Exploring the Spatial Variation in the Rated Carbon Dioxide Emissions of Local Car Fleets across Scotland

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1 Abstract

The incremental decrease in the rated grams of carbon dioxide emitted per kilometre (grams CO_2/km) from the cars registered in Scotland represents the main mechanism through which short to medium term reductions in the carbon account of the Scottish transport sector will be realised. This paper provides a spatial analysis of the mean rated grams CO_2/km of the car fleets registered across the local authorities of Scotland and the rest of the United Kingdom. The analysis indicates that a significant degree of spatial variation is present, with certain local car fleets displaying relatively low levels of mean grams CO_2/km compared to others. Significant spatial clustering is observed in the mean grams CO_2/km across the local authorities of the United Kingdom, with Scotland and the North-East of England representing a region with a relatively clean car fleet whilst London and the South-East of England contains a comparatively high pollution car fleet. Statistical modelling suggests that certain socioeconomic, household and car fleet characteristics are valid indicators of the mean grams CO_2/km of local car fleets. In particular, the proportion of the population classified as self employed, the mean personal income of the populace and the mean age of the local car fleet all prove useful in explaining variance in the mean grams CO_2/km. The results of this analysis may prove of interest to transport policy teams in understanding spatial variation in transport emissions and in informing projected scenarios of decarbonisation in the transport sector.

2 Introduction

The gradual de-carbonisation of the national car fleet represents an explicit requirement of achieving a low-carbon personal mobility system in Scotland. One of the primary indicators used to evaluate the progress made concerning this requirement is the mean rated grams of carbon dioxide emitted per kilometre travelled (gCO_2/km) of the cars registered in Scotland. The Committee on Climate Change (2015) makes use of this metric in their evaluations of the Greenhouse Gases (GHGs) emissions from Scotland's transport sector, noting that the mean emissions rating of new cars registered in Scotland in 2014 was 124.4 gCO_2/km. This metric also forms the basis of the European Commission's (EC) car emission regulations. Two legal targets have been established by the EC, requiring automotive manufacturers to achieve a mean carbon intensity of the cars which they sell within the European Union of 130 gCO_2/km by 2015, decreasing to 95 gCO_2/km by 2021 (European Commission, 2014).

The discussions which surround this metric tend to focus on temporal issues, such as considering how quickly reductions in the mean gCO_2/km of new cars can be achieved and what trajectory the annual trend is likely to follow. This is likely generated by the prominent GHG emissions reduction targets set in Scotland and further afield, which favour the production of forecasting models and scenario assessments. The degree to which the mean gCO_2/km of the national car fleet varies across space represents a topic which has attracted relatively less attention. However, understanding the spatial dimension of the national car fleet rated carbon intensity is likely to be of use in both evaluating progress and developing policy. For example, determining the spatial variation of mean gCO_2/km of the national car fleet may provide insights regarding areas which appear to be delayed in their de-carbonisation, thus allowing geographically targeted interventions to be considered.

It is the aim of this paper to provide an initial evaluation of the spatial variation of the mean gCO_2/km of the car fleet across the local authorities of Scotland and the rest of the United Kingdom (UK). Firstly, the spatial variation is visually mapped in order to illustrate its range and consider the differences

which exist across the government office regions of Great Britain. Secondly, spatial diagnostic are performed which aim to detect the presence of spatial clustering and determine if cold spots or hot spots of mean gCO_2/km for the car fleet are apparent. Thirdly, a series of bivariate and multivariate statistics are employed to consider how the mean gCO_2/km for the car fleets registered across the local authorities of Scotland and the rest of the UK are associated with other characteristics of these areas.

3 Methodology

3.1 Data: Spatial Resolution

The analysis reported in this paper utilises data which aggregates mean gCO_2/km at the lower-tier local authority level (referred to in the paper as simply local authority) of UK administrative geography. This level contains 378 spatial units inclusive of 32 Scottish local authorities, 22 principal areas of Wales, 256 non-metropolitan districts of England, 36 metropolitan districts of England and 32 boroughs of London.

3.2 Data: Sources

3.2.1 Car Fleet Statistics

The data which relates to the mean gCO_2/km of the cars registered across the local authorities has been extracted from the Department for Transport's Vehicle Licensing Statistics Database (VLSD) (Department for Transport, 2015). This metric is attained from the New European Driving Cycle (NEDC) process, which tests the emissions levels of each new car model sold in the European Union (European Commission, 2007). Equation 1 describes how the mean gCO_2/km for the car fleet registered in each local authority has been calculated:

$$Y_i = \frac{(CMCO_j * CMR_{ji} + CMCO_k * CMR_{ki} + \ldots CMCO_n * CMR_{ni})}{N_i} \quad (1)$$

where:

Y_i is the mean gCO_2/km of the car fleet registered in local authority *i*
$CMCO_j$ is the assigned gCO_2/km for car model *j*
CMR_{ji} is the quantity of car model *j* registered in local authority *i*
N_i is the total quantity of cars registered in local authority *i*

A series of additional characteristics of the car fleet registered across the local authorities are also extracted from the VLSD. These statistics cover the number of company cars registered, the number of hybrid electric cars registered and the mean age of the registered cars.

3.2.2 Other Area Characteristics

The data which relates to the other characteristics of the local authorities covers the socioeconomic composition of the populace and the features of the households. Data covering these characteristics has been sourced from the UK population census (Office of National Statistics, 2011; National Records for Scotland, 2011) and Her Majesties Revenue and Customs (2015).

3.3 Data: Preparation

A series of modifications has been enacted to the data to make it suitable for analysis. Firstly, an integrated dataset has been produced which includes the car fleet characteristics and other area characteristics of the local authorities. Secondly, the non-contiguous spatial units of Shetland, Orkney, Ellinair Sair, Isle of Anglesey and the Isle of Wight have been removed from the integrated spreadsheet. Thirdly, the integrated dataset has been spatially joined to a GIS shapefile which covers

the local authority spatial units of the UK (Office of National Statistics, 2013). The integrated dataset is summarised in Table 1 which details the variables which it contains and some descriptive statistics concerning these variables.

Table 1: Descriptive statistics of the variables related to the socioeconomic, household and car fleet characteristics of the local authorities of the United Kingdom included in the analysis (n = 374)

Variable	Mean	S.D.	Min.	Max.
Socioeconomics				
Mean Age (years) [A]	40.27	2.82	30.9	47.7
No Qualifications (%) [A]	22.80	5.14	6.72	36.04
Level 1 Qualification (Standard Grade) (%) [A]	14.30	3.43	4.30	28.26
Level 2 Qualification (Higher Grade) (%) [A]	15.55	1.98	6.58	18.55
Level 3 Qualification (College) (%) [A]	12.08	2.03	7.16	32.59
Level 4 Qualification (University Degree) (%) [A]	26.93	7.71	1.42	68.36
Mean Personal Income ('000 GBP) [B]	29.73	10.58	20.20	131.00
Full Time Employment (%) [A]	38.83	3.97	26.41	51.45
Employed (%) [A]	52.86	3.89	38.00	63.00
Unemployed (%) [A]	4.06	1.23	2.01	8.02
Retired (%) [A]	14.79	3.51	4.71	24.06
Home or Family (%) [A]	4.11	0.84	2.33	7.42
Disabled (%) [A]	3.99	1.60	1.35	9.64
Household				
Detached House (%) [A]	25.91	12.68	0.39	60.52
Semi-Detached House (%) [A]	30.22	8.27	0.21	48.85
Terraced House (%) [A]	23.40	8.81	1.45	56.13
Flats/Apartments (%) [A]	15.91	12.16	3.20	86.34
Population Density (per hectare) [A]	15.02	22.52	.09	138.70
Own Home Outright (%) [A]	32.44	7.07	8.45	47.96
Own Home Mortgage (%) [A]	33.47	5.19	12.83	44.16
Rent (social) (%) [A]	16.64	6.61	5.35	43.72
Rent (private) (%) [A]	15.27	5.52	4.89	39.66
No Car in Household (%) [A]	23.06	10.48	8.04	69.40
One Car in Household (%) [A]	42.27	2.93	25.09	50.20
Two Cars in Household (%) [A]	26.45	7.14	3.95	42.09
Three Cars or more in Household (%) [A]	6.03	2.20	0.51	11.19
Car Fleet				
Hybrid Electric Vehicles per 1000 cars [C]	6.25	6.54	.83	60.59
Company Cars per 1000 cars [C]	77.68	143.12	24.66	1620.43
Mean Car Age (years) [C]	8.12	0.91	4.36	9.98
Mean Car CO_2 (grams per km) [C]	155.23	6.09	134.99	188.77

A: data sourced from the UK census (England and Wales: Office of National Statistics (2011); Scotland: National Records for Scotland (2011)); B: data sourced from Her Majesty's Revenue and Customs (2015); C: data sourced from the Department for Transport (2015)

3.4 Data: Limitations

The prepared dataset utilised in the analysis reported in this paper is limited by a number of deficiencies which may affect the validity of the results. Firstly, the spatial resolution of the dataset (lower-tier local authority level) is somewhat coarse, and likely masks a significant degree of variation which exists within each of the local authorities. Secondly, whilst the spatial resolution across the different data utilised in the analysis remains constant, a certain degree of temporal drift in the data

collection is apparent. For example, the data relating to car fleet characteristics was collected at the end of 2014 whereas the data associated with some of the socioeconomic characteristics was collected in 2011. Thirdly, the data measuring the mean gCO_2/km is calculated from the NEDC procedure, which has been subject to criticism concerning the validity of the test outcomes (Sileghem et al. 2014). Fourthly, as the NEDC was brought into effect in March 2001, only 83% of the cars registered in the VLSD have associated gCO_2/km ratings.

3.5 Statistical Approach

The acquisition of geo-referenced data covering the local authorities of the UK allows for the application of spatial statistics (Fischer and Getis, 2009). Two specific spatial analysis techniques are utilised to examine the mean gCO_2/km of the car fleets registered across the local authorities. Firstly, spatial autocorrelation analysis (Getis, 2009) is employed to determine if any spatial clustering can be observed. Secondly, spatial regression analysis (Elhorst, 2014) is used to construct a series of models which aim to explain the observed variation in mean gCO_2/km for the local authority car fleets.

4 Results

The results of the analysis conducted on the integrated dataset are presented in four stages. Firstly, exploratory analysis is conducted which illustrates the range present concerning the mean gCO_2/km of the car fleet across the local authorities of Scotland and the rest of the UK. Secondly, spatial autocorrelation analysis is applied in order to determine if there is any spatial organisation in the mean gCO_2/km and if hot spots and cold spots can be identified. Thirdly, correlation analysis is applied which attempts to identify other characteristics of the local authorities which can act as useful indicators of mean gCO_2/km. Fourthly, regression analysis is employed to investigate the degree to which the other characteristics of the local authorities can be of use in explaining the observed variation in mean gCO_2/km.

4.1 Exploratory Analysis

The mean gCO_2/km of the car fleets registered across the government office regions of Great Britain and sub-regions of England is reported in Table 2. The means range from a low of 149.22 gCO_2/km for the car fleet registered in Northern Ireland to a high of 166.25 gCO_2/km for the car fleet registered in London. Scotland displays a relatively low value of 150.57 gCO_2/km, indicating that Scotland has one of the least carbon intensive regional car fleets of Great Britain.

Table 2: Mean grams of carbon dioxide emitted per kilometre of the car fleets registered across the regions of Great Britain and the sub-regions of England

Region	Mean gCO_2/km	Standard Deviation
England	155.66	6.16
East Midlands	154.68	3.82
East of England	157.31	4.32
London	166.25	6.55
North East	149.22	1.38
North West	151.60	3.23
South East	158.59	7.05
South West	155.37	5.00
West Midlands	153.00	4.30
Yorkshire and Humberside	153.59	5.05
Northern Ireland	150.36	2.47
Scotland	150.57	3.28
Wales	151.62	2.67
Great Britain	155.24	6.40

Figure 1 illustrates the spatial variation in the mean gCO_2/km for the car fleets registered across the local authorities of Scotland. Glasgow City represents the local authority with the least carbon intensive car fleet, returning a mean figure of 142.4 gCO_2/km, whereas Aberdeenshire has a car fleet which has the highest pollution potential with a mean figure of 156.62 gCO_2/km. The spatial patterning of mean gCO_2/km seems to indicate that local authorities in the central belt of Scotland tend to contain cars which have relatively lower pollution potentials.

Enlarging the scope of the analysis, Figure 2 (left image) illustrates the mean gCO_2/km for the car fleets registered across all the local authorities of the United Kingdom. A large degree of spatial variation is apparent, with the London Borough of Westminster and Chelsea displaying the highest value of 188.77 mean gCO_2/km whereas the local authority of Slough holds the lowest mean of 134.99 gCO_2/km.

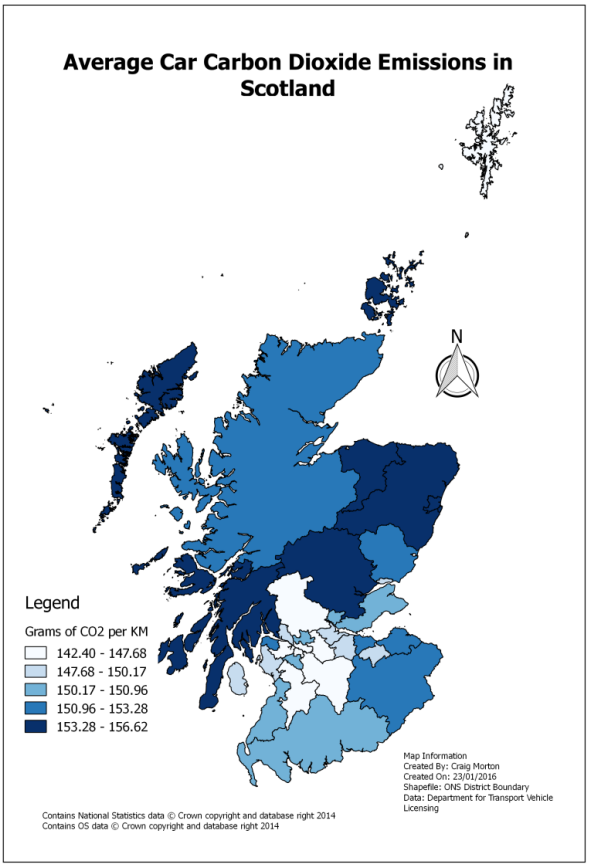

Figure 1: Choropleth map illustrating the spatial variation in mean carbon dioxide emitted per kilometre from the car fleets registered across the local authorities of Scotland

A one-way analysis of variance indicates that the local authorities which comprise the government office regions of the UK (England, Wales and Scotland) are significantly different in the mean gCO_2/km of their car fleets ($F(2,371) = 16.971$, $p = .000$). A Tukey's post-hoc test indicates that the local authorities of England display significantly higher levels of mean gCO_2/km for their car fleets (155.91 ± 6.16) than the car fleets of Wales (151.32 ± 2.67) and Scotland (150.36 ± 3.28). No statistically significant difference is identified between the mean gCO_2/km of the car fleets registered across the local authorities of Scotland and Wales.

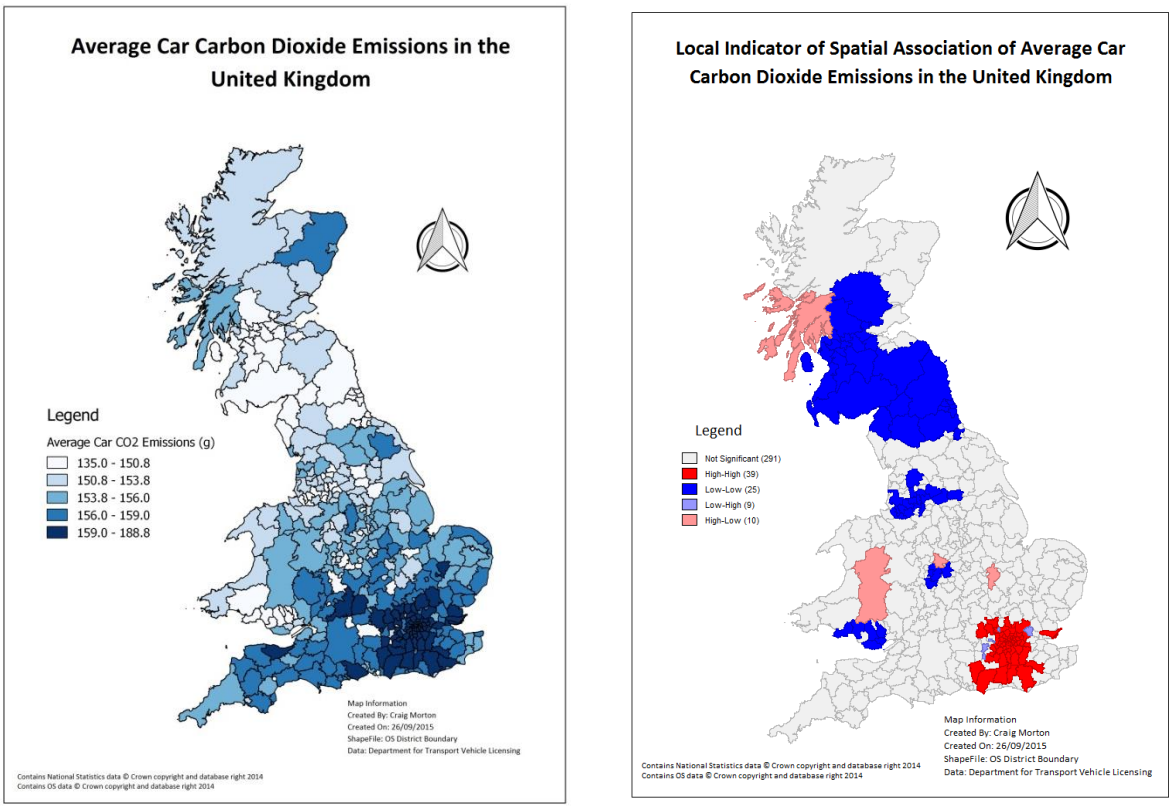

Figure 2: (left image) Choropleth map illustrating the spatial variation in mean carbon dioxide emissions per kilometre of the car fleets registered across the local authorites of the United Kingdom (right image) Local indicator of spatial association analysis for the mean carbon dioxide emissions per kilometre of the car fleets registered across the local authorites of the United Kingdom

4.2 Spatial Autocorrelation Analysis

Whilst a significant degree of spatial variation across the local authorities of Scotland and the rest of the UK is clearly visible in Figures 1 and Figure 2 (left image), there is the possibility that this variation simply represents the manifestation of a random process. In order to determine if any spatial organisation is present in the mean gCO_2/km of the car fleets registered across the local authorities of the UK, a spatial autocorrelation analysis has been conducted. This analysis considers if the observed values of mean gCO_2/km in particular local authorities appear to be in some way related to the observed values of mean gCO_2/km in neighbouring areas. The Moran's I test of spatial autocorrelation calculates a coefficient of 0.591 (p-value less than .001), which indicates that the observed values of mean gCO_2/km across the local authorities of the UK are moderately connected with the observed values of mean gCO_2/km in neighbouring local authorities.

This global statistics can be further spatially refined through the application of Local Indicator of Spatial Association (LISA) analysis. This approach is useful in identifying spatial clusters of similar values, which may indicate the presence of hot spots and cold spots for the mean gCO_2/km of the local car fleets. The results of the LISA analysis are presented in Figure 2 (right image) and suggest that a number of clusters of high values and low values concerning mean gCO_2/km are present. Southern Scotland and parts of Northern England appear to represent a cold spot (shaded in deep blue), with the local authorities contained in this area displaying relatively low levels of mean gCO_2/km. A number of smaller cold spots are also present, covering Southern Wales, the conurbation of Manchester and Liverpool as well as the Greater Birmingham. Conversely, one large hot spot (shaded in deep red) is identified covering the Greater London area and a number of the local authorities surrounding Greater London.

4.3 Correlation Analysis

A series of Spearman's rank correlation analyses have been conducted between mean gCO_2/km and other characteristics of the local authorities of the UK. The first analysis utilises the socioeconomic characteristics of the local authority residents and is reported in Table 3 (appendix). A number of moderate to strong significant relationships are identified by the analysis, with mean gCO_2/km correlated with the proportion of the population who have no formal qualifications (r_s: -.556) and with the proportion of the population who have a level 4 qualification which relates to the attainment of a university degree (r_s: .502). In addition, both the proportion of the population who are classified as self employed (r_s: .702) and the mean personal income of the population (r_s: .603) hold positive correlations with mean gCO_2/km.

The second analysis employs the household features of the local authorities and is detailed in Table 4 (appendix). In this instance, the proportion of households with no car access (r_s: -.313) and with access to three or more cars (r_s: .340) display moderate significant correlations with mean gCO_2/km. The variables measuring household tenancy also interact with mean gCO_2/km, with the proportion of households which are rented socially[1] negatively correlated (r_s: -.311) with mean gCO_2/km. In addition, house type classification displays a number of significant relationships with mean gCO_2/km, with the proportion of the household stock classified as semi-detached (r_s: -.352) and terraced (r_s: -.348) holding significant negative correlations.

The third analysis considers the interactions between mean gCO_2/km and ancillary attributes of the car fleets registered in the local authorities and is reported in Table 5 (appendix). The results of the analysis suggest that a number of these ancillary attributes can act as valid indicators of mean gCO_2/km, with the mean age of vehicles registered in a local authority (r_s: .736), the number of company cars registered per thousand cars in a local authority (r_s: -.546) and the number of hybrid vehicles registered per thousand cars in a local authority (r_s: .402) all being associated with moderate to strong correlation coefficients. The positive coefficient observed between the number of hybrid vehicles registered and mean gCO_2/km seems somewhat counterintuitive. As hybrid vehicles tend to emit relatively low levels of gCO_2/km the expectation is that, as the registration of these vehicles increases, mean gCO_2/km should decrease. However, local authorities which have relatively high levels of hybrid vehicle registrations may also exhibit characteristics which are likely to increase mean gCO_2/km. Therefore, this positive correlation might be picking up the effect of omitted variables.

4.4 Regression Analysis

The final stage of the analysis employs regression modelling to consider the degree to which the other characteristics of the local authorities can be of use in explaining the observed variance in mean gCO_2/km which acts as the dependent variable in the models.

4.4.1 Ordinary Least Squares Regression Models

A series of benchmark Ordinary Lease Squares (OLS) regression models have been formatted with the results reported in Table 6. Four models are specified utilising different sets of independent variables, with the first considering the effect of socioeconomic characteristics (Model 1), the second household features (Model 2), the third car fleet attributes (Model 3) whilst the final model (Model 4) integrates all of the characteristics considered in the first three models as well as two dummy variables which distinguish whether a local authority is located within the Government Office Region of Wales or Scotland.

Focusing on the integrated model (Model 4), the results of the analysis indicate that all four variable sets display some degree of explanatory power over mean gCO_2/km. The results of the spatial autocorrelation analysis discussed in Section 3.2 indicates that a moderate degree of spatial

[1] Rented socially refers to tenancies which are provided in social housing supplied by their the local government or a housing association

dependence exists between the observed values of mean gCO_2/km in a particular area and those observed in neighbouring areas. To test whether this spatial dependence has been corrected through the inclusion of the independent variables specified in the integrated model, two spatial diagnostic tests, referred to as the Robust Lagrange Multipliers (LM) have been conducted. The results of these tests are reported in the lower section of Table 6 and indicate that the model could be improved through the inclusion of spatial interaction effects.

Table 6: Ordinary least squares regression models using the mean grams of carbon dioxide emitted per kilometre from a local authority's car fleet as the dependent variable

Variable	Model 1		Model 2		Model 3		Model 4	
	Beta	Std. Err.	Beta	Std. Err.	Beta	Std. Err.	Beta	Std. Err.
(Constant)	139.43	2.2053	160.14	2.25	127.16	2.12	116.30	2.28
Socioeconomic Characteristics								
No Qualification (%)	-3.736	5.6421					-5.57	3.09
Self Employed (%)	**83.733****	**9.2018**					**20.14****	**6.89**
Mean Income (GBP)	**0.0002****	**0.00002**					**0.0002****	**0.00001**
Household Features								
3 Plus Cars (%)			2.79	13.31			2.89	8.18
Rent Social (%)			1.01	6.23			**7.57****	**2.42**
Terraced (%)			**-22.70****	**3.68**			-0.61	1.51
Car Fleet Attributes								
Mean Cars Age (years)					**3.21****	**0.25**	**3.44****	**0.21**
Company Cars [A]					**-0.017****	**0.001**	**-0.009****	**0.001**
Hybrid Electric Vehicles [A]					**0.52****	**0.033**	**0.12****	**0.027**
Government Office Region								
Wales							**-1.63****	**0.479**
Scotland							**1.30***	**0.563**
Spatial Diagnostics								
Robust LM (lag)	**46.50****		1.15		**47.76****		**31.54****	
Robust LM (error)	0.1591		**13.32****		1.59		**48.38****	
Model Fitting								
R^2	.571		.103		.656		.884	
AIC	2100.54		2376.34		2017.22		1618.2	

*: p-value < 0.05; **: p-value < 0.01; [A]: per 1000 cars

4.4.2 Spatial Regression Models

To consider the effect of introducing spatial interaction effects into the analysis, three spatial regression models have been calculated with the results displayed in Table 7. The first of these models is referred to as the Spatial Lag Model (SLM) and introduces a spatially lagged version of the mean gCO_2/km (W* mean gCO_2/km) as a dependent variable in the model. This allows the model to consider if spatial dependence in mean gCO_2/km remains having accounted for the effect of the

specified independent variables. The second of these models is referred to as the Spatial Error Model (SEM) and introduces a spatially lagged version of the benchmark OLS model's (Model 4) residual (W*error) as a dependent variable in the model. This allows the model to consider if spatial autocorrelation is present concerning the variables which effect mean gCO_2/km but have been omitted from the model. The third of these models is referred to as the SAC model and includes both a spatially lagged version of the mean gCO_2/km and a spatially lagged version of the benchmark OLS model's residual as dependent variables.

Table 7: Spatial regression models using the mean grams of carbon dioxide emitted per kilometre from a local authority's car fleet as the dependent variable

Variable	SLM		SEM		SAC	
	Beta	Std. Err.	Beta	Std. Err.	Beta	Std. Err.
(Constant)	62.21	0.032	119.86	2.053	91.59	7.21
Socioeconomic Characteristics						
No Qualification (%)	2.62	2.55	-0.93	2.75	-0.46	2.78
Self Employed (%)	**15.30****	**5.65**	**25.219****	**6.025**	**26.07****	**6.01**
Mean Income (GBP)	**0.0002****	**0.0001**	**0.0002****	**0.0001**	**0.0002****	**0.0001**
Household Features						
3 Plus Cars (%)	3.53	4.51	0.14	5.42	-0.65	7.92
Rent Social (%)	3.19	1.94	0.49	1.91	1.43	1.99
Terraced (%)	-1.23	1.22	-1.39	1.37	-1.66	1.37
Car Fleet Attributes						
Mean Cars Age (years)	**2.21****	**0.20**	**3.32****	**0.22**	**3.22****	**0.22**
Company Cars [A]	**-0.01****	**0.001**	**-0.006****	**0.001**	**-0.007****	**0.001**
Hybrid Electric Vehicles [A]	0.04	0.02	-0.025	0.021	-0.010	0.022
Government Office Region						
Wales	**-0.86***	**0.39**	-0.70	1.19	-0.91	0.90
Scotland	**1.28****	**0.44**	1.007	1.38	1.77	0.97
Spatial Interaction Effects						
W* mean gCO_2/km	**0.420***	**0.032**			**0.18****	**0.045**
W*error			**0.82****	**0.029**	**0.69****	**0.042**
Model Fitting						
R^2	.924		.944		.941	
AIC	1485.45		1429.13		1427.62	

*: p-value < 0.05; **: p-value < 0.01; [A]: per 1000 cars

Inspecting the model fitting statistics, the specification of the spatial regression analysis appear to offer a marked improvement over the benchmark integrated OLS model (Model 4). This finding implies that the introduction of spatial interaction effects as independent variables in the model improves the model's ability to account for variance in the mean gCO_2/km. Of the spatial regression models specified, the results suggest that the SAC model offers the best fit.

A number of the independent variables included in the SAC model across the socioeconomic characteristics, car fleet attributes and spatial interaction effects are associated with significant model coefficients. In terms of the socioeconomic characteristics, the results indicate that the proportion of the populace who are classified as self employed (Beta: 26.07) and mean household income levels (Beta: 0.0001) positively affect mean gCO_2/km. For the car fleet attributes, the variable measuring the mean age of the car fleet (Beta: 3.22) appears to positively affect mean gCO_2/km whilst the variable noting the number of company cars registered (Beta: -0.007) displays a negative effect. Both of the spatial interaction effects included in the model are associated with significant coefficients (Beta: 0.18; 0.69), implying that spatial autocorrelation in both the dependent variable and amongst the variables omitted from the analysis remain an issue. This result suggests that the model could be further improved through the inclusion of additional variables which may have an influence over mean gCO_2/km.

5 Discussion and Conclusions

The analysis reported in this paper provides an evaluation of the spatial variation in mean gCO_2/km for the car fleets registered across the local authorities of Scotland and the rest of the UK. Considering how Scotland performs on this metric in comparison with the other Government Office Regions of the UK and sub-regions of England (reported in Table 2), it is apparent that Scotland's car fleet has relatively low levels of mean gCO_2/km, implying that Scotland is somewhat more advanced in the decarbonisation of the car fleet. Exploring the degree of variation which exists across the local authorities of Scotland (reported in Figure 1), the analysis illustrates that a significant range of mean gCO_2/km is present, with the local authorities located in Scotland's central belt tending to contain cars with relatively low emission levels whereas rural local authorities appear more inclined to contain comparatively high emission cars. Extending the scope of the analysis to include the local authorities located in the rest of the UK, the application of spatial autocorrelation analysis (reported in Figure 2 right image) indicates that the area of Southern Scotland and North-East England contains a cluster of local authorities which tend to display relatively low mean gCO_2/km for their car fleets. These findings imply that the variation observed in mean gCO_2/km is not being generated by a random process, but that some degree of spatial organisation exists.

Illustrating the spatial variation which is present and considering the degree to which this variation exhibits signs of spatial organisation represent the first steps in understanding if local conditions appear to be affecting the mean gCO_2/km of local authority car fleets. To offer additional insights on this issue, the analysis reported in this paper assesses the degree to which mean gCO_2/km is related to other characteristics of the area (reported in Section 3.3). The results of this analysis indicate that a number of variables covering the socioeconomic characteristics of the local populace, the features of the households located in a local authority as well as some of the ancillary attributes of the car fleet registered in a local authority are moderately to strongly correlated with mean gCO_2/km. Progressing the analysis, a series of regression models have been specified (reported in Section 3.4) in an attempt to explain the observed variation in mean gCO_2/km. The results of these analyses imply that a relatively simple model, which includes the independent variables covering the proportion of the local populace classified as self employed, the mean personal income of the local populace, the mean age of the cars registered in the local authority, the number of cars registered as company cars as well as a number of spatial interaction effects, can account for a high proportion of the observed variation in mean gCO_2/km.

The findings presented in this paper might be of use to policy makers in a number of different areas. Firstly, understanding the degree to which the car fleet registered in Scotland differs from the other government office regions of the UK in terms of its mean gCO_2/km could be of use in evaluating progress towards Scotland's climate change targets. Secondly, developing an appreciation for the degree of variability which exists within Scotland concerning mean gCO_2/km can assist in identifying regions which display relatively high levels of mean gCO_2/km. This identification would likely form the initial stage in the development of local policies aimed at reducing the mean gCO_2/km. Thirdly,

considering the degree to which the mean gCO_2/km of cars registered across the local authorities of the UK are connected with other features of these areas can be useful in understanding what might be motivating the degree of spatial variation which is observed. For instance, with mean gCO_2/km been strongly related to the mean age of cars registered, one interpretation of this finding is that developing strategies intended to reduce the mean age of local car fleet may lead to improvements in mean gCO_2/km. Moreover, the strong positive relationship observed between the proportion of the populace classified as self employed and mean gCO_2/km may indicate the presence of conditions which encourage self employed individuals to purchase relatively carbon intensive cars. Additional research could be of use in determining if this observation can be corroborated at a disaggregate level and what these conditions are.

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8 Appendix

Table 3: Spearman's correlation analysis between average gCO_2/km of the car fleets and the socio-economic characteristics of the local authorities of the United Kingdom

Variable	A	B	C	D	E	F	G	H	I	J	K	L	M	N
gCO_2/km (A)	-													
Mean Age (B)	.040	-												
No Qualification (C)	-.566**	.157**	-											
Level 1 Qual (D)	-.367**	.080	.607**	-										
Level 2 Qual (E)	-.016	.393**	.154**	.465**	-									
Level 3 Qual (F)	-.188**	-.028	-.196**	-.289**	.165**	-								
Level 4 Qual (G)	.502**	-.059	-.912**	-.691**	-.363**	.063	-							
Employed (H)	.023	-.119*	-.296**	.243**	.253**	.060	.116*	-						
Self Employed (I)	.702**	.418**	-.587**	-.416**	.111*	-.131*	.605**	-.021	-					
Unemployed (J)	-.395**	-.527**	.589**	.329**	-.212**	-.245**	-.549**	-.302**	-.685**	-				
Retired (K)	-.183**	.925**	.408**	.208**	.410**	-.030	-.301**	-.213**	.166**	-.289**	-			
Home/Family (L)	.277**	-.535**	.060	.066	-.047	-.251**	-.159**	-.113*	-.078	.446**	-.491**	-		
Disabled (M)	-.581**	-.155**	.765**	.309**	-.086	-.101	-.660**	-.491**	-.670**	.801**	.117*	.114*	-	
Mean Income (N)	.603**	-.032	-.819**	-.391**	-.119*	-.042	.812**	.357**	.598**	-.556**	-.282**	.006	-.776**	-

Table 4: Spearman's correlation analysis between average gCO_2/km of the car fleets and the household features of the local authorities of the United Kingdom

Variable	A	B	C	D	E	F	G	H	I	J	K	L	M	N
gCO_2/km (A)	-													
No Car (B)	-.313**	-												
One Car (C)	-.192**	.275**	-											
Two Car (D)	.244**	-.978**	-.383**	-										
Three Car+ (E)	.340**	-.968**	-.348**	.954**	-									
Own Outright (F)	.137**	-.699**	.048	.631**	.702**	-								
Own Mortgage (G)	-.070	-.438**	-.213**	.531**	.392**	.045	-							
Rent Social (H)	-.311**	.703**	-.043	-.645**	-.652**	-.760**	-.305**	-						
Rent Private (I)	.209**	.426**	.260**	-.487**	-.438**	-.371**	-.541**	.067	-					
Detached (J)	.166**	-.846**	-.161**	.814**	.838**	.799**	.190**	-.645**	-.410**	-				
Semi-Detached (K)	-.352**	-.109*	-.019	.173**	.102*	.131*	.390**	-.077	-.332**	.071	-			
Terraced (L)	-.348**	.464**	.279**	-.437**	-.454**	-.459**	-.034	.421**	.217**	-.595**	-.017	-	-	
Flats (M)	.163**	.549**	.072	-.542**	-.546**	-.656**	-.165**	.471**	.327**	-.663**	-.433**	.137**		-
Pop. Density (N)	.044	.655**	.055	-.620**	-.667**	-.704**	-.036	.420**	.400**	-.801**	-.030	.313**	.643**	-

Table 5: Spearman's correlation analysis between average gCO_2/km of the car fleets and ancillary car fleet attributes

Variable	A	B	C	D	E
gCO_2/km (A)	-				
Mean Car Age (B)	.736**	-			
Company Cars (C) *	-.546**	-.524**	-		
Electric Vehicles (D) *	.128*	-.116*	.183**	-	
Hybrid Vehicles (E) *	.402**	.047	.070	.465**	-

*: per 1000 cars