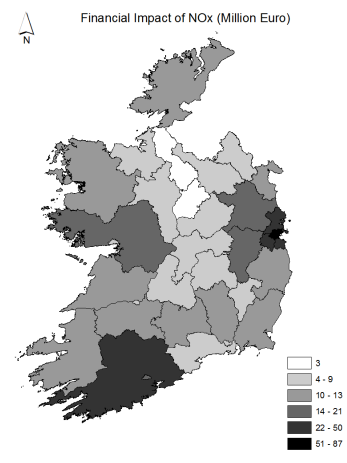


Figure 10. Spatial

distribution of cost impact due to excess NOx

It can be observed from the figures that the impacts are higher in the areas where the vehicle and population densities are higher. If the faulty vehicles continue to be in use, the number of mortality incidences in the urban areas will be higher provided the dominant impact on those areas. Therefore, this study suggests for immediate action to prevent the future loss especially in the areas with highest impact.

## **Conclusion**

This paper aims to quantify the disparity between the expected, modelled, real-world lab tested and PEMS estimated NO<sub>x</sub> emissions resulted from diesel Euro 5 LDVs that are present in Ireland. It can be observed from the NO<sub>x</sub> emission levels that even though emission standards became tighter with every progressive euro standard directive (e.g. NO<sub>x</sub> limit is 0.25 g/km for Euro 4 and 0.18 g/km for Euro 5), the real-world (PEMS estimates) as well as lab tested emissions are more than the expected emission levels. This clearly indicates that Euro 5 vehicles are not obeying the respective standards. The reason/s behind this excessive discharge of NO<sub>x</sub> should be examined and measures should be taken to make sure that vehicles follow the euro standard emission limits. Moreover, there is mismatch between COPERT 4 estimated and actual emission levels and the differences are significantly high. COPERT 4 (both v11.3 and v11.4) overestimated PC NO<sub>x</sub> emission levels and in case of LCVs COPERT 4 v11.3 underestimated and COPERT 4 v11.4 overestimated the PEMS estimated real-world NO<sub>x</sub> emissions by considerable amount. Provided COPERT's substantial applicability in many fields, this issue should also be focused on and suitable measures should be implemented accordingly so that COPERT reflects the real emission as accurately as possible.

Even though few Volkswagen and Audi PC models have been proved to be cheating the NO<sub>x</sub> emission, the results show that the amount of PEMS estimated real-world NO<sub>x</sub> emissions for all diesel light duty vehicles are huge. All potentially faulty diesel Euro 5 LDVs have emitted in 6740 tonnes of excess NO<sub>x</sub> in Ireland in last 5 years (2011-2015). The defective Euro 5 LDVs are probably responsible for 70 death incidences and approximately 606 DALYs. The average lifetime of a car in Europe is around 17 years (Transport & Environment, 2016) and this means that the Euro 5 LDVs are going to be

excessively polluting for more than 10 years from now. This will have huge financial and health impacts. Consequently, extensive testing on different Euro 5 and Euro 6 vehicle of various makes and models are required to be carried out. It is also recommended that the tax incentives introduced to encourage the uptake of diesel vehicles should be revised accordingly. More incentives should rather be provided to buy electric vehicles, especially in the urban areas where the automobile density and resulting health impact is high. Also, policies to support phasing out of diesel vehicles as has been planned to be followed in other EU countries should be explored.

**Annexure:**

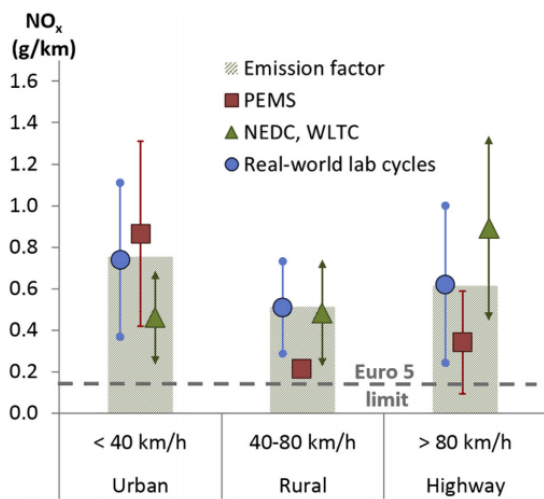


Fig. 1. Simplified current model NO<sub>x</sub> EFs and measured emission levels for diesel Euro 5 passenger cars. PEMS tests correspond to two vehicles only. Uncertainty ranges correspond to ±standard deviation.

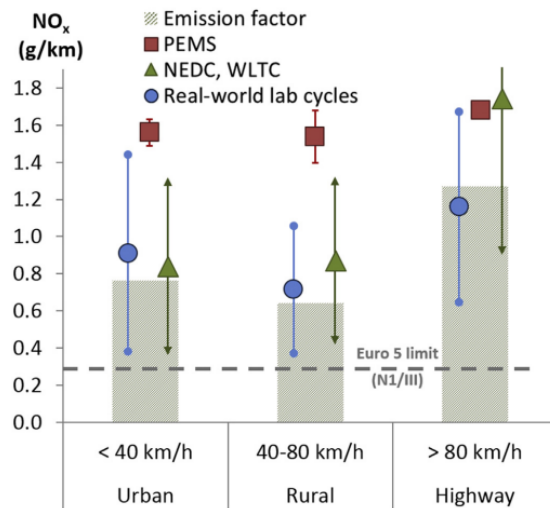


Fig. 2. Simplified current model NO<sub>x</sub> EFs and measured emission levels for diesel Euro 5 light commercial vehicles. Uncertainty ranges correspond to ±standard deviation.

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