

## Variations in car type, size, usage and emissions across Great Britain and relationships with socio-demographic characteristics

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### Abstract

This paper is an early output from the EPSRC/RCUK Energy Programme project, MOT (Motoring and vehicle Ownership Trends in the UK). The MOT test record dataset recently released by the Department for Transport provides the ability to estimate annual mileage figures for every individual light duty vehicle greater than 3 years old within Great Britain. Vehicle age, engine size and fuel type are also provided in the MOT dataset and these allow further estimates to be made of fuel consumption, energy use, and air pollution and greenhouse gas emissions per vehicle. The use of this data permits the adoption of a new vehicle-centred approach to assessing emissions and energy use in comparison to previous road-flow and national fuel usage based approaches. The MOT dataset currently also allows a spatial attribution of each vehicle to a postcode area, through the reported location of relevant vehicle testing stations, allowing this new vehicle data to be linked with socio-demographic data in order to determine the probable location of vehicle owners and consequently potential characteristics of the drivers.

This paper provides a broad overview of the types of analyses that are made possible by this data, with a particular focus on distance driven and pollutant emissions. The analyses provided in the paper are, due to space, admittedly cursory. However, the intention is to demonstrate the very broad potential for this data, and to highlight where further drilling down into the data could be useful. The findings from the work have important implications, not just for understanding the distributional impacts of transport related policies, but also for the targeting of messaging and interventions for the reduction of car use.

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## Introduction

Efforts to reduce greenhouse gases in the UK are regularly framed in terms of the overall 'legally binding' commitment for an 80% reduction in greenhouse gas emissions relative to 1990 levels that is set out in the 2008 Climate Change Act. 24% of current domestic UK GHG emissions are from transport (DECC, 2013). Car travel contributes 58% of this, light vans 12.5% and motorbikes/mopeds 0.5% (DfT, 2011). Due to the inability for some source sectors to make an 80% reduction themselves, such as agriculture, waste and domestic aviation, it will be necessary for other sectors, particularly domestic surface transport, to decarbonise almost entirely (DECC, 2011). In addition to the problem of greenhouse gases and climate change, road transport is responsible for over 95% of the Air Quality Management Areas declared under the UK's Air Quality Strategy and Local Air Quality Management (LAQM) framework.

This paper sets out how new data released by the Department for Transport can offer a radically new perspective on these emissions through calculations at the level of the individual vehicle. Through linking this spatially with socio-demographic data, it is possible to work towards an assessment based on *who* is responsible for the emissions (in terms of area of residence and general demographic characteristics), rather than *why* they are emitted (e.g. journey purpose – see, for example, DfT (2008) Chapter 3) or *where* they are emitted (e.g. emissions calculations based on flows for road links, as used in the UK National Atmospheric Emissions Inventory (see Waygood *et al.* (2013) for a short description of the NAEI and similar methodologies).

The vehicle data presented in this paper are primarily attributed to Postcode Areas (PCAs), the largest geographical postcode domain which splits Great Britain into 120 unequal areas (see below for further details). Environmental impacts (pollution emissions and energy use) are calculated for each individual vehicle in the MOT dataset and then averaged over each PCA to provide an indication of the average vehicle characteristics for each area. The spatial resolution of PCAs could be considered to be too large to derive a sensible picture of an average vehicle, or to determine meaningful relationships with socio-economic data over the same areas. However, we present this as exploratory work, setting out a range of possible analyses as a proof-of-concept. We acknowledge not only the limitations that this spatial resolution brings, but conversely the advantages associated with the initial presentation and analysis of the spatial data for Great Britain divided over only 120 PCAs as opposed to tens of thousands of smaller spatial areas such as census Lower Layer Super Output Areas (LLSOAs). Within the data presented below though, there is a clear indication of patterns that merit further research and exploration at a depth that is impossible within a single paper. This paper demonstrates the potential value and diversity of analyses afforded by the MOT dataset, including estimations of currently used statistics (e.g. vehicle km/year for private vehicles) but from a different data source to allow triangulation, as well as completely novel calculations that have been, to date, impossible at a national level. In particular, this work highlights the difference between a *potentially* dirty car (i.e. one with high emissions or fuel consumption per km) and an *actually* dirty car (i.e. based on total emissions per year).

## MOT dataset

In 2010, DfT began publishing results from the annual MOT tests which, with the application of some mathematics (see, for example, Wilson *et al.*, 2013a, Wilson *et al.*, 2013b, Cairns *et al.*, 2013), allow an estimation of annual mileage to be made for the majority of light duty vehicles (LDV) in the UK<sup>1</sup>. DfT have also undertaken some analysis of this dataset focussing primarily on age and mileage (DfT, 2013). In addition to the mileage of the vehicle at each test, the dataset includes details of the make and model of the vehicle, engine size, fuel type, date of first registration and colour. The primary unit in the current public release of the data is the vehicle test (rather than the vehicle). Each test (and therefore the vehicle undergoing the test) is spatially attributed to the PCA of the relevant Vehicle Testing Station (VTS), which can therefore be used as a proxy for the vehicle location, in the absence of any other locational information. Key caveats around this data are:

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<sup>1</sup> In practice, this 'annual' value is based on a two-year weighted average of mileage readings from vehicles – from a year before to a year after the date when the average is taken (see Wilson *et al.*, 2013a).

- The location of the VTS is not an ideal proxy for the location of the owner of the vehicle.
- The dataset does not include the majority of vehicles <3 years of age as these are not currently required to undergo an annual MOT test. In the DfT data release in September 2013, <0.1% of vehicles listed were registered in 2010-12 and these are likely to have atypical patterns of usage. Work is currently being undertaken to identify and utilise additional datasets relating to rented and leased vehicles to improve the knowledge of these.
- Vehicles disappear from the dataset after their last test, so an unknown mileage is driven between a vehicle's last test and when it is scrapped or taken off the road.
- A certain number of vehicles will not have an MOT test and will therefore be driven on the roads illegally. Due to the increasing computerisation of the system, this is a decreasing number. DVLA carry out annual number plate surveys which estimate the scale of this problem to be small.
- The current dataset contains a range of vehicle types, including cars, Light Goods Vehicles <3.5 t (LGVs), motorbikes and private buses. Our analysis has not differentiated between different vehicle types.

The dataset used is from the September 2013 release (VOSA, 2013). Following processing of the data, estimates of annual mileage for 2012 and other vehicle parameters have been identified for 24,391,789 individual vehicles.

### Environmental impacts and energy use

This paper focuses on the impacts of car travel through two main factors: emissions of pollutants and energy use. Through considering 'conventional' air pollutants (particulate matter (PM) and nitrogen oxides (NO<sub>x</sub>)), there is some overlap with local environmental issues. Other public health issues associated with car use such as noise, road safety, and use of public space are not considered directly here (though they could be seen as having mileage as a proxy variable). Emphasis is placed on abstracted car use linked to the (presumed) location of the vehicle owner (via the location of the VTS), rather than considering specific local effects such as resultant concentrations of air pollutants at the point of use. This approach is particularly relevant with regard to greenhouse gases, where spatial location of emissions is largely immaterial, compared to conventional air pollutants (see Tiwary *et al.*, 2013). However, it is also relevant to energy use where, in a future when Plug-In Vehicles may have become established, the majority of energy required by the LDV fleet may need to come from the local electricity distribution grids of the owners rather than in liquid/gas form from filling stations. The approach also affords a new approach to assessing environmental and social justice issues around air pollution, building on work such as Mitchell and Dorling (2003) to investigate the relationship not just between air pollution exposure and car ownership, but looking at the relationship with actual car usage.

### Calculating emissions and energy use

Per kilometre emissions and energy use are calculated here as an outcome of three key variables from the MOT dataset: date of registration (indicating likely pollution control technologies), engine size and fuel type (both impacting on both fuel economy and emissions). These are then multiplied by the calculated annual distance travelled to estimate annual emissions and energy usage for each individual vehicle.

The MOT dataset categorises vehicles according to fuel type under the classes: Petrol, Diesel, Liquefied Petroleum Gas (LPG), Liquefied Natural Gas (LNG), Compressed Natural Gas (CNG), Steam, Fuel Cell, and Other. For the purposes of this analysis, steam-powered vehicles have been removed and, following examination of make/model information, 'Fuel Cell' and 'Other' have been grouped together and treated as Hybrid (petrol electric). Due to the very small proportion of alternative fuel vehicles, the spatial presentation of fuel type has focussed on the proportion of diesel vehicles for each PCA.

In terms of the relative environmental impacts of petrol and diesel vehicles, although diesel vehicles have been heavily incentivised by national and local government policies (i.e. VED and the congestion charge) on the basis of lower CO<sub>2</sub> emissions, the higher emissions of PM lead to increased short-term warming and significantly higher human health impacts compared to petrol (Uherek *et al.*, 2010; UNEP, 2011). Table 1 shows recent figures (Defra, 2010) which found that monetisation of these impacts indicates an equivalence in the

combined air quality and climate impacts between petrol and diesel cars, highlighting the importance of considering both greenhouse gases and conventional air pollutants.

**Table 1: Typical annual environment and health cost of car travel (Defra, 2010)**

Costs with regard to:	Petrol Car	Diesel Car	Petrol Hybrid
Climate Change	£166	£146	£98
Air Quality	£1	£21	£1
<b>Total</b>	<b>£167</b>	<b>£167</b>	<b>£99</b>

### Emissions calculations

No account has been taken in this analysis of differentiation between vehicle types (e.g. car, LGV, two-wheeler). Initial attempts have been made to manually categorise the vehicles using appropriate vehicle classes, including sub-groupings (e.g. 'city-car', 'saloon' etc.) but this has proved impractical with over 33,000 unique combinations of make and model within the dataset. Provision of an indicator of 'body type' in future data sets will allow better treatment of this. It is also anticipated that future releases of the data may also include vehicle manufacturers' values for emissions and fuel economy which will allow for an assessment of uncertainty to be made with regard to the calculations presented here. However, it is of note that numerous studies show that manufacturers' reported emissions do not accurately reflect in-use emissions (e.g. Carslaw *et al.*, 2011; Melios *et al.*, 2013).

Emissions and energy use have been calculated on the basis of vehicle age, fuel type, engine size and derived km/year. All cars reported as 'Fuel Cell' or 'Other' have been treated as petrol hybrids. Steam vehicles have been discounted from the analysis ( $n = 62$ ). There has been an attribution of hybrid vehicles to other fuel types (including steam,  $n = 14$ ) which has been possible to partially identify by searching for "PRIUS". This highlights some potential issues with the data quality which merit further attention. However it has been impractical in this exploratory work to focus on identifying these misclassifications and calculations have been based on engine size and fuel type as stated.

Emissions of NO<sub>x</sub>, PM<sub>10</sub> and CO<sub>2</sub> have been calculated from a set of generic emission factors developed by AQMRC (Barnes and Bailey, 2013). These are based on the best available data for the UK from a range of sources (primarily COPERT 4 (v8.1), TRL (2009), NAEI (2013a) and EMEP/EEA (EEA, 2013)). The emission factors for NO<sub>x</sub>, PM<sub>10</sub> and CO<sub>2</sub> used were for cars of different fuel types: Petrol (<1400cc, 1400-2000cc, and >2000cc: Pre-Euro and Euro 1-6), Diesel (<2000cc and >2000cc: Pre-Euro and Euro 1-6), LPG (all engine sizes: Euro 1-6 (pre-Euro 1 treated as Euro 1)), Hybrid (single factor). These emission factors were available for urban, rural and motorway driving. A compound emission factor was calculated based on figures from Transport Statistics Great Britain (DfT, 2012) that split total mileage for cars, motorbikes and LGVs between 19% motorways, 28% urban and 43% rural. Euro standards for the vehicles have been based on date of first registration in relation to the EU compliance date for the relevant standards (see Table 2). As described above, due to the absence of data on body type, all vehicles have been treated as cars.

**Table 2: Dates for introduction of Euro standards for cars/LDVs**

	Euro1	Euro2	Euro3	Euro4	Euro5	Euro6
<b>Cars</b>	July 1992	Jan 1996	Jan 2000	Jan 2005	Sept 2009	Sep 2014
<b>LDVs</b>	Oct 1994	Jan 1998	Jan 2000	Jan 2005	Sept 2009	Sept 2014

Due to a lack of information on emission factors for light duty CNG and LNG vehicles, NO<sub>x</sub> and PM<sub>10</sub> emissions for these were based on LPG, by km travelled. CO<sub>2</sub> emissions from LNG were also set on the basis of LPG. However, additional data allowed CO<sub>2</sub> emissions for CNG to be calculated on a g/litre basis, which is because of the significantly different volume:energy ratio due to the compressed nature of the fuel. This is described below.

### Fuel economy and fuel consumption calculations

Fuel economy figures for petrol and diesel vehicles were derived from data for Ireland (CSO, 2013) due to the likely similarity of the vehicle fleet and the quality and availability of the data, which gives average fuel economy figures for petrol and diesel vehicles sold between 2000 and 2011 breaking vehicles down in to 100cc bands between 900cc and 3000cc. All vehicles registered before 2000 were treated as 2000, which may lead to some bias from

understating older vehicles, however <15% of the vehicles in the dataset were registered before 2000. It is recognised that there may be significant differences in vehicle purchasing patterns between the UK and Ireland, and further work is planned to validate and improve these initial assumptions and will be aided by the addition of manufacturers' figures within future releases of the MOT dataset.

Due to lack of suitable fuel economy figures for LPG and LNG vehicles, these have currently been set as for petrol, although usually LPG is 5-10% less efficient. Fuel economy for CNG vehicles has been calculated by taking an average gCO<sub>2</sub>/km from the two CNG vehicles on the carfueldata.gov website (VCO, 2013) of 156.5 gCO<sub>2</sub>/km. On the basis that the carbon content of 1l of petrol is emitted as 2,252 gCO<sub>2</sub> (Ecoscore, 2013), the fuel use of CNG vehicles has been estimated at 6.9494 l/100km. Fuel economy for hybrids has been calculated by taking an average 122.7 gCO<sub>2</sub>/km from the 70 hybrid vehicles on the carfueldata.gov website (VCO, 2013) and, on the basis that 1l of petrol emits 2,392 gCO<sub>2</sub> (Ecoscore, 2013), fuel use of hybrids is estimated as 5.1296 l/100km. These fuel economy figures of l/100km were then multiplied by the estimated annual vehicle mileage to generate fuel consumption figures – specifically, a figure of litres of fuel per year for each vehicle.

As with any estimation of vehicle emissions, these calculations represent a notional value that, irrespective of details such as the bandings of engine size, can only ever loosely reflect precise in-use emissions which will depend on a variety of factors such as power/acceleration, engine temperature and engine condition. However, the most representative available figures for in-use emissions and fuel economy have been used. Future work will try to improve these further and, should they become available in future releases of the dataset, utilise manufacturers' emission and fuel economy figures.

### Energy use calculations

Energy use of all vehicles, other than electric, has been calculated on the basis of Defra Greenhouse Gas Reporting Guidelines (Defra, 2013a). These provide the calorific value for all relevant fuels (kWh/kg) along with a density (l/tonne) from which a calorific value of kWh/l was calculated. This was then multiplied by the fuel used per year to estimate total energy usage per vehicle. Electric vehicle energy use was set at 0.211 kWh/km with CO<sub>2</sub> emissions of 70 g/km (Wilson, 2013), however no emissions of PM or NO<sub>x</sub> were attributed for these.

**Table 3: Emission factors, fuel economy and calorific values used for all fuel types**

Measure	NO <sub>x</sub>		PM <sub>10</sub>		CO <sub>2</sub>		Fuel Economy		Carbon Content of Fuel	Calorific Value of Fuel
	Min	Max	Min	Max	Min	Max	Min	Max		
Units	g/km	g/km	g/km	g/km	g/km	g/km	l/100 km	l/100 km	gCO <sub>2</sub> /l	kWh/l
<b>Petrol (66%)</b>	0.02	2.97	0.002	0.008	263.8	104.8	4.2	12.6	2,392	9.14
<b>Diesel (34%)</b>	0.16	0.80	0.001	0.212	231.0	94.8	3.3	11.0	2,640	10.01
<b>LPG (0.09%)</b>	0.03	0.31	0.002	0.004	140.0	139.5	As Petrol		1,665	6.66
<b>LNG (0.0001%)</b>	As LPG		As LPG		As LPG		As Petrol		As LPG	6.00
<b>CNG (0.0002%)</b>	As LPG		As LPG		156.5		6.9494		2,252	2.32
<b>Hybrid (0.047%)</b>	0.0200		0.0021		22.8		5.1296		As Petrol	As Petrol
<b>Electric (0.087%)</b>	N/A		N/A		70.0		N/A		N/A	N/A

### Postcode Areas (PCAs)

As described above, the current public release of the MOT dataset attributes each vehicle test to a PCA on the basis of the VTS location. Within the process set out in earlier work (Wilson *et al.*, 2013b; Cairns *et al.*, 2013), each calculation of annual mileage for a vehicle results in two PCAs being attributed per vehicle, one for the first test and one for the second. Within this paper, the final (second) PCA has been used to represent the location of the vehicle. Table 4 provides descriptive information highlighting the varied nature of PCAs. The PCA boundaries are shown in the various maps produced below (e.g. Figure 1).

Table 4: Characteristics of 120 GB postcode areas

	Minimum	Mean	Maximum
Area (km <sup>2</sup> )	3.4	1,552	6,433
Households (2011)	613	219,754	821,717
Population (2011)	1,553	559,022	2,191,953
Population density (p/km <sup>2</sup> )	0.24	1,501	15,878

**Spatial variations in vehicle parameters**

Five key parameters have been taken for each vehicle in the MOT dataset for 2012 and then a mean calculated for each PCA to represent an ‘average vehicle’. These parameters are:

**Odometer Reading:** The odometer reading from the second test provides an indication of the total mileage driven by the vehicle. This could be taken as a proxy for wear and tear in addition to vehicle age, but only accounts for how far a vehicle has been driven, not how hard it has been driven or how well it has been maintained.

**Engine Size:** The average engine size (in cc) taken from the MOT record. These have been screened to exclude obviously erroneous recordings for engine sizes above 9000cc. As described above, for the fuel consumption calculations, there are 100cc bins for all vehicles ≥900cc and ≤3100, and single bins for all vehicles below or above these sizes.

**Vehicle Age:** This is taken to be the number of years between the test year (the year of the chosen straddle date) and the year of first registration.

**Annual Mileage per Vehicle:** This is the estimated annual mileage calculated from the interval between vehicle test results. A straddling date of 1<sup>st</sup> July 2012 has been set to represent vehicle usage for the calendar year 2012.

**Fuel Economy:** Although this data is not (currently) available within the MOT dataset itself, this has been calculated for each vehicle as described above, and has been included within these parameters as a vehicle characteristic, and not an energy or emission outcome. As described above the fuel consumption calculations treat pre-2000 as 2000, and so there is likely to be an underestimation of fuel consumption of older vehicles.

The spatial variation in the mean values for these parameters by PCA are presented in Figure 1 alongside three further values: The number of ‘cars’ in each PCA, the density of ‘cars’ per km<sup>2</sup>, and the proportion of diesel vehicles within the PCA. Figure 2 presents scatterplots for six of these parameters indicating the varying relationship between them (including linear regression lines and R<sup>2</sup> values calculated in the statistics package R).

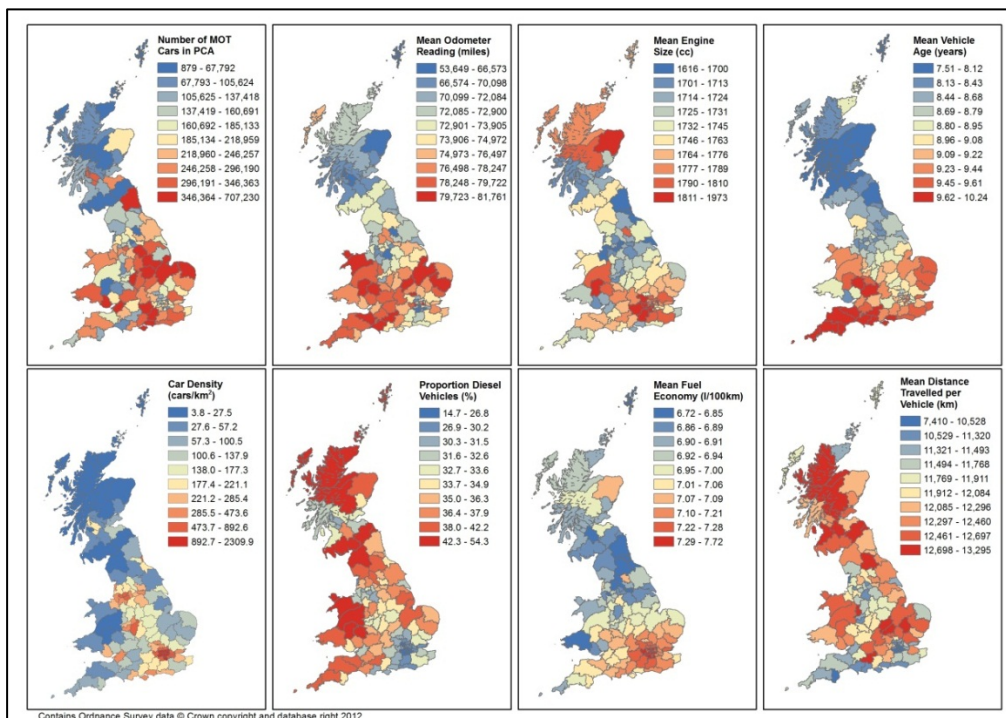
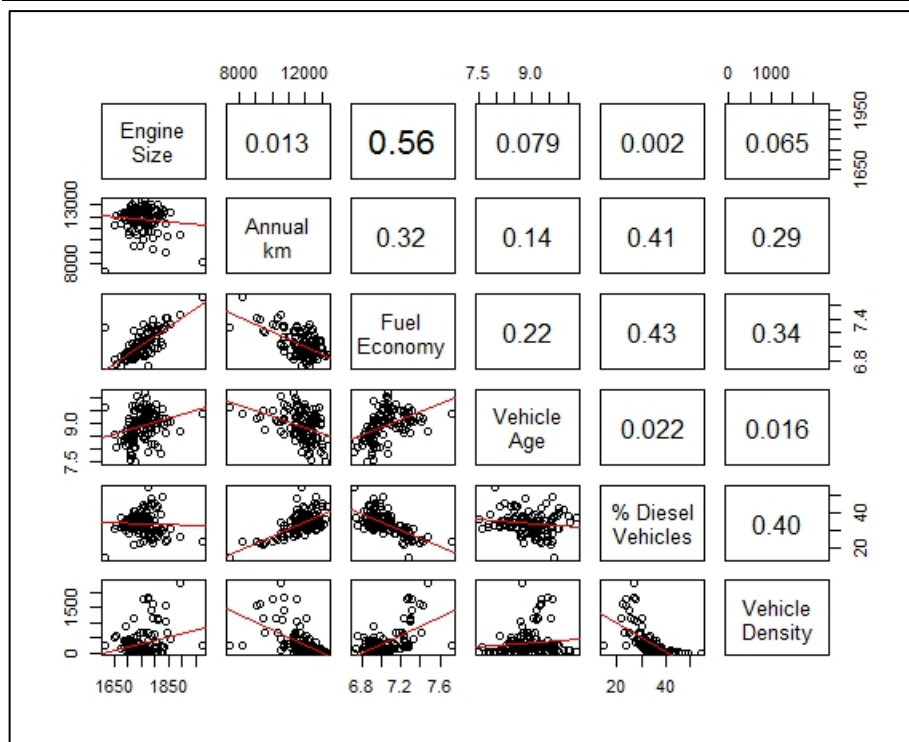


Figure 1: Spatial variation in key vehicle parameters across postcode areas



**Figure 2: Relationships between mean vehicle parameters by PCA ( $R^2$  values for the regression lines are presented in upper panel diagonally opposite the relevant plots)<sup>2</sup>**

**Observations on spatial variation and relationships for mean key vehicle parameters**

From the data presented in Figures 1 and 2, a number of patterns can be seen:

- Density of vehicles is greatest around the main conurbations (London, Birmingham, Cardiff, Liverpool, South Coast etc.)
- Vehicles with highest odometer readings are mainly in East Anglia, Wales, Midlands and South West).
- Engine size is greatest in northern Scotland, the Home Counties and mid-Wales.
- The oldest vehicles are in East Anglia, South West and South Coast.
- The greatest proportions of diesel vehicles are in Wales, Scottish Highlands and Borders and South West, and, as might be expected, the relationship between fuel economy and the percentage of diesel vehicles is negative ( $R^2 = 0.43$ ).
- Fuel economy of vehicles (l/100km) is worst in South East and Aberdeenshire.
- Greatest mean annual mileage per vehicle is in Scottish Highlands and Borders, northeast England, and an area across the South and East Midlands. Places with higher annual per vehicle mileage also tend to have better fuel economy ( $R^2 = 0.32$ ).
- The strongest relationship is between engine size and fuel economy ( $R^2 = 0.56$ ), which has a stronger relationship than vehicle age and fuel economy ( $R^2 = 0.22$ ).

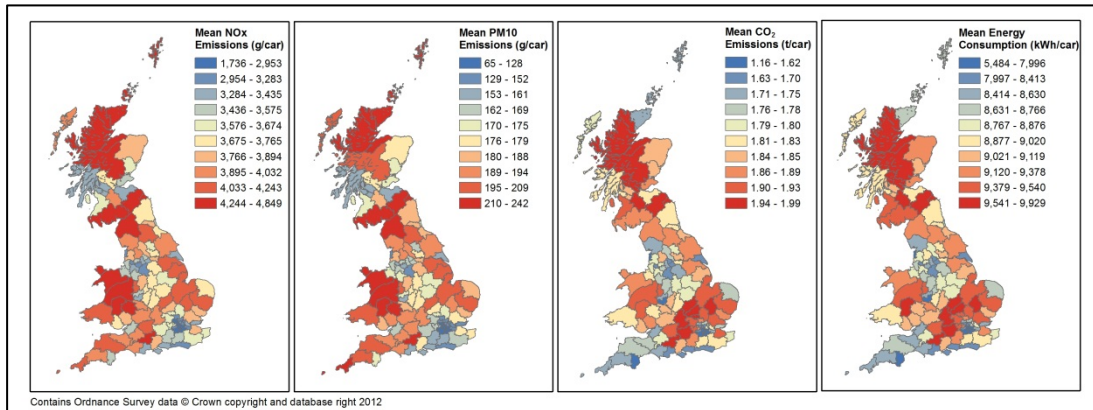
As the purpose of this paper is to demonstrate the potential for this dataset to reveal patterns of interest rather than to undertake detailed analyses of these, we do not go into these further at this point. All these points merit far more analysis than is possible within this paper.

**Spatial variations in emissions and energy consumption**

As with the key vehicle parameters above, annual emissions for NO<sub>x</sub>, PM<sub>10</sub> and CO<sub>2</sub> have been calculated for each individual vehicle before deriving the mean value for each PCA. Figure 3 shows the spatial variations in these. The highest values across both sets of

<sup>2</sup>  $R^2$  values are included calculated from the Pearson correlation coefficient (R) for the regression line. The nearer the value to 1 the stronger the correlation, for example, approximately 56% of the variance in vehicle fuel economy is related to variance in engine size.

pollutants tend to be Scottish Highlands and Borders and a band across the South and East Midlands. Wales and the far South West have higher emissions of NO<sub>x</sub> and PM<sub>10</sub> than they do emissions of CO<sub>2</sub> and energy consumption. Analysis of the relationship between the variables shown in this figure, conducted on a similar basis to that reported above, shows that NO<sub>x</sub> and PM<sub>10</sub> are strongly correlated ( $R^2 = 0.97$ ), as are CO<sub>2</sub> and energy consumption ( $R^2 = 0.99$ ). NO<sub>x</sub> and PM<sub>10</sub> are less well correlated with CO<sub>2</sub> and energy, with  $R^2$  values between 0.55 and 0.65.



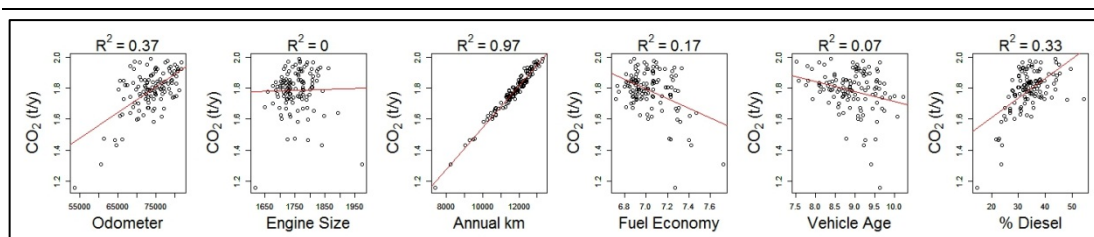
**Figure 3: Spatial variation in mean emissions and energy use per vehicle**

#### Determinants of average CO<sub>2</sub> emissions

Figure 4 shows the relationship between the mean vehicle CO<sub>2</sub> emissions and six key vehicle parameters for each PCA. For the purpose of this paper, CO<sub>2</sub> has been chosen as being, to some extent, illustrative of all emissions and energy use given the strong relationships demonstrated above. Again, it should be noted that this paper provides an overview of the data and spatial differences in the means of parameters. Further work is justified in exploring the variance and relationships between these parameters at the level of individual vehicles. However, some interesting points can be noted:

- The strongest relationship is between average CO<sub>2</sub> per vehicle and average annual mileage per vehicle – indicating that in terms of environmental impacts, it is not necessarily the type of car that is important but the distance travelled, at least at this level of spatial aggregation;
- CO<sub>2</sub> emissions per vehicle appear to increase with the proportion of diesel vehicles in the PCA. This is counter-intuitive given that diesel vehicles have lower emissions per km. However, it could be that due to better fuel economy, diesel vehicles are often driven further than petrol vehicles. Again, further analysis at the level of individual vehicles may reveal more about this.
- Vehicle age in years appears to be very weakly related ( $R^2 = 0.07$ ), and inversely proportional to CO<sub>2</sub> emissions, possibly reflecting the findings in Wilson *et al.*, 2013b regarding the tendency for annual mileage to decrease with vehicle age. However, the further the vehicle has been driven, in terms of total distance on the odometer, the higher the annual CO<sub>2</sub> emissions ( $R^2 = 0.32$ ). This suggests that there are complex factors relating historical mileage with distance travelled in the current year.
- As average fuel economy worsens (l/100km increases), average CO<sub>2</sub> emissions decrease. This is counter-intuitive because, due to the comparatively small amount of carbon emitted as CO or as particulate matter, the CO<sub>2</sub> emissions of a vehicle are in a (near) direct relationship to the carbon content of the fuel. Therefore, the worse the fuel economy of a vehicle, the higher the CO<sub>2</sub> emissions should be. However, this doesn't account for differences between the carbon content of diesel and comparative fuel efficiency of diesel vehicles, and so this merits more detailed future analysis.
- At the aggregate level, average engine size is not clearly related to average emissions of CO<sub>2</sub>, and this is likely to be due to a combination of vehicle age, fuel type and, most importantly, average distance driven exerting a much stronger influence on these emissions.



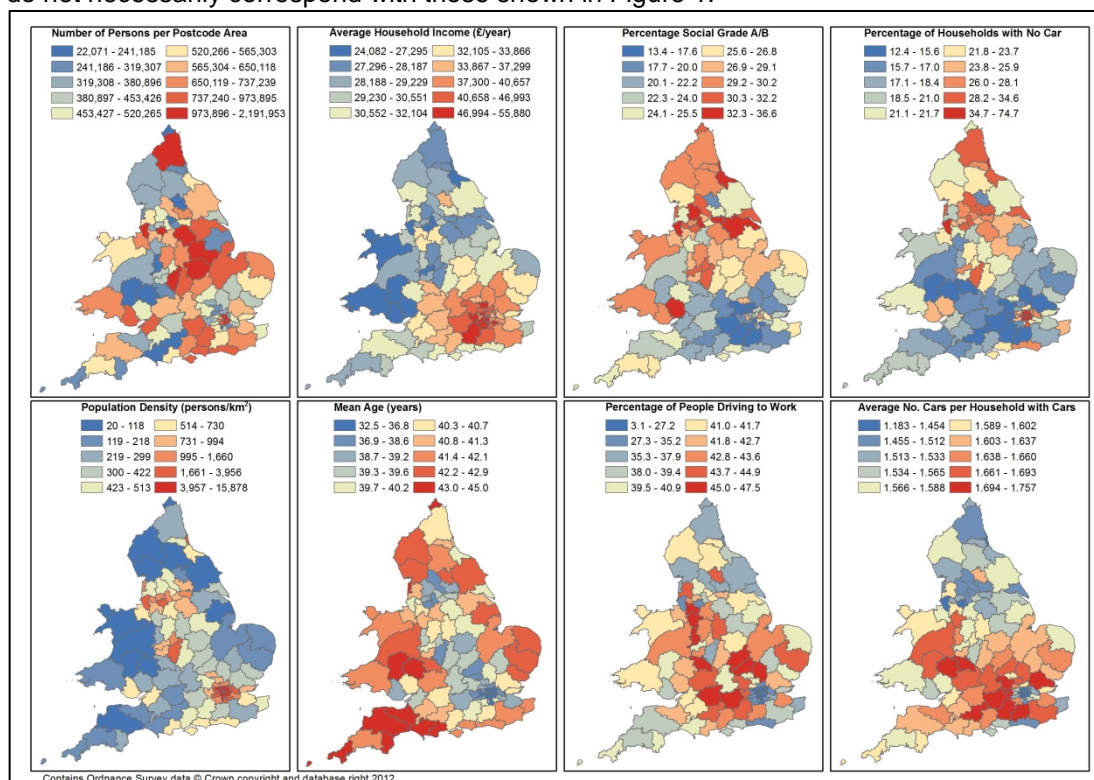


**Figure 4: Relationship between mean key vehicle parameters and mean CO<sub>2</sub> per vehicle by PCA**

### Linking to socio-economic data

Not only can the spatial attribution of data help to identify the general location of the owners of relatively clean or dirty cars but it can be used with data from the census (and other sources) to identify a profile of what type of person may be likely to be responsible for these vehicles. Figure 5 shows some key socio-demographic parameters. Five of these have been taken directly from the 2011 Census (ONS, 2011): Number of persons per PCA, mean age, percentage of households of social grade AB (by 'Household Reference Person'), percentage of households with no access to a car, average number of cars per household (for those households with a car), and percentage of workers driving to work. Population density has been calculated from the PCA area and total census population. Average income has been calculated using Experian median household income data (Experian, 2011). All data has been aggregated upwards from data for Lower Level Super Output Areas. As with the aggregation of the vehicle parameters, the intention is to provide an indication of the average qualities of an area, rather than making statements about what any individual person/household may be like (and thus fall foul of ecological fallacy). Due to differences in data collection and geographies for Scotland, socio-demographic data has currently only been analysed for England and Wales.

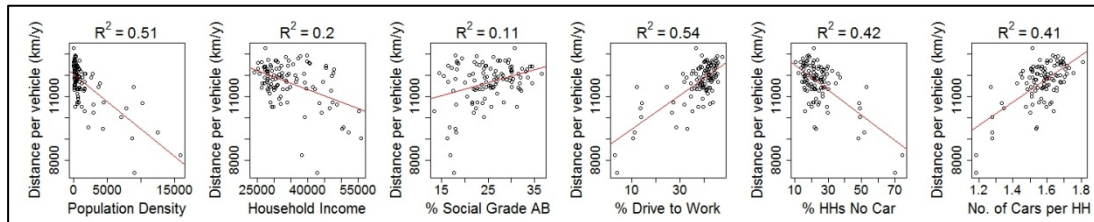
As with the plots in Figure 2 relationships have been investigated between these parameters. However as focus of this paper is on the MOT dataset and not the socio-demographic patterns these are not presented here. The most notable feature, though, is that each of these variables is also significantly spatially variant, and the patterns of variance do not necessarily correspond with those shown in Figure 1.



**Figure 5: Key socio-demographic parameters from 2011 Census and Experian data**

### Relationships between vehicle type, and emissions and socio-demographic data

Figure 6 shows the relationships between both mean km driven per vehicle for each PCA, and six of the socio-demographic characteristics. Due to the strong correlations between average km driven per vehicle and CO<sub>2</sub>, energy consumption, NO<sub>x</sub> and PM<sub>10</sub> (described above) the similar plots for the other outcome parameters have not been presented here.



**Figure 6: Relationship between average km driven per vehicle and average socio-demographic characteristics (HH = Household)**

There are only two plots with an  $R^2 > 0.5$ . These demonstrate a positive relationship between the percentage of people driving to work and km driven per vehicle, and an inverse relationship between population density and km driven per vehicle.  $R^2$  values between 0.4 and 0.5 are found for the relationships between km driven per vehicle and the percentage of households with no car (negative), and the average number of cars per household (positive). Income and percentage of households of social grade AB are not strongly related to either km driven per vehicle or CO<sub>2</sub> emissions per vehicle, at the PCA level at least.

### Linking to air pollution emissions and exposure

In addition to socio-demographic data, it is also possible to analyse the data in relation to available data on air pollution emissions from road transport and levels of exposure to air pollutants. This data is available for the whole of the UK on a 1 km<sup>2</sup> resolution grid (Defra, 2013b; NAEI, 2013b). For the purposes of this paper, these data have been aggregated up to the PCA level. This type of analysis might present interesting opportunities in relation to improving aspects of emissions inventory construction (e.g. cold starts), as well as investigating issues of social and environmental justice regarding relationships between responsibility for emissions and exposure (as mentioned above regarding Mitchell and Dorling, (2003)). This aspect in particular would be improved given better spatial resolution for the MOT dataset. Comparison between total emissions for road transport from the NAEI, and total emissions from the vehicles in the MOT dataset for each area show very strong correlations ( $R^2 = 0.87-0.90$ ), despite being based on completely different methodologies (road flows vs. individual vehicles). This strongly suggests that there may be some relationship between location of vehicle based on the PCA of VTS and location of use.

### Longitudinal change across postcode areas (2009-2012)

It is also possible to look at longitudinal changes using the data. The dataset presented here for 2012 has been compared with a similar snapshot for 2009, allowing changes in the vehicle parameters at each PCA to be considered over the period since the onset of the global recession. Although it must be remembered that these do not contain many vehicles under three years old, it can be argued that this section of vehicles are predominantly owned by a specific set of companies, and individuals with a strong preference for new vehicles and are not likely to be representative of the majority of vehicles. As such there is likely to be some relevance in considering the changes identifiable from the dataset.

The comparison suggests that the number of vehicles, density of vehicles, their age, the odometer readings and the proportion of diesels have all tended to increase over this period. Meanwhile, aside from a small handful of areas, the distance travelled per vehicle has reduced. Fuel economy has improved across the board, and there has been a mixed pattern with regard to increase or decreases in engine size. There is considerable spatial variation within these patterns, but the initial analysis suggests that the dataset has something to offer to the further exploration of the 'Peak Car' debate, particularly with regard to the universality of the phenomenon in the UK (see Le Vine and Jones, 2012; Headicar, 2013).

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## Discussion and conclusions

The range of analyses presented in this paper clearly demonstrates the great potential for the MOT dataset to contribute to our understanding of patterns of car ownership and use and their consequent impacts. One potentially interesting finding is the relatively small influence of engine size and fuel type on overall energy use and emissions compared with that of distance driven. There are many policy initiatives focused on vehicle type (encouraging people to buy newer cars, to choose diesel rather than petrol, to buy smaller vehicles etc.) If it is true that differences in mileage driven contribute to a substantially greater proportion of the overall variation in energy use and emissions from vehicle use than variations in vehicle type, that could have considerable implications for transport policy, and the relative balance of spending on different policies. More analysis would be needed to draw these conclusions with any certainty.

It has only been possible within the paper to give the briefest of descriptions of the patterns found, but it has set out the key areas that future work will explore. The work as presented here has represented extremes of insights into individual vehicles and patterns across very large (PCA) areas by VTS. If future releases of data are able to attribute cars (by registered keeper) to finer areas such as census LLSOAs, different, and potentially more meaningful, patterns may become visible. Other aspirations for better data include improving the knowledge about vehicles less than three years old, acquiring more information on vehicle body types, and information on whether the vehicle is in household or business ownership.

Work is also underway to link this information on transport-related emissions and energy use to data on domestic energy usage from gas and electricity in order to estimate overall household carbon footprints from direct energy usage. Further analyses are also planned to examine these spatial differences in relation to a range of other factors such as per capita investment in public transport, DfT accessibility indicators, and a range of other economic and health indicators. Work will also be undertaken in relation to the census travel to work origin-destination datasets in order to explore the component of mileage that might be attributable to commuting journeys. Future work, possibly beyond the scope of this project, will seek to also consider estimates of household footprints associated with non-direct energy usage, such as emissions relating to the consumption of water and other goods and services including public transport.

Data from vehicle maintenance tests are collected in a number of different countries (e.g. Ireland, Netherlands and New Zealand) however there is little evidence of this data being used in this way elsewhere. Some of the other countries pose interesting problems. For example, in non-island countries, a much smaller proportion of km travelled on the national roads will be undertaken by domestically registered vehicles. The approach proposed here, looking at the registered location of the vehicle, may provide one interesting perspective for considering national responsibility for emissions, even where vehicles are driven in other neighbouring countries.

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MOT Project website <http://www.abdn.ac.uk/ctr/research/currentbr-research-projects/mot/>

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