In advance of Clean Air Day 2018, researchers at the University of Oxford and University of Bath have produced new research - “The health costs of air pollution from cars and vans”. The report, below, shows the different costs for cars and vans with different fuel types, and the difference that comes from where the pollution is created.

For more information on Clean Air Day, and the actions that people can take to reduce pollution and their exposure to pollution, visit the Clean Air Day website at www.cleanairday.org.uk

The health costs of air pollution from cars and vans

Authors: Dr Christian Brand, University of Oxford and UK Energy Research Centre | Dr Alistair Hunt, University of Bath

Date: 18 May 2018

0 Executive summary

0.1 Fossil fuel cars and vans – especially diesels – are major sources of outdoor air pollution

There are over 31 million cars on the road in the UK today. Each car is driven, on average, about 12,800 km a year, totaling 400 billion km across the nation. In addition, there are over 3.7 million vans[1] in operation, travelling over 20,000 km each and totaling 75 billion km each year. While bringing major economic and social benefits, using a car or van contributes to road traffic congestion (excess delays), accidents, physical inactivity, climate change and local noise and air pollution.

Conventional diesel cars emit nearly ten times of nitrogen oxides (NO_X) and three times of fine particulate matter ($PM_{2.5}$) more per car and year than their petrol equivalent. Roughly two out of five cars (12 million) run on diesel today, and three out of five (19 million) on petrol. A small but growing share – about 1 in 500 – run purely on electricity. Battery electric cars are the cleanest overall as they produce zero tailpipe emissions but are liable to non-tailpipe emissions from tyre, brake and road wear, just like conventional fossil fuel vehicles.

A van emits about five times as much NO_X and over three times as much $PM_{2.5}$ per year as a car, mainly because of higher annual mileages[2] and pollutant emissions rates for each km travelled. Again, battery electric vans are the cleanest overall. They are increasingly being taken up by businesses thus making a growing contribution to reducing air pollution in our cities.

0.2 The health impacts of outdoor air pollution costs the UK society tens of billions of pounds each year

The health problems resulting from exposure to air pollution have a high cost to people who suffer from illness and premature death, to our health services and to business. Overall human exposure to both $PM_{2.5}$ and NO_X is linked to around 40,000 early deaths and hundreds of thousands of life-years lost in the UK each year, with an average loss per person of life expectancy of approximately six months. This compares to the roughly 98,000 preventable deaths attributable to smoking in the UK.

---

[1] Goods vehicles not exceeding 3.5 tonnes gross vehicle weight. Includes all car-based vans and those of the next largest carrying capacity such as transit vans. Also included are ambulances, pickups and milk floats.

[2] Vans generally have higher annual mileages as they are owned and used commercially as well as privately. Company cars are mainly diesels due to the fuel economy advantage and used for business and private use as well.

The associated annual health costs of these health outcomes have been estimated at between £22.6 billion and £71.3 billion.

So why the huge difference in costs? The main difference between the lower and the higher estimate is because analysts use different methods, air pollutants and 'metrics' to derive these costs. In particular, there are profoundly different ways of valuing premature deaths.

If you are interested in the different approaches, read on – otherwise skip the detail and move on to the next fact. The standard approach in the UK models the entire impact *pathway* from the source of pollution (e.g. road transport in London) to dispersion and atmospheric conversion (e.g. from primary NO_X to secondary pollutants such as ozone, O_3) all the way to its health impact (e.g. number of hospital admissions, premature deaths) and monetization by valuing the 'life years lost' due to air pollution. It captures the impact of air pollution on chronic mortality effects (quantifying the numbers of life-years lost or gained); acute mortality effects (quantifying the numbers of deaths brought forward); and the morbidity effects (quantifying the number of hospital admissions resulting per year, for both respiratory and cardiovascular illnesses). An alternative approach that is often used in international comparisons estimates the economic cost of air pollution from all sources by monetizing health impacts using the value of a statistical life (VSL) metric. Here, each premature death is valued the same, no matter when death occurs. Our results indicate that use of the VSL increases the health cost estimates by a multiple of four, on average.

0.3 A quarter of the total health costs of outdoor air pollution in the UK is from cars and vans, equivalent to over 10,000 premature deaths per year

Using the standard UK 'impact pathway approach' we estimate that cars and vans are responsible for more than a quarter (£5.9 billion a year) of the total UK health damage costs from air pollution, with cars contributing about a sixth (£3.8 billion) and vans about a tenth (£2.2 billion). About four fifths of the car health costs are due to pollution from diesel cars and one fifth due to conventional and hybrid electric petrol cars. Virtually all of the annual van health damage costs are due to diesel vans.

The total annual health costs for cars and vans correspond to more than 10,000 premature deaths each year.

Around 15% of the total costs – equal to roughly £0.6 billion for cars and £0.3 billion for vans – may be attributed to health treatment costs from hospital admissions and treatment of related illnesses.

0.4 The annual health costs from air pollution per fossil fuel car is £121

So how much does each car and van contribute to the above total? We estimate that the health cost per average fossil fuel car is £121 per year. The health cost of diesel cars is £258 per year, with petrol cars lower at £37 a year and BEVs the lowest, at only £13 a year.

Similarly, the average health damage cost per diesel van is £593 per year. For BEV vans the health costs are much lower at £35 a year.

0.5 The lifetime costs per car or van greatly depend on whether they run on petrol, diesel or electricity – and where they are driven

The health costs from air pollution that could be attributed to a typical UK car over its 14-year lifetime amount to about £1,640. A van cost £5,107 over its shorter 9-year lifetime.

The health damage costs are most acute in urban environments, particularly in densely populated cities. In inner London, for instance, the lifetime health costs rise to £7,714 and £24,004 for fossil fuel cars and vans respectively. The lifetime costs are much higher for diesel cars and vans in inner London at £16,424 and £24,555 respectively – and they are much lower for battery electric cars and vans at £827 and £1,443. The health costs of battery electric cars and vans are respectively 9 and 17 times lower than for their fossil fuel equivalents, on average.

The summary results of air pollution costs of UK cars and vans are summarized in Table 1.

Table 1: Summary results for the UK comparing the standard UK approach with international comparisons

		'Bottom up' (standard UK approach[$])	'Top down' (international comparisons[$])
Annual total costs	**From all air pollution (transport, industry, etc.)**	**22.6**	**73.1**
GBP Billion per year	Cars	3.8	16.7
	Vans	2.2	6.4
	Cars and vans together	5.9	23.1
Annual costs per car/van	Per car	121	536
GBP per car/van per year	Per van	580	1,717
Lifetime costs per car/van	Per car	1,641	7,245
GBP, Net Present Value	Per van	5,107	15,130

[$]**Bottom up**: PM+$NO_X$ health costs (central values), car and van fleet weighted averages, using Value of Life Years metric + costs of morbidity/illness. **Top down**: $PM_{2.5}$ only, using Value of a Statistical Life + some health costs, approx. breakdown by emission source.

All 2015 values and prices. See main text for full list of sources and analysis.

0.6 These health costs are conservative estimates – they may be higher still

The derived health costs are relatively conservative estimates of the true health costs of different types of car and van. The health impacts which are not currently included in the quantitative analysis due to lack of robust evidence but which are recognized as potentially important are: lung function, A&E visits and GP consultations, infant mortality, long term exposure and morbidity, and carcinogenic and neurological effects. Additionally, our estimates do not include the global health impacts that may be attributed to carbon dioxide emissions from the different vehicle types we consider here. While significant, these have been estimated to be lower than the external costs of air pollution, accidents, physical inactivity and congestion.

Notwithstanding these limitations it is clear that the valuation of health effects associated with diesel vehicles are at least five times greater than those associated with petrol vehicles, and around twenty times greater than battery electric vehicles. These differences in valuation are likely to be substantially exacerbated if all health effects were included and a 'Value of a Statistical Life' metric were used instead of the 'Value of Life Years' metric for valuing premature deaths.

0.7 An inconvenient truth?

Given the scale of the challenge of cleaning the air in our cities and towns, the UK Government, on its own admission, acknowledges that existing strategies, plans and measures will only deliver the pollutant emissions reductions needed to meet UK air quality standards for NO_X by the mid-2020s. The challenge is even greater if we adhered to the tougher air quality standards recommended by the World Health Organization (WHO).

So, what can we do about it? The truth is, we all have a role to play in accelerating action on air pollution by reducing NO_X and PM emissions from our travel and avoiding exposure to polluted air – we cannot just wait for governments and business to fix the problem. For meeting our transport needs, we can AVOID making a trip or delivery altogether (or over shorter distances), SHIFT transport to cleaner travel modes or IMPROVE air pollutant emission per unit of service (per km travelled). Examples of AVOID include working from home, car-pooling and lift-sharing, tele-conferencing, and avoiding exposure to highly polluted air by taking a different route. SHIFT options include making different and healthier travel choices such as leaving the car at home for work, school or leisure trips and go on foot, by bike or by clean public transport instead. IMPROVE options include buying or using (shared ownership via electric car clubs) a zero or ultra low emission car or van such as the BEVs our results show have huge advantages. The more we can do any of these actions the cleaner our air will become.

1 Air pollution from cars and vans

Air pollution is the largest environmental cause of disease and death in the world today, responsible for an estimated 9 million premature deaths in 2015 [1]. 92% of all air pollution-related mortality is seen in low-income and middle-income countries, with about 720,000 deaths occurring each year in high income countries such as the UK. The data reported in the Lancet [1] indicate that three air pollutants alone (particulate matter, PM; nitrogen dioxide, NO_2; and ozone, O_3) are responsible for 400,000 premature deaths per year in the EU including some 70,000 directly linked to nitrogen dioxide (NO_2).

Human health damages from air pollution caused by road traffic are significant, in particular in urban areas where most people live and/or work [2]. Urban transport is also one of the reasons why many urban areas are in breach of air pollution regulatory limits. Road transport is the principal source of pollution, though domestic and background emissions also contribute to the problem [3]. Current regulatory breaches relate to NO_2, generated from emissions of nitrogen oxides (NO_X), and particulate matter, the latter both in its coarser PM_{10} form (particles with an average diameter of 10 micrometres or less) and the fine $PM_{2.5}$ form (2.5 micrometres or less). NO_X is mainly a by-product of fuel combustion, whilst PM results from fuel combustion as well as road, brake and tyre wear [4, 5]. While more than a third of all car (38%) and van (34%) miles in the UK happen on urban roads, the majority (cars 43%, vans 45%) happen on rural roads and one fifth (20% for both cars and vans) on motorways and dual carriageways [6].

There are over 31 million cars on the road in the UK today, or 1.15 for each household [7]. Each car is driven about 12,800 km (8,000 miles) a year, totaling 400 billion car-km (250 billion miles) across the nation [6]. In addition, there are over 3.7 million vans on our roads, travelling over 20,000 km (12,600 miles) each and totaling 75 billion van-km (47 billion miles) each year. While bringing major economic and social benefits, using a car or van contributes to road traffic congestion (excess delays), accidents, physical inactivity, climate change and local noise and air pollution [8]. The societal impacts of air pollution include premature (or 'earlier than expected') deaths, illnesses, health expenditures, lost productive work time, crop yield losses, inefficient production, and lost trade and savings [9, 10]. These impacts bear a cost to the wider society, which are largely unpaid for directly by the driver.

2 Conventional diesel cars emit nearly ten times of NO_X and three times of PM more per year than their petrol equivalent

So which types of car or van are the main culprits? Whilst heavy-duty vehicles (buses and lorries) are still a key source of NOx and $PM_{2.5}$ emissions, the contribution from diesel cars and vans has increased rapidly over the last decade because of the gradual 'dieselisation' of the car and van fleets, which is a consequence of the government and industry focus in Europe on climate change and better fuel economy of diesels since the late 1990s [3]. As shown in Table 2, roughly two out of five cars (12 million) run on diesel today, three out of five (19 million) on petrol[3] and a small but growing share on electricity (0.1% in 2015) [7]. In contrast, almost all vans run on diesel. Crucially, diesel cars are driven *further* than petrol cars[4], so that about half of all car miles are done on diesel [7]. We highlight this here because the type and amount of direct air pollution vary drastically depending on whether a vehicle runs on petrol, diesel or electricity. As we will find out, this difference has profound consequences for the health impacts for different vehicle types.

Table 2: The UK vehicle fleet and traffic of cars and vans (2015 data)

	Cars					**Vans**			
	All cars	Petrol ICE	Diesel ICE	Petrol HEV$	BEV$	All vans	Petrol ICE*	Diesel ICE*	BEV*
Vehicle fleet (million)	31.171	18.929	11.928	0.248	0.025	3.727	0.135	3.587	0.005
share of fleet total	*100%*	*60.7%*	*38.3%*	*0.8%*	*0.1%*	*100%*	*3.6%*	*96.3%*	*0.1%*
Distance travelled per car or van (km/year)	12,791	10,248	16,928	10,248	10,248	20,260	20,260	20,260	20,260
Annual distance travelled (billion km)	398.7	194.0	201.9	2.5	0.3	75.5	2.7	72.7	0.1
share of car/van traffic	*100%*	*48.7%*	*50.6%*	*0.6%*	*0.1%*	*100%*	*3.6%*	*96.3%*	*0.1%*

$Assumed to equal distance travelled by petrol ICE cars. *Assumed to equal distance travelled by all vans. ICE=internal combustion engine, HEV=hybrid electric vehicle, BEV=battery electric vehicle.

Before we move on to health impacts and costs, let's take a brief look at emissions of the two key pollutants from car and van use for the year 2015, the latest year we have reliable 'real world' data for. Total NO_X emissions from passenger cars and vans were 147 kilo-tonnes (kt) and 91 kt respectively. Cars were responsible for half of total NO_X from road transport and a sixth of the national total [11, 12]. Vans were responsible for a third of total NO_X from road transport and a tenth of the national total. As for particulates, cars and vans were responsible for 3.1 kt and 1.9 kt

---

[3] This is made up of 61% petrol internal combustion engine cars and 1% of petrol hybrid electric cars.
[4] The main reason is that diesel is the preferred choice for company and fleet cars, which are driven further when primarily used for business travel – at least for the first few years before being sold off to the second hand market.

of $PM_{2.5}$ respectively. Cars made up 78% of total miles driven but produce 22% of exhaust $PM_{2.5}$ whereas vans made up 15% of total miles driven and produce 14% of exhaust $PM_{2.5}$ from road transport.[5] The difference is because vans are virtually all diesels whereas cars are made up of only two fifths of diesels. Note that emissions resulting from the resuspension of particles caused by the turbulence of passing vehicles are not included here, to avoid double counting, but are important in reconciling roadside concentration measurements.[6]

In terms of total annual emissions Table 3 (bottom section) shows that the grand total of 238 kt of NO_X from cars (62%) and vans (38%) are dominated by diesel vehicles, with diesel cars contributing 86% of all NO_X from cars and 99% of all NO_X from vans. The story is similar for particulate emissions where the grand total of 16.1 kt of PM_{10} (11 kt of $PM_{2.5}$) is due to three quarters from cars and one quarter from vans. Again, diesel vehicles dominate PM emissions, particularly for vans.

Table 3: Annual emissions of NO_X and PM per car or van and for the total car or van fleet (2015 data)

	Cars					Vans			
Pollutant	**All cars**	Petrol ICE	Diesel ICE	Petrol HEV	BEV	**All vans**	Petrol ICE van	Diesel ICE van	BEV van
	Per car (kg per car per year)					Per van (kg per van per year)			
NO_X	**4.71**	1.09	10.56	0.73	0.00	**24.44**	9.86	25.02	0.00
PM_{10}	**0.38**	0.24	0.62	0.23	0.22	**1.12**	0.63	1.14	0.60
$PM_{2.5}$	**0.25**	0.13	0.45	0.13	0.12	**0.83**	0.36	0.85	0.33
	Car fleet total (kt per year)					Van fleet total (kt per year)			
NO_X	**146.7**	20.7	125.9	0.180	0.000	**91.1**	1.3	89.8	0.000
PM_{10}	**12.0**	4.4	7.4	0.057	0.006	**4.2**	0.1	4.1	0.003
$PM_{2.5}$	**7.9**	2.5	5.3	0.032	0.003	**3.1**	0.0	3.0	0.002

Notes: ICE=internal combustion engine, HEV=hybrid electric vehicle, BEV=battery electric vehicle.

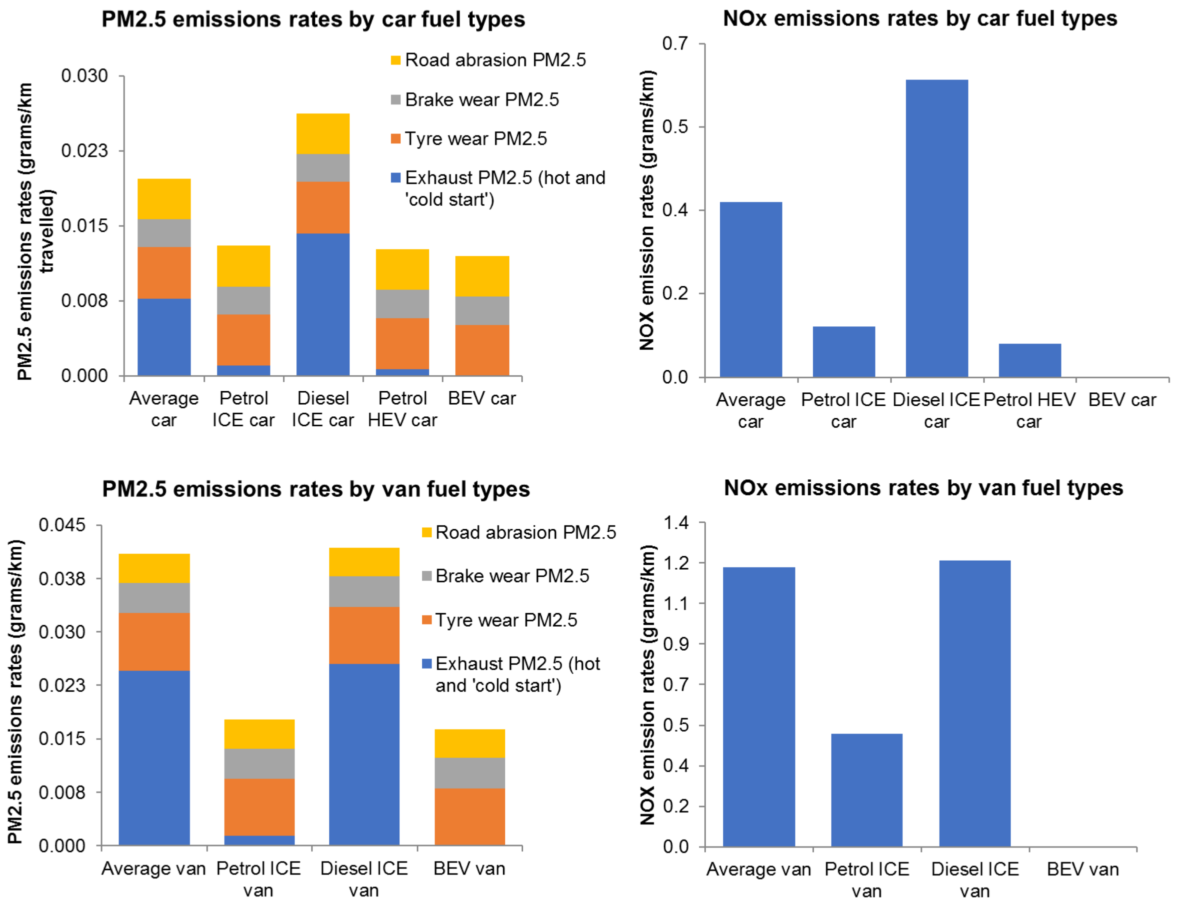
Source: Authors' modelled estimates based on data from the European Environment Agency [13], the UK National Atmospheric Emissions Inventory [14] and UK road traffic statistics [7].

Based on the latest 'real world' [15] emissions[7] data developed for the European Environment Agency[8] [13] – and which are used in the UK National Atmospheric Emissions Inventory[9] [14] –

[5] Road transport – $PM_{2.5}$: cars and taxis 22%, light vans 14%, heavy goods vehicles 6%, buses and coaches 2%, motorcycles and mopeds 0.3%, tyre and brake wear 38%, road abrasion 19%. Road transport – NO_X: cars and taxis 47%, light vans 30%, heavy goods vehicles 16%, buses and coaches 6%, motorcycles and mopeds 0.3%.
[6] In 2015 resuspension emissions were 21.2 kt of PM_{10} and 6.1 kt of $PM_{2.5}$ (BEIS, 2017).
[7] In terms of real world vs type approval, the NO_X emissions rate for a typical diesel car in the UK in 2015 is 0.624 g/km, whereas the European emission standards for NO_X limit emissions rates to less than 0.18 g/km ('Euro 5' standard for vehicles registered between 09/2009 and 09/2014) and 0.08 g/km ('Euro 6' standard for vehicles registered after 09/2014). The two car vintages make up the majority of vehicles on the road today, so the difference between 'real world' and 'type approval' is about a factor of 4-5, which compares well with the literature (e.g. ICCT, 2017).
[8] The EMEP/EEA air pollutant emission inventory guidebook 2016 publishes air pollutant emissions under the UNECE Convention on Long-Range Transboundary Air Pollution and the EU Directive 2016/2284/EU on National Emissions Ceilings.
[9] The UK National Atmospheric Emissions Inventory provides pollutant emissions for PM_{10}, $PM_{2.5}$ and NO_X.

Figure 1 shows the $PM_{2.5}$ and NO_X emissions rates (in grams of pollutant per km travelled) for cars and vans in the UK in 2015. This shows substantial differences between petrol, diesel and electric vehicles, particularly for NO_X where diesel ICE cars emit nearly six times more per km than petrol ICE cars. BEVs do not emit any NO_X when in use. $PM_{2.5}$ (and PM_{10}, not shown) emissions are more equally distributed, although there are clear differences as well, with non-diesel cars and vans emitting two thirds of the fleet average, and less than half of diesel cars and vans. BEV have zero exhaust emissions and contribute the lowest PM emissions of these vehicle types. They do, though, contribute a small but significant share of non-exhaust emissions of particulate matter due to tyre, brake and road surface wear [5, 16-19].[10]

Figure 1: Exhaust and non-exhaust emissions of $PM_{2.5}$ (left) and NO_X (right) per ca-km (top) and van-km (bottom) travelled



Notes: ICE=internal combustion engine, HEV=hybrid electric vehicle, BEV=battery electric vehicle.

By multiplying the above emissions rates (in grams per km) with observed annual mileages (in km

---

We have used fleet-weighted averages taking into account car age, size and fuel type under 'real world' conditions to characterise an "average car".

[10] Non-exhaust emissions from road vehicles are in general terms enhanced by increased vehicle weight. Timmers and Achten (2016), for instance, acknowledge the benefits of regenerative brakes on electric vehicles and made a conservative estimate of zero brake-wear emissions for electric vehicles. Hence, their claim that electric vehicle particulate matter emissions are comparable to those of conventional vehicles was based upon the greater tyre and road surface wear, and resuspension associated with a greater vehicle weight.

per car per year) for the different car and van technologies obtained from the DfT [6] we get annual emissions per car or van (Table 3, top section). Again, this shows notable differences between petrol, diesel and electric vehicles, with diesel ICE cars emitting nearly ten times (NO_X) and three times ($PM_{2.5}$, PM_{10}) more *per year* than their petrol equivalent. A UK van emits about five times as much NO_X and over three times as much $PM_{2.5}$ per year as a UK car, mainly because of higher annual mileages[11] and pollutant emissions rates for each km travelled. Again, battery electric vans are the cleanest overall. Note that these results relate to fleet-weighted averages taking into account vehicle age, size and fuel type under 'real world' traffic conditions. Individual car and van emissions will vary depending on the specific patterns of acceleration/deceleration, braking, age of vehicle, manual or automatic, etc., and actual driving conditions (congestion or free flow).

3 Putting a value on the health impacts of air pollution

3.1 Introducing the UK standard 'bottom-up' approach

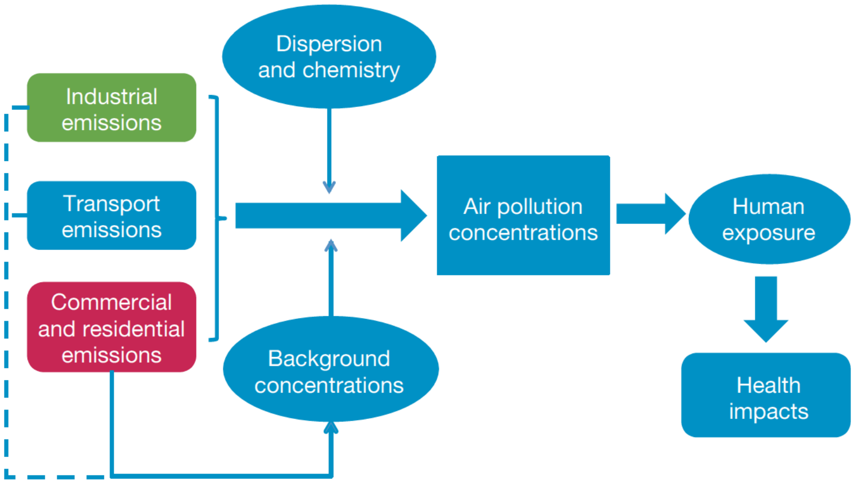
So, what is the economic cost of the adverse health impacts of this pollution? Unfortunately, there is no definite answer to this question as analysts use different approaches and metrics, including 'top-down' and 'bottom-up' approaches. Within those, the main difference in reported figures lies in the way the non-market costs of premature deaths are valued.

The standard approach adopted in the UK (and by the European Commission [20]) is what could be called a 'bottom up' approach, enabled by advanced data-set availability, which models the entire impact *pathway* from the source of pollution (e.g. road transport in London) to dispersion and atmospheric conversion (e.g. from primary NO_X to secondary pollutants such as ozone, O_3) all the way to its health impact [21].

Developed by the UK Department for Environment, Food and Rural Affairs (DEFRA) and the Committee on the Medical Effects of Air Pollutants (COMEAP) [22, 23], the UK impact pathway approach captures the impact of air pollution on chronic mortality effects (quantifying the numbers of life-years lost or gained over a hundred years per tonne of pollutant); acute mortality effects (quantifying the numbers of deaths brought forward); and the morbidity effects (quantifying the number of hospital admissions resulting per year, for both respiratory and cardiovascular illnesses, per tonne of pollutant), where the quantitative relationships are quantified and well-established. For both PM and NO_X, these factors vary according to the source of emission, with transport also varying by geographical location. For example, saving a tonne of PM_{10} from road transport in inner London would have a greater positive impact on respiratory admissions than saving a tonne of emissions from transport in a rural area, reflecting the overall level of human exposure to the pollution in these location types. The relationships between emissions, concentrations, exposure and health impacts are illustrated in Figure 2.

[11] Vans generally have higher annual mileages as they are owned and used commercially as well as privately. Company cars are mainly diesels due to the fuel economy advantage and used for business and private use as well.

Figure 2: The relationships between emissions, concentrations, exposure and health impacts



Source: RAC Foundation [3]

A full impact pathway assessment is relatively resource and time intensive. Fortunately, DEFRA provides summary unit values (known as 'damage costs'), disaggregated by location and source category [22, 23], and derived from the full impacts pathway analysis. In this way they provide a proportionate approach to valuing of the impacts of changes in air quality. Their central 'transport' damage costs are £21,044 per tonne of NO_X and £58,125 per tonne of PM (2015 prices). DEFRA recommends using sensitivity ranges wherever possible to account for the scientific uncertainty around the lag between exposure and health impact and, for NO_X, the link between exposure and early death.[12] The highest value is for 'transport in inner London' at £98,907 per tonne of NO_X and £273,193 per tonne of PM (central values, 2015 prices), reflecting different population densities and age profiles. As expected, the lowest values are for 'transport in rural areas' at £7,829 per tonne of NO_X and £18,020 per tonne of PM (central values, 2015 prices). Table 4 provides a small selection of damage cost values by pollutant and source – with further values for transport and non-transport sources (e.g. power generation, household/domestic) given in Defra [22].

Table 4: Health damage costs per tonne of pollutant by location and source (2015 prices) [22]

GBP_{2015} per tonne		Sensitivities	
	Central estimate	Low central range	High central range
NO_X [$]			
Transport average	**£21,044**	£8,417	£33,670
- Transport inner London	**£98,907**	£39,563	£158,251
- Rural	**£7,829**	£3,131	£12,526
PM			
Transport average	**£58,125**	£45,510	£66,052
- Transport inner London	**£273,193**	£213,898	£310,447
- Rural	**£18,020**	£14,108	£20,476

[$]These are NO_X damage cost values when also assessing PM exposure to avoid double counting.

[12] NO_X damage cost values are reduced by up to 33% to avoid double-counting with PM exposure.

Using this approach, COMEAP estimated a loss of 340,000 life-years in 2008, equivalent to about 29,000 attributable deaths from $PM_{2.5}$ and an average loss per person of life expectancy of approximately six months [24].[13] The corresponding cost to public health was valued by DEFRA [25] at between £8.6 billion and £18.6 billion a year (central value £16.4 billion, all at 2008 prices). The transport contribution in urban areas alone was estimated at between £4.5 billion and £10.6 billion, in other words approximately half of the total [8]. Cars emit about half of road transport's $PM_{2.5}$ pollution [11], so on this basis accounted for between £2 to £5 billion per year.[14]

More recently, and building on the latest evidence of the *direct* effects of exposure to NO_X[15] [23] the Royal College of Physicians (RCP) and Royal College of Paediatrics and Child Health (RCPCH) concluded that overall exposure to both PM and NO_X is linked to around 40,000 early deaths in the UK each year, with an associated annual social cost of £22.6 billion (both with a range for a central estimate of ±25%) [26]. The RCP 2018 update [27] reinforced the message to *"accelerate action on air pollution"*.

According to the NAEI, national air pollutant emissions[16] data from transport were 24.7 kt of PM_{10} in 2015, with NO_X emissions adding about 417 kt [11]. Applying the 'Transport average' damage costs to both pollutants produces a combined damage cost for transport of about £10 billion in 2015; that is, slightly less than half of the £22.6 billion of total costs *from all sources* reported by the RCP/RCPCH [26, 27] and in line with previous estimates for transport [8, 28] once adjusted for price inflation.

3.2 Putting this into context: 'top-down' global assessments of air pollution costs

Most global and international country comparisons (such as OECD, WHO or the Global Burden of Disease studies reported in the Lancet) use a 'top-down' approach [1, 29, 30], reflecting the fact that international data is often available only at an aggregate level. Here the economic cost of air pollution from all sources, including that from road transport, is estimated by combining average pollution exposure estimates with epidemiological relationships that link exposure to health impact, and monetizing the resulting physical estimates. These may then be further broken down and attributed to broad emission source categories such as power generation, industrial emissions and transport. However, any attempts to attribute costs down to the level of cars or vans are virtually non-existent.

Premature mortality usually comes out as the dominant monetary cost category, making up about 90% of total economic costs of air pollution [9, 10, 29, 31]. One of the reasons for the dominance of mortality in global assessments is that premature deaths are often valued using what is called the 'Value of a Statistical Life', or VSL, a valuation metric derived, for example, from surveys asking people about their 'willingness to pay' for not dying prematurely. In this approach, every premature death has the same value whatever the age at which death occurs. The UK value for the VSL varies according to application, with a recent international comparison by the OECD giving USD_{2015} 3.923 million (or £2.615 million at 2015 prices) per statistical life [31]. So, according to this approach the roughly 27,300 premature deaths associated with PM air pollution in the UK [31] have the non-

---

[13] For transport, the health impacts per tonne of PM_{10} were estimated at 2.059 to 2.238 years of life lost over 100 years; 0.017 respiratory hospital admissions per year; and 0.017 cardiovascular hospital admissions per year.

[14] These values are at 2008 prices and would therefore be about 23% higher if shown at 2015 prices.

[15] Over and above the indirect effects of producing secondary pollutants such as nitrates, which are classified as PM and therefore included in the impact assessment and valuation of PM.

[16] Excluding road transport resuspension.

market economic cost of 27,300 * £2.615 million = £71.4 billion a year.

So how does this number compare with other global and national assessments that used the VSL metric? First, it is remarkably close to the UK figure for 2015 reported in a recent OECD study [31] (once converted from USD to GBP at 1.50 USD/GBP). Second, it is also comparable to the figures reported in recent OECD [32] and WHO [33] studies, which quote non-market costs of premature deaths from PM emissions in 2010 in the UK of £55 billion (at 2010 prices) [33]. Illness-related costs from morbidity, plus two types of direct market costs from health expenditure and loss of productivity, was estimated to cost the UK an additional 10% on top of mortality costs (or £5.5 billion in 2010). This compares with UK estimates of the total cost of poor air quality on productivity alone of up to £2.7 billion in 2012 [34]. Direct market costs from crop yield losses in 2010 were £0.34 billion, and indirect market costs added £1.34 billion to this. As a result, the WHO estimated that the total 2010 cost of air pollution caused by PM in the UK was £62.6 billion. Adjusting this figure to 2015 by the 2010 to 2015 changes in real GDP, inflation and PM concentration changes gives a total real economic cost in 2015 of £73.1 billion for the UK (see also Appendix, Table 7) – so very close to the £71.4 billion a year derived above.

In the absence of an assessment using the impact pathway we have apportioned national health impacts and associated costs to broad source categories. With regard to ambient PM in the UK, the OECD suggests that road transport's share of the economic cost of premature deaths is approximately 40%, or £29.2 billion based on the total costs above [33]. In addition, about 57% (cars) and 22% (vans) of the $PM_{2.5}$ emitted by road transport originated from cars and vans in 2015 [11]. Assuming that emissions are a suitable indicator for apportioning impacts we estimate that some £16.7 billion (cars) and £6.4 billion (vans) of the 2015 annual economic cost of air pollution of PM in the UK originated from cars and vans. To recall, the air pollution cost from all sources of NO_X *and* PM in the UK was about £22.6 billion according to the RCP/RCPCH estimate [26].

To take this a little further, dividing the above costs of PM pollution by the total of 31.2 million cars and 3.7 million vans on UK roads in 2015 gives an average annual cost per vehicle, which turns out to be around £536 for cars and £1,717 for vans (2015 prices), equating to lifetime costs of £7,245 and £15,130, respectively. As we will see below, this is roughly a factor of four higher than the figure derived using the UK standard 'bottom-up' approach.

In sum, this relatively simple approach allows for cross-country comparisons to be made (e.g. OECD & WHO studies, top-down GBD assessment). However, the way it uses the VSL metric ignores when death occurs and it ignores the effects of other pollutants (NO_X, O_3) on public health outcomes. To adjust for the first effect, the practice adopted by the UK Government (and the European Commission [20]) when calculating their unit damage costs is to use estimates of a Value of Life Year (VOLY) metric, which is tries to represent the fact that life-time lost from air pollution is typically a few months or years. The central VOLY in the UK is approximately £37,000. Crucially in the top-down approach, any meaningful disaggregation by source category (e.g. road transport, cars, vans) and location (e.g. inner London vs rural) is difficult as the impact pathway is not assessed in any level of detail.

4 The lifetime economic costs of PM and NOx pollution from an average car in the UK is about £1,640 – for vans this is £5,107

So how much do cars and vans contribute? By applying the 'bottom-up' approach and multiplying 'transport average' PM and NOx damage costs (Table 4) by annual emissions per car (Table 3), the economic cost per car is £121 per year (with a sensitivity range between low £57 and high £184). Over the lifetime of a car, this gives an economic cost of £1,641 per car (low £772, high £2,486).

These estimates have been made assuming a 14-year economic life-span for a typical UK car [35], a 'health discount rate' of 1.5% (in line with Treasury Green Book recommendations [36]), a 2% annual *increase* for health cost values (in line with Defra guidance [22]) and a projected 1% annual *decrease* in fleet-average emissions rates [37].

Similarly, the average economic cost per van is £580 per year (range between 'low' £257 and 'high' £897). Over the lifetime of a van, this gives an economic cost of £5,107 per van (low £2,263, high £7,904), assuming a 9-year economic life-span for a typical UK van [35].

Using the alternative 'top-down' approach, lifetime costs are about £7,245 for cars and £15,130 for vans.

Figure 3 (cars) and

Figure 4 (vans) show the results for different car and van technologies and health damage cost values, reflecting some of the uncertainty around where the pollution occurs (UK average vs rural vs inner London) and which vehicle fuel type and propulsion technology contributes most.

So, location matters: if a car were driven in inner London for all of its life the health damage cost would be much higher at £7,714; and it would be even higher for a diesel ICE car – £16,424. In contrast, lifetime health damage costs would be much lower if a car was used only in rural areas (£592), reflecting the fact that the size of the local population affected by the pollution from the car is less in these rural areas.

Similarly, if a van were driven in inner London for all of its life the health damage cost would be higher at £24,004 – and lower £1,864 if driven mainly in rural areas.

While the latter scenarios are somewhat unrealistic they highlight that location, source and vehicle technology are all important factors for the valuation of health costs in the UK (and elsewhere).

Table 5 summarizes this nicely.

Figure 3: Lifetime health damage costs of cars in the UK using the standard UK approach (Net Present Value, 2015 prices)

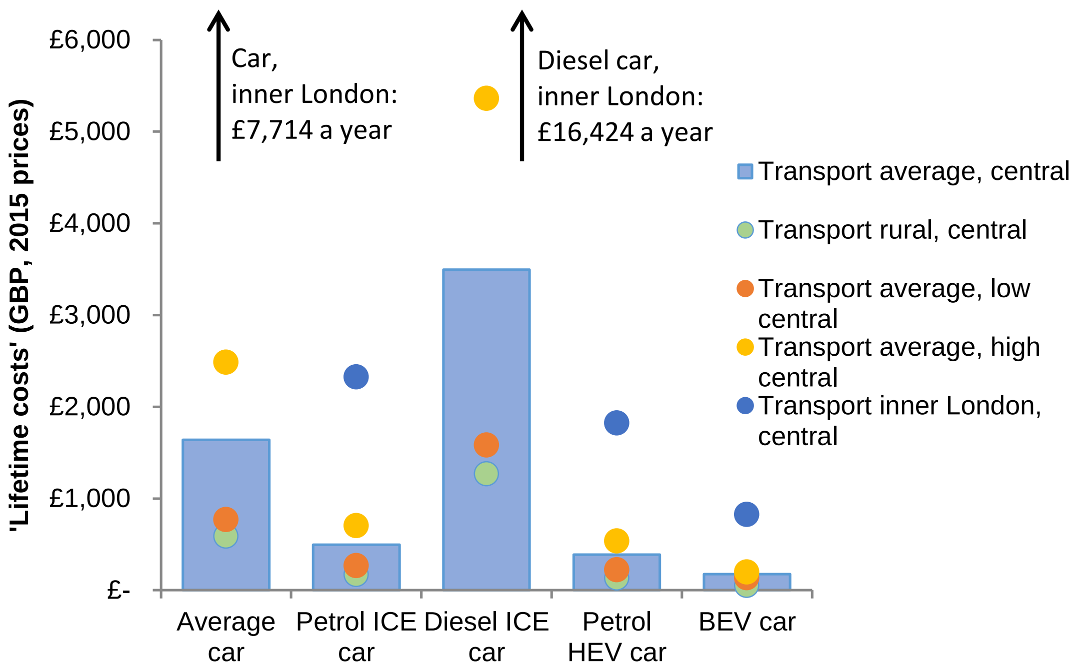


Figure 4: Lifetime health damage costs of vans in the UK using the standard UK approach (Net Present Value, 2015 prices)

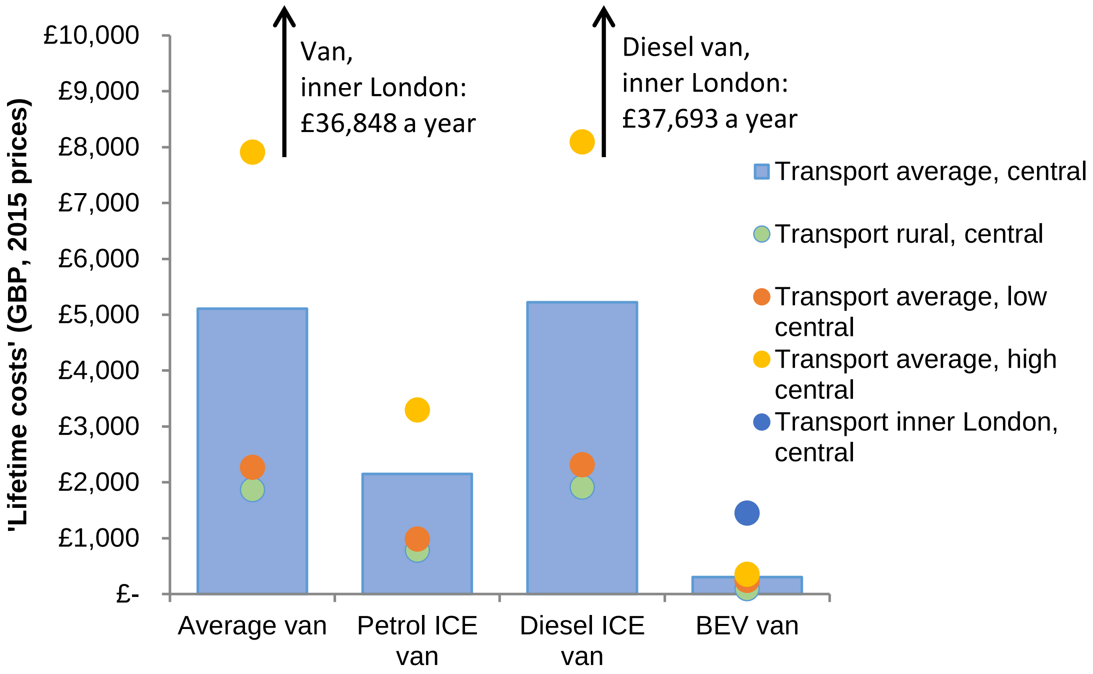


Table 5: Lifetime health damage costs of cars and vans in the UK using the standard UK approach (Net Present Value, 2015 prices)$

Location and sensitivity	Cars					Vans			
	All cars	Petrol ICE	Diesel ICE	Petrol HEV	BEV	**All vans**	Petrol ICE	Diesel ICE	BEV
Transport average, central	**1,641**	495	3,495	388	176	**5,107**	2,149	5,224	307
Sensitivity range									
Transport average, low	**772**	269	1,586	225	138	**2,263**	983	2,314	240
Transport average, high	**2,486**	707	5,364	537	200	**7,905**	3,289	8,088	349
Example locations									
Transport rural	**592**	173	1,270	133	55	**1,864**	780	1,907	£95
Transport inner London	**7,714**	2,327	16,424	1,824	827	**24,004**	10,101	24,555	1,443

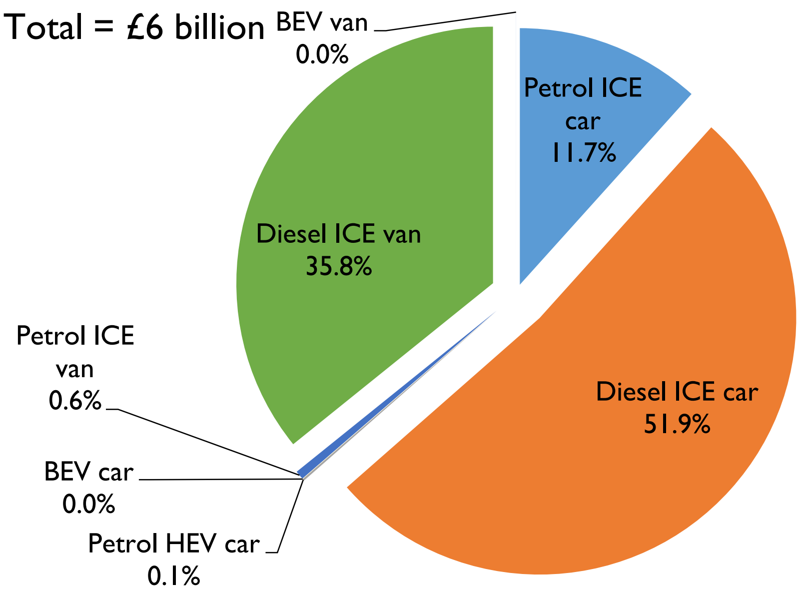
$This assumes a 14-year economic life-span for a typical UK car [35], 9 years for a van [35], a 'health discount rate' of 1.5% (in line with Treasury Green Book recommendations [36]), a 2% annual increase for damage cost values (in line with Defra guidance [22]) and a projected 1% annual decrease in fleet-average emissions rates [37].

It is important to note that the results presented in this section are based on the Defra unit health damage costs for the UK, given in Table 4, above. These unit health damage costs are calculated using the value of life year (VOLY) metric. The unit health damage costs that would result from using the value of a statistical life (VSL) metric are not known. However, given that there remains a lack of consensus internationally as to which metric to use, it is important to capture this source of uncertainty in the results. One way in which we can get a sense of how this parameter affects the results is to see how important this is in sensitivity analyses of previous economic appraisals. One such that is available to us is the cost-benefit analysis of the EU Clean Air Package [20]. Whilst this analysis considers a broader range of measures than simply transport[17] it provides a first indication of the possible influence of this parameter since it presents the net benefits resulting from various policy options adopting a low and high values for both VOLY and VSL. The low value of VOLY broadly equates to the VOLY of approximately £37,000 adopted by Defra whilst the high value of VSL broadly equates to the VSL adopted by OECD, of £2.6 million. The results indicate that use of the VSL increases the health benefits estimates by a multiple of four, on average. The transferability of this multiplier is reduced by the fact that the mix of pollutants and their associated health effects are rather different, though it is not known in which direction these factors influence the multiplier.

5 Using the 'bottom-up' approach total health costs of the car and van fleet are £6 billion a year – diesels account for 88% of the damage costs

In this section, we present the aggregate health costs for the UK associated with the per vehicle results given in the previous section. We estimate that the annual health damage cost of all cars in 2015 is about £3.8 billion (low £1.8 billion, high £5.7 billion), with the lion's share (81%) due to pollution from diesel cars (Figure 5). Petrol cars contributed less than a fifth (18.5%). Likewise, total health costs of vans is about £2.2 billion (low £1.0 billion, high £3.3 billion), with almost all (98%) due to pollution from diesel vans. In both cases, BEVs comprise under 0.01% of the total health costs due to their low emissions and overall low numbers operating on the road today.

Figure 5: Health costs of the car and van fleet, by fuel type (central health damage cost values)



The total of £6 billion for both cars and vans represents about 60% of the transport damage costs of £10 billion and 26% of the total UK damage costs of £22.6 billion estimated by the RCP/RCPCH [26, 27]. This is comparable with figures reported elsewhere in the scientific literature [8, 28]. While cars contribute to 'only' 8% ($PM_{2.5}$, PM_{10}) and 16% (NO_X) of national emissions – and vans adding 3% of PM and 10% of NO_X – they play a much greater role in urban air pollution problems, because

[17] The study includes emissions from industry, traffic, energy plants and agriculture.

they are concentrated on the road network in towns and cities.

Table 6: Annual damage costs from car and van use, including central ranges (billion GBP, 2015 prices)

Central and sensitivity	Cars					Vans			
	All cars	Petrol ICE	Diesel ICE	Petrol HEV	BEV	**All vans**	Petrol ICE	Diesel ICE	BEV
Transport avg., central	**3.783**	0.693	3.082	0.007	0.000	**2.160**	0.033	2.127	0.000
Sensitivity range									
Transport average, low	**1.779**	0.376	1.398	0.004	0.000	**0.957**	0.015	0.942	0.000
Transport average, high	**5.730**	0.989	4.731	0.010	0.000	**3.344**	0.050	3.293	0.000

The health damage costs reported in

Table 5 and Table 6 are comprised of both non-fatal (morbidity) and fatal (mortality) components. In turn, the morbidity costs are comprised of hospital treatment costs for respiratory and cardiovascular hospital admissions as well as a non-market cost of the disutility (i.e. willingness to pay to avoid pain and suffering), whilst mortality costs are comprised of disutility costs only. We estimate that around 15% of the total costs – equal to roughly £0.5 billion for diesel cars, and £0.6 billion for all cars – may be attributed to health treatment costs. These estimates are based on evidence from previous cost-benefit analysis of the EU Clean Air Package [20], combined with the morbidity valuation data from the UK Government Interdepartmental Group on Costs and Benefits [38]. The remaining 85% is attributed to disutility costs.

6 Final Comments

Our results, presented in sections 5 and 6 above, should be regarded as being relatively conservative estimates of the true health costs of different types of car and van. This is because a number of additional health impacts are thought to be associated with PM and NOx, the weight of quantitative evidence is not judged sufficient to justify inclusion in the damage cost estimation. The health impacts which are not currently included in the quantitative analysis but which are recognized as potentially important are: lung function, A&E visits and GP consultations, infant mortality, long term exposure and morbidity, and carcinogenic and neurological effects. Additionally, our estimates do not include the global health impacts that may be attributed to carbon dioxide emissions from the different vehicle types we consider here. While significant, these have been estimated to be lower than the external costs of air pollution, accidents, physical inactivity and congestion [8].

Notwithstanding these limitations it is clear that the valuation of health effects associated with diesel vehicles are at least five times greater than those associated with petrol vehicles, and around twenty times greater than battery electric vehicles. These differences in valuation are likely to be substantially exacerbated if all health effects were included and a VSL metric were used instead of the VOLY metric for valuing premature mortality risks. Nevertheless, these results raise important questions as to how best to develop effective and fair air quality and transport strategies in urban areas.

Given the scale of the challenge of cleaning the air in our cities and towns, the UK Government, in its own admission, acknowledges that existing strategies, plans and measures will only deliver the pollutant emissions reductions needed to meet UK air quality standards for NOX by the mid 2020s

[34]. The challenge is even greater if we adhered to the tougher air quality standards recommended by the WHO.

So, what can we do about it? The perhaps inconvenient truth is, we all have a role to play in accelerating action on air pollution by reducing NOX and PM emissions from our travel and avoiding exposure to polluted air. Clean air transport options typically focus to AVOID making a trip or delivery altogether (or over shorter distances), SHIFT transport to cleaner travel modes or IMPROVE air pollutant emission per unit of service (per km travelled). To give some examples, AVOID options you can do today include tele-shopping, tele-working, tele-conferencing or tele-socialising – and also avoiding exposure to highly polluted air by taking a different route. SHIFT options include making different and healthier travel choices such as leaving the car at home for work, school or leisure trips and go on foot, by bike or by clean public transport instead. The positive effects on our air quality of, say, car free days and the London Marathon closing down streets for road traffic have shown this is feasible and effective. IMPROVE options include buying or using (shared ownership via electric car clubs) a zero or ultra low emission car or van such as the BEVs our results show have huge advantages. The http://www.nextgreencar.com/ website is excellent and can help car buyers find, compare and buy a greener, more economical car. The more we can do any of these actions the cleaner our air will become.

7 References

1. Landrigan, P.J., et al., *The Lancet Commission on pollution and health.* The Lancet, 2018. **391**(10119): p. 462-512.
2. House of Commons, *Improving air quality, last accessed at https://publications.parliament.uk/pa/cm201719/cmselect/cmenvfru/433/43305.htm on 18/04/2018*. 2018, Environment, Food and Rural Affairs, Environmental Audit, Health and Social Care, and Transport Committees - House of Commons: London.
3. Hitchcock, G., et al., *Air Quality and Road Transport: Impacts and solutions*. 2014, RAC Foundation: London.
4. Grigoratos, T. and G. Martini, *Brake wear particle emissions: a review.* Environmental Science and Pollution Research International, 2015. **22**: p. 2491-2504.
5. Grigoratos, T. and G. Martini, *Non-exhaust traffic related emissions. Brake and tyre wear PM: Literature review*, in *JRC Science and Policy Reports*. 2014, Joint Research Centre, European Commission: Ispra.
6. DfT, *Transport Statistics Great Britain: 2017 Edition*. 2017, Department for Transport: London.
7. ONS, *Vehicle licensing statistics: 2017*. 2018, Office for National Statistics, Department for Transport and Driver and Vehicle Licensing Agency: London.
8. Cabinet Office, *The wider costs of transport in English urban areas in 2009, last accessed at http://webarchive.nationalarchives.gov.uk/+/http:/www.cabinetoffice.gov.uk/media/307739/wider-costs-transport.pdf on 20/04/2018*. 2009, Cabinet Office, with DfT, DCLG, DEFRA and DoH: London.
9. WHO, *Review of evidence on health aspects of air pollution-REVIHAAP project: final technical report. http://www.euro.who.int/en/health-topics/environment-and-health/airquality/publications/2013/review-of-evidence-on-health-aspects-of-air-pollutionrevihaap-project-final-technical-report*. 2013, World Health Organziation Regional Office for Europe: Copenhagen.
10. WHO, *Burden of disease from ambient and household air pollution, http://www.who.int/phe/health_topics/outdoorair/databases/en/ [last accessed 21/1/16]*. 2016, WHO: Copenhagen.
11. BEIS. *UK National Atmospheric Emissions Inventory: 2017 edition. Last accessed at http://naei.beis.gov.uk/ on 20/04/2018*. 2017.
12. UNECE, *Guidance documents and other methodological materials for the implementation of the 1999 Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (Gothenburg Protocol), last accessed at http://www.unece.org/environmental-policy/conventions/envlrtapwelcome/guidance-documents-and-other-methodological-materials/gothenburg-protocol.html on 18/04/2018*. 1999, United Nations Economic Commission for Europe: Geneva.
13. EEA, *COPERT 5.1, last accessed at http://emisia.com/products/copert/copert-5 on 16/04/2018*. 2017, European Environment Agency: Copenhagen.
14. Brown, P., et al., *Methodology for the UK's road transport emissions inventory: Version for the 2016 National Atmospheric Emissions Inventory. Report for the Department for Business, Energy & Industrial Strategy*. 2018, Ricardo Energy & Environment: Harwell.
15. ICCT, *Road tested: Comparative overview of real-world versus type-approval NOX and CO2 emissions from diesel cars in Europe, ICCT White Paper. Last accessed at https://www.theicct.org/sites/default/files/publications/ICCT_RoadTested_201709.pdf on 18/04/2018*. 2017, International Council on Clean Transportation: Berlin.
16. Ntziachristos, L. and P. Boulter, *EMEP/EEA air pollutant emission inventory guidebook 2016: Technical Annex on 1.A.3.b.vi Road transport: Automobile tyre and brake wear and 1.A.3.b.vii Road transport: Automobile road abrasion*. 2016, European Environment Agency: Copenhagen.
17. Timmers, V.R.J.H. and P.A.J. Achten, *Non-exhaust PM emissions from electric vehicles.* Atmospheric Environment, 2016. **134**: p. 10-17.
18. Loeb, J. *Particle pollution from electric cars could be worse than from diesel ones, last accessed at https://eandt.theiet.org/content/articles/2017/03/particle-pollution-from-electric-cars-could-be-worse-than-from-diesel-ones/ on 13/04/2018*. E&T Magazine, 2017.

19. Williams, M.L., et al., *The Lancet Countdown on health benefits from the UK Climate Change Act: a modelling study for Great Britain.* The Lancet Planetary Health, 2018. **2**(5): p. e202-e213.
20. Holland, M., *Cost-benefit Analysis of Final Policy Scenarios for the EU Clean Air Package, Version 2, Corresponding to IIASA TSAP Report 11, Version 2a, October 2014. Last accessed on 03/05/2018 at: http://ec.europa.eu/environment/air/pdf/TSAP%20CBA.pdf*. 2014, EMRC.
21. Rabl, A., J.V. Spadaro, and M. Holland, *How much is clean air worth?: Calculating the benefits of pollution control*. 2014. 1-671.
22. DEFRA, *Air quality economic analysis: Damage costs by location and source, last accessed at https://www.gov.uk/guidance/air-quality-economic-analysis on 18/04/2018*. 2015, Department for Environment, Food and Rural Affairs: London.
23. DEFRA, *Valuing impacts on air quality: Updates in valuing changes in emissions of Oxides of Nitrogen (NOX) and concentrations of Nitrogen Dioxide (NO2)*. 2015, Department for Environment, Food & Rural Affairs: London.
24. COMEAP, *The Mortality Effects of Long-Term Exposure to Particulate Air Pollution in the United Kingdom*. 2010, Didcot, UK: The Committee on the Medical Effects of Air Pollutants.
25. DEFRA, *Valuing the Overall Impacts of Air Pollution, last accessed at http://webarchive.nationalarchives.gov.uk/20130403213251/http://archive.defra.gov.uk/environment/quality/air/airquality/panels/igcb/documents/100303-aq-valuing-impacts.pdf on 30/04/2018*. 2010, Department of Environment, Food and Rural Affairs: London.
26. Royal College of Physicians, *Every breath we take: the lifelong impact of air pollution, Report of a working party*. 2016, RCP: London.
27. Royal College of Physicians, *Reducing air pollution in the UK: Progress report 2018*. 2018, RCP: London.
28. Yim, S.H.L. and S.R.H. Barrett, *Public Health Impacts of Combustion Emissions in the United Kingdom.* Environmental Science & Technology, 2012. **46**(8): p. 4291-4296.
29. OECD, *The Cost of Air Pollution: Health Impacts of Road Transport*. 2014, OECD Publishing: Paris.
30. Lim, S.S., et al., *A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the global burden of disease study 2010.* Lancet, 2012. **380**.
31. Roy, R. and N.A. Braathen, *The Rising Cost of Ambient Air Pollution thus far in the 21st Century: Results from the BRIICS and the OECD Countries", OECD Environment Working Papers, No. 124*. 2017, OECD Publishing: Paris.
32. OECD, *The economic consequences of outdoor air pollution, last accessed at http://www.oecd.org/environment/indicators-modelling-outlooks/Policy-Highlights-Economic-consequences-of-outdoor-air-pollution-web.pdf on 30/04/2018*. 2016, OECD Publishing: Paris.
33. WHO Regional Office for Europe, O., *Economic cost of the health impact of air pollution in Europe: Clean air, health and wealth, last accessed at http://www.euro.who.int/__data/assets/pdf_file/0004/276772/Economic-cost-health-impact-air-pollution-en.pdf on 28/04/2018*. 2015, WHO Regional Office for Europe: Copenhagen.
34. Defra, *UK plan for tackling roadside nitrogen dioxide concentrations*. 2017, London: Defra and DfT.
35. SMMT, *2017 UK Automotive Sustainability Report*. 2017, Society of Motor Manufacturers and Traders: London.
36. HM Treasury, *The Green Book: Central Government Guidance on Appraisal and Evaluation*. 2018, London: HM Treasury.
37. BEIS. *Emission factors for transport, 2017 edition, UK National Atmospheric Emissions Inventory. Last accessed at http://naei.beis.gov.uk/data/ef-transport on 20/04/2018*. 2017.
38. IGCB, *Economic Analysis to inform the Air Quality Strategy. Last accessed on 03/05/2018 at: http://webarchive.nationalarchives.gov.uk/20090731140558/http://www.defra.gov.uk/environment/airquality/publications/stratreview-analysis/index.htm*. 2007, DEFRA: London.

8 Appendix

Table 7: Summary of economic costs of all PM Emissions in UK and OECD, 2010 and 2015 according to the ‘top-down’ approach using the VSL metric

PM Economic cost categories			The UK		OECD[18]
Non-market costs (2010 USD billion)		Premature deaths[19]		83.07	1,420
		Illnesses	WHO study[20]: “The chosen indicative estimate for the additional cost of morbidity in the present study is – as shown by the OECD – about 10%.” It includes direct health expenditure and loss of productivity and illness, i.e., 10% * 83.1 = 8.31		130
Market costs (2010 USD billion)	Direct	Health expenditures			10
		Loss of productivity		8.31	30
		Crop yield losses	In OECD, crop yield losses are 5.9% of the total of (Illness + direct health expenditure + direct loss of productivity). For the UK this means 8.31 * 0.059 = 0.491 * 1.03 = 0.506[21]	0.51	10
	Indirect	Reallocation of factors of production	OECD indirect market costs contain 22.2% of direct market costs and Illness. For the UK this means (8.31 + 0.491) = 8.801 * 0.222 * 1.03 = 2.012[22]		
		International trade changes			
		Changes in savings		2.01	40
Total (2010 USD billion), in 2010 real dollars				93.9	
Total (2015 USD billion)[23] Cumulative real GDP change in 2010-2016 period: +10.4%				103.7	
Total (2015 USD billion)[24] Cumulative inflation in period 2010-2016: +15.6%				119.9	
Total (2015 USD billion)[25] PM concentration reduction, 2010 to 2015: –0.05%				119.8	1,640
Total (2015 GBP billion)[26] at 0.61 USD/GBP				73.1	1,330
TOTAL ECONOMIC COST (2015 GBP billion)				73.1	1,330

18 Total welfare costs of air pollution, central projection: http://www.keepeek.com/Digital-Asset-Management/oecd/environment/the-economic-consequences-of-outdoor-air-pollution/total-welfare-costs-of-outdoor-air-pollution-central-projection_9789264257474-table23-en#.V779N7KLSUl#page1

19 WHO & OECD - Economic cost of the health impact of air pollution in Europe: http://www.euro.who.int/__data/assets/pdf_file/0004/276772/Economic-cost-health-impact-air-pollution-en.pdf?ua=1 p. 25

20 WHO & OECD - Economic cost of the health impact of air pollution in Europe: http://www.euro.who.int/__data/assets/pdf_file/0004/276772/Economic-cost-health-impact-air-pollution-en.pdf?ua=1 p. 21 – 24.

21 Based on the difference between the OECD annual income per capita (USD 40,585) and the annual income per capita in the UK (USD 41,756), we can therefore adjust the crop yield losses and indirect market costs for UK by a factor of USD 41,756 / USD 40,585 = 1.03 (based on: https://en.wikipedia.org/wiki/Organisation_for_Economic_Co-operation_and_Development)

22 Based on the difference between the OECD annual income per capita (USD 40,585) and the annual income per capita in the UK (USD 41,756), we can therefore adjust the crop yield losses and indirect market costs for UK by a factor of USD 41,756 / USD 40,585 = 1.03 (based on: https://en.wikipedia.org/wiki/Organisation_for_Economic_Co-operation_and_Development)

23 This total figure is the 2010 USD figure adjusted by 2010-2015 accumulated GDP growth to reflect the opportunity cost of the damage caused in growing 10.4% real, from a £1.66 Trillion economy to a £1.83 trillion economy measured in seasonally adjusted GBP. Source: https://www.ons.gov.uk/economy/grossdomesticproductgdp/timeseries/abmi/pn2

24 This total figure is the 2010 USD figure adjusted by 2010-2015 accumulated GDP growth to reflect the Consumer Price Inflation rate for the period. Source: https://www.ons.gov.uk/economy/inflationandpriceindices/timeseries/d7g7/mm23

25 Based on the UK PM10 and PM2.5 falling by an average of 0.05% over the 2010-2014 period for which data is available. Here assumed unchanged for 2015. Source: http://naei.defra.gov.uk/data/data-selector-results?q=100223

26 Exchange rate used is long-term average USD-GBP end-of-year average exchange rate for years 2000-2015 to reflect the long-term nature of the underlying problem (air pollution) and to smooth out intra-year fluctuations. Source: https://data.oecd.org/conversion/exchange-rates.htm