Creating and evidencing a Sustainable Commuting Index for London, United Kingdom

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Abstract

Objective: The purpose of this research is two-fold: firstly, to understand daily journey-to-work commuting behaviour in London and link this to environmental and health impact, and secondly to devise a replicable framework through which areas can be rated based on low carbon and active travel with this information then used support policy implementation for more sustainable commuting.

Method: A composite index is proposed combining data on commuting patterns and carbon footprints of respective transport means to rank each district based on current performance and related environmental and health impacts. The research is evidenced on the city of London, United Kingdom, but is designed such that it could be readily applied elsewhere.

Results: The outcome implies a strong distance decay effect whereby active travel is most pronounced in central districts and less so on the city fringes, Westminster and City of London score most favourably with Havering performing worst. Similarly, the central districts also have a lower carbon footprint.

Discussion: The product of this research is not only a replicable and transferable framework to measure sustainable commuting given its high political importance but also a means to support decision-making and the implementation of policies to improve opportunities for low carbon and active travel and the directly related impacts on human health and the environment.

Keywords: Active travel, Sustainable commuting, Carbon footprints, Spatial analysis, Urban mobility.

Introduction and rationale

Population growth and urbanisation are having a big impact on cities and the global ecosystem. People move to cities in search of jobs and prosperity, while expanding cities and rising house prices result in ever-increasing commuting times and distances (Morley, 2016). British cities have some of the longest commutes in Europe, with nearly a third of surveyed individuals in and around London reporting commuting times equal to or in excess of two hours (ibid). This makes London a prime location on which to base this research into commuting behaviour and active travel.

The main aim of this paper is to analyse commuting behaviour and quantify its environmental and health impacts in London. The paper presents a spatial composite index of sustainable commuting across London's 33 local authority districts (boroughs) with each scored and ranked based on commuting emissions and participation in 'active travel'. This research defines 'active travel' as the process of walking or cycling for transportation purposes, typically to/from employment (Panter *et al.*, 2008). A hierarchy is created on which more sustainable and healthy commuting policy decisions can be made. The methodology is discussed in full, including the formulation of the composite index, its results, implications and limitations. The index comprises solely freely available data thus ensuring ease of replication for other cities in both the United Kingdom (UK) and elsewhere.

The Impacts and Carbon Footprint of Commuting

As reported in the most recent national census of population in 2011, England and Wales has a working population of 26.5 million people employed across a range of sectors. Of these people, 81.2% undertake a regular commute to a fixed onshore location with the remaining 18.8% either working from home, outside of the UK, offshore or having no fixed place of work. Those completing a regular commute travel an average distance of 15.0 km, an increase of 1.6 km from the previous census in 2001. London commuters in managerial, professional and skilled roles typically travel the furthest with an average distance of more than 20.0 km (ONS, 2014).

Whilst some people have the opportunity to commute on foot or by bicycle, the majority must use some combination of modes of inactive transport, such as private car, that result in either direct (as in the combustion of vehicle fuels) or indirect (from producing the electricity used to power these vehicles) emissions. Particulate matter from tailpipe emissions damage air quality and are harmful to human health, having been linked to cancer, dementia, asthma and heart disease (RCP, 2016). In the UK, these conditions incur annual health costs in excess of £20 billion (GBP) and account for 40,000 deaths each year (NHS Choices, 2014). Carbon commuting also supports an unhealthy sedentary lifestyle, leading to decreased physical activity and an increased potential of obesity (ibid).

In addition to economic and health problems, emissions of greenhouse gases contribute to environmental degradation caused by global warming and climate change with varying global warming potentials measurable by the analysis of carbon dioxide equivalents (CO_2e) (Carbon Trust, 2012). Like many countries, the UK Government (2016) provides a comprehensive annual report of greenhouse gas conversion factors that can be used to determine the carbon footprint of activities, products or organisations. By using data on commuting distances and means of transportation per geographical area as obtainable from the national census, it is possible to estimate the carbon footprint of commuting and suggest policies to reduce this further.

Carbon Footprints and Active Travel

While carbon commuters are directly contributing to the production of emissions, it is those who walk and in particular those people who cycle that suffer most from these activities, principally due to breathing hazardous particulate matter from tailpipe emissions on or beside major roads. Despite the apparent negative health implications, this form of active travel still boasts multiple health and environmental benefits, which in most cases have been reported to outweigh the costs (Boseley, 2016). An evidence brief by the UK Clinical Research Collaboration's Centre for Diet and Activity Research (CEDAR), one of five Centres of Excellence in Public Health in the UK that studies the factors that influence dietary and physical activity related behaviours, reports that people are currently failing to meet recommended levels of physical activity. However, it is stated that commuting by active travel (on foot and/or by bicycle) would be one way to address this (CEDAR, 2013). This recommendation is supported through a physical health study by Goodman *et al.* (2012) who found that people who increased participation in recreational sports in a bid to increase physical activity often, as a consequence, increased their carbon footprint by travelling to the activities. Active travel therefore has the potential to reduce obesity, strokes and heart disease resulting in health-related economic savings through averted expenditures whilst at the same time reducing traffic incidents, congestion and vehicle emissions.

Methodology: Creating the Sustainable Commuting Index

The primary focus of this research is to match freely available data on commuting patterns and behaviour with associated environmental impacts, specifically in terms of carbon emissions and active travel, through the creation of a composite index. The index developed in this research is evidenced on the city of London in the UK, however, it is designed to be transferable and hence could be applied more widely subject to comparable data availability.

Composite indices have seen widespread adoption across a variety of applications, the most noteworthy being the Index of Multiple of Deprivation (IMD). The IMD is the official statistical measure of relative deprivation for small areas (neighbourhoods) in England. It scores and ranks small areas from 1 (most deprived) to 32,844 (least deprived) based on a summation of seven weighted domains (income, employment, education/skills, health/disability, crime, barriers to housing services, and living environment). The IMD has been released on regular basis since 2007 and is widely adopted by the public sector for area targeting, the allocation of scarce resources and comparisons between small areas over space and time (ONS, 2015). Such indices are typically employed when attempting to analyse phenomena that are difficult to quantify and may encompass multiple dimensions (Lucy and Burns, 2017). Previous examples of spatial composite indices (also referred to as synthetic indices) include environmental health (Saib *et al*, 2015), crime (Chainey, 2008), wellbeing (Bradshaw *et al.*, 2009) and loneliness in ageing populations (Lucy and Burns, 2017).

Whilst composite indices have been readily applied in a range of domains, previous quantitative work in the field of commuting with a primary focus on links to environmental and health impacts is more limited. Travel to Work Areas (TTWA) represent a logical starting point with such areas derived from 2011 census commuting data and released in August 2015. TTWAs must meet the criteria of having at least 75% of its economically active population living and working in the area (ONS, 2016). The UK is comprised of 288 TTWs (2011) and whilst such a zoning system is useful for public transport planning, little has explored with regards to environmental, health or carbon footprints.

The design of this composite index, although preceded by an analysis of carbon footprints by London district, seeks to quantify environmental impact. The methodological work can be separated into several phases of development as discussed in the following sections.

Sourcing Data

London was chosen as the city on which to evidence the index due to its large network of commuters and increasing travel distances and times. The spatial scale of analysis chosen was that of local authority district (equivalent to English local authorities) given that specific sustainable transport decisions and projects are typically taken at this level, rather than at the broader city or smaller area level. London is comprised of 33 local authority districts (boroughs) with an average population in 2011 of 247,695 and median population of 254,096. Croydon is the largest district by population (363,378) and City of London the smallest (7,375) (London Data Store, 2011).

Commuting data incorporating predominant method of travel to work and distance between home and work location were required. These data were obtained from the UK Data Service's InFuse facility, using the most recent census data from 2011. This dataset combined information on the economically active population (working or actively looking for work) aged 16-74, the Euclidian (straight line) distance (in kilometres) between residential and workplace location (split into eight categories ranging from <2 km to >60 km), and method of travel to work (incorporating ten modes such as on foot, bicycle, car driver or passenger etc). Although the dataset also included those not in employment as well as those who work mainly from home, these were excluded as the purpose of the index is to reflect the behaviour of the commuting population, only. Boundary data for the 33 local authority districts of London were obtained from the same freely available online source thus enabling ease of replication.

Determining the Index Structure

One goal of this research is to visualise the carbon footprint of commuting by London district/borough. However, as carbon commuting includes no indication of active travel performance (emissions being zero), it was decided that the two could be combined to create a 'sustainable commuting' index. This would score each local authority district based on (1) average carbon footprint per capita and (2) the proportion of commuters that use active travel, thus combining both health and environmental benefits.

Data Processing

Each category of distance travelled was treated as a separate section (e.g. number of people whose commute is less than 2 km who walk, who cycle, who drive, etc; number of people whose commute is between 2km and 5km who walk, who cycle, who drive, etc). A subset of the data can be seen in Table 1; note that this continues up to a commuting distance of >60 km.

Table 1: Sample of commuting data (units: people), *Source: UK Data Service (2011).*

Distance travelled	**Less than 2 km (Average 1 km)**								**2-5 km (Average 3.5 km)**			**…**
Means of travel / District	**Total**	**Train / Metro**	**Bus**	**Driving**	**Passenger**	**Bicycle**	**Foot**	**Other**	**Total**	**Train /**	**Bus**	**…**
Barking and Dagenham	8130	670	978	2792	267	252	3092	79	13133	1207	3776	…
Barnet	1723	955	2038	6532	468	285	6816	137	20907	1757	5367	…
Bexley	1093	476	842	4774	432	262	4053	99	17374	540	3224	…
…	…	…	…	…	…	…	…	…	…	…	…	…

Defining scope

In order to calculate the carbon footprint of each London district, some of the data categories had to be manipulated. Zachariadis *et al.* (2001) emphasise how the age of transport vehicles can have a significant bearing on the level and type of air emissions generated. However, as no specific data on the specifications or age of cars or other vehicles were available on a per local authority district basis, precise measurements could not be made. Instead, these were made based on some core assumptions. The census data grouped transport via train, underground, metro, light rail and tram into one category and buses, minibuses and coaches into another. Furthermore, walkers and cyclists as well as drivers and passengers of cars or vans were separated, but all other means of transport were grouped into one category, which includes motorcycles and scooters but also non-traditional forms of transport ranging from skateboards and Segway's to private planes and horses. No emissions estimations were realistic for this final category. Additionally, as commuting distances were given in ranges as opposed to raw figures (as noted in Table 1), the midpoint of the range width was taken – in the case of a range of 2-5 km, a midpoint of 3.5 km was chosen. When dealing with the final category (>60km), an arbitrary figure of 75 km was chosen, although the data allows for theoretical commuting distances of up to 1200 km.

Due to a lack of specificity in the data for modes of transport on matters such as age, type, condition, wear etc., rather than making use of the official conversion factors, the average emissions per passenger kilometre were taken from a detailed report compiled for the Sustainable Cities Collective by Thorpe (2016) as shown in Figure 1. Average emissions of small cars (42 gCO_2/p/km) and suburban utility vehicles (SUV) (55 gCO_2/p/km) were taken to represent all cars, whilst the emissions for trains (14 gCO_2/p/km) were also taken to categorise the underground. Drivers and passengers were split into *passengers of full cars* (42 gCO_2/p/km) and *lone drivers* (4*42 gCO_2/p/km), to simplify the calculation of aggregate emissions. Lone drivers were calculated by subtracting [passengers/3] from drivers, thus making cars of 1 or 4 based on occupancy.

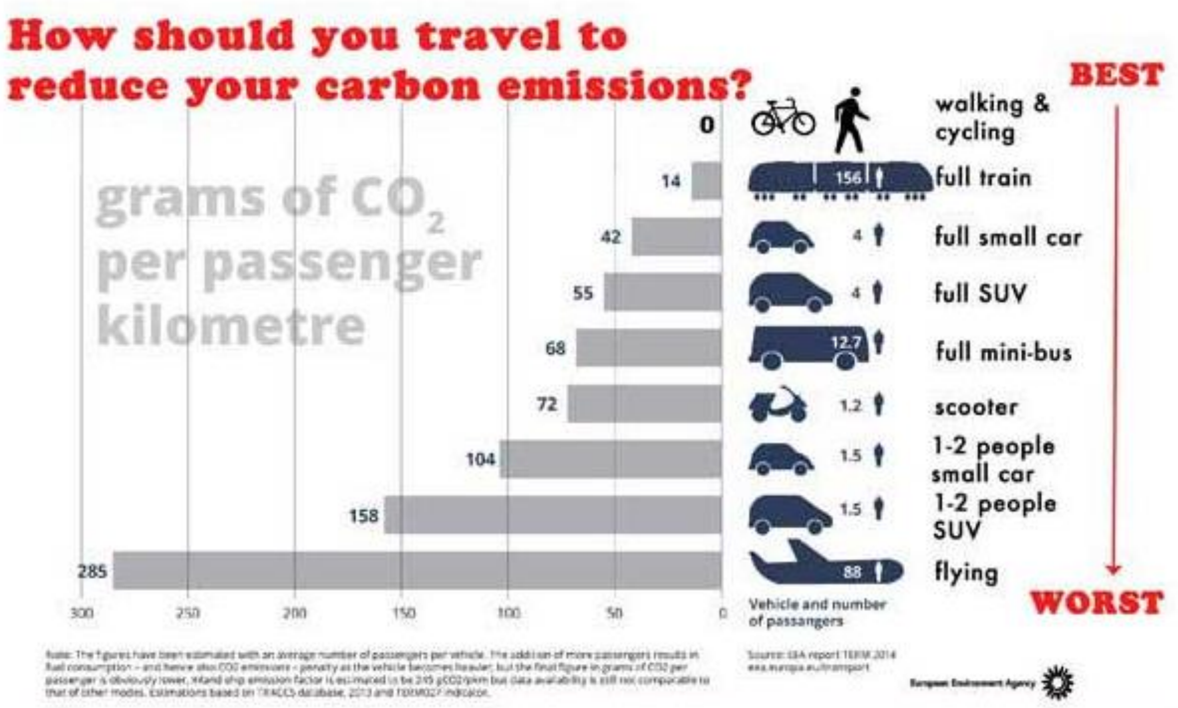

Figure 1: Grams of CO_2e per passenger kilometre. *Source: Thorpe (2016).*

Calculating the Carbon Footprint of Travel

Using the core assumptions specified, the daily carbon emissions for each transport mode were calculated, given the distance travelled. This was completed using the following formula, where:

$people$ = The total number of people commuting using a given mode of transport

km = The total distance travelled for a one-way commute

gCO_2e = carbon equivalent emissions in grams per passenger kilometre

$$Daily\ carbon\ emissions\ (kgCO_2e) = \frac{(people) * (km) * 2 * (gCO_2e/person/km)}{1000}$$

This calculation considers the amount of people using a mode of transport, multiplied by two times their commuting distance (to represent a round trip), multiplied by the carbon equivalent emissions in grams of that mode of transport per passenger kilometre, divided by 1000 to convert into kilograms of CO_2e. As the emissions of cycling and walking are zero, and given that determining a figure for 'other' modes of transport was unrealistic, these will show a result of zero. A sample of the table with calculated daily carbon emissions is presented in Table 2.

Table 2: Sample of daily carbon emissions per mode of travel (units: kg CO_2e)

Avg km	1 km							3.5 km		…
gCO_2e	14	68	194	48.5	0	0	N/A	14	68	…
Mode/ District	Train Metro	Bus	Lone Drivers	Passengers (full	Bicycle	Foot	Other	Train Metro	Bus	…
Barking and Dagenham	18.76	133.01	1048.76	25.90	0	0	0	118.29	1797.38	…
Barnet	26.74	277.17	2473.89	45.40	0	0	0	172.19	2554.69	…
Bexley	13.328	114.51	1796.44	41.90	0	0	0	52.92	1534.62	…
Brent	33.54	359.18	1604.64	32.69	0	0	0	442.57	4346.36	…
…	…	…	…	…	…	…	…	…	…	…

The total figures combining each category of commuting distance with the associated emissions were then compiled into one table showing the carbon footprint of each district according to the mode of travel. In all cases, the units were converted from $kgCO_2e$ to tCO_2e by dividing by 1000. The carbon footprints of the first and last five London local authority districts (sorted alphabetically) are shown in Table 3.

Table 3: Daily carbon footprint of commuting by mode of travel (tCO_2e)

District	Train / Metro	Bus	Lone Drivers	Passengers (full car)	Carbon Footprint
Barking and Dagenham	9.7	8.8	99.2	1.8	119.4

Barnet	17.8	17.9	207.9	2.6	246.2
Bexley	13.1	10.3	176.4	2.5	202.3
Brent	14.2	22.1	120.1	1.8	158.2
Bromley	21.7	11.1	215.0	2.3	250.1
...	...	...	...	...	...
Sutton	8.7	7.9	141.9	1.7	160.1
Tower Hamlets	12.2	10.0	48.7	1.3	72.2
Waltham Forest	15.5	12.0	107.1	1.5	136.2
Wandsworth	23.9	18.4	96.6	1.0	140.0
Westminster	9.4	9.8	41.9	0.6	61.6

Calculating the Share of Active Travellers

Following similar methods of aggregation across categories, the quantities of cyclist and on foot commuters were then combined. These were then labelled as those who use 'active travel' to commute to employment. The information presented in Table 3, along with these aggregated numbers of active travellers and all commuters, were then joined to digital map boundaries to produce standardised choropleth maps of the average daily carbon footprint per capita by district, and the share of active travellers as a percentage of all commuters. These are shown in Figures 2 and 4 respectively and discussed as part of this papers results in subsequent sections.

The Sustainable Commuting Index

The final stage of this research was to devise a composite index which scores and ranks each London district based on sustainable travel performance. The two inputs for this index include the carbon footprint per capita (Table 3; Figure 2) and percentage of active travellers per district (Figure 4).

To create this bi-variate index, each dimension was first normalised onto a scale from 0 to 1 to remove any discrepancies between variations in original size and scale. Each Variable, x_{raw}, was normalised, x_{norm}, using the following equation:

$$x_{norm} = (x_{raw} - \min_i)/(\max_i - \min_i)$$

Where:

min_i = minimum value for variable x_i

max_i = maximum value for variable x_i

i = variable number from 1 to n

Both dimensions were then assessed for polarity/directionality. This is necessary as variables may differ in directionality and thus a high value in one variable may contradict a high value in another variable (E.g. Variable 1: High value = favourable outcome; Variable 2: High value = unfavourable outcome). A lower overall carbon footprint per capita is more desirable, whereas a higher share of existing active travellers is more desirable. The lowest average carbon footprint per capita was therefore given a score of 1, while for active travel this was given to the highest percentage of active travellers. A value of zero was attributed to the reverse and all other values positioned proportionally in between, thus ensuring uniform directionality.

As no evidence was found to support uneven weighting between the two elements, a process commonly considered when creating a composite index (Lucy and Burns, 2017), thus an equal 50:50 weighting was deemed suitable. Table 4 shows 11 of the 32 London districts and their associated normalised carbon footprint and active travel values, along with the resulting Sustainable Commuting Index score, consisting of an average of the two intermediary grades. From these results, it can be seen that of all the London districts Hackney has the highest share of active travellers whereas Islington has the lowest daily carbon footprint per capita. Nevertheless, it is the areas of Westminster and City of London, the most central of all districts, which achieve the highest overall index score.

Table 4: Five best and worst districts in terms of the Sustainable Commuting Index. Full results included in Appendix I.

Rank	District	Ave. Carbon Footprint per capita (kgCO$_2$e)	Norm. Carbon Footprint per capita	Active Travel (% Total Commuters)	Norm. Active Travel	Sustainable Commuting Index Score
1	**City of London**	0.697	0.982	28.6%	0.981	**0.981**
1	**Westminster**	0.697	0.982	28.6%	0.981	**0.981**
2	**Islington**	0.663	1.000	27.9%	0.946	**0.973**
3	**Hackney**	0.779	0.938	29.0%	1.000	**0.969**
4	**Tower Hamlets**	0.712	0.974	26.7%	0.893	**0.933**
5	**Camden**	0.710	0.975	25.4%	0.834	**0.904**
…	**…**	…	…	…	…	**…**
28	**Bromley**	2.057	0.256	8.6%	0.053	**0.154**
29	**Harrow**	2.131	0.216	8.1%	0.031	**0.123**
30	**Bexley**	2.252	0.151	7.5%	0.000	**0.076**
31	**Hillingdon**	2.536	0.000	9.2%	0.080	**0.040**
32	**Havering**	2.472	0.034	8.0%	0.025	**0.030**

Results & Analysis

When spatially analysing the average daily carbon footprint per capita of London's 33 local authority districts, there appears to be a clear distance decay effect whereby the carbon footprint increases as distance from the city centre increases. Parking fees, charges and high volumes of traffic in the city discourage people from having cars, making alternative modes of travel more convenient and cost-efficient.

Although there are generally more commuters in the central districts, emissions are lower as distances are more conducive to active travel. This is shown clearly in Figure 2 with the carbon footprint mapped in quintiles. This pattern is reinforced by Figure 3 which shows the predominant mode of transport within each district in addition to the carbon footprint. Districts closer to the city centre are dominated by use of trains and the underground (public transport), while districts further away are principally categorised by driving (private transport). Buses are more desirable than other transport means in Hackney only.

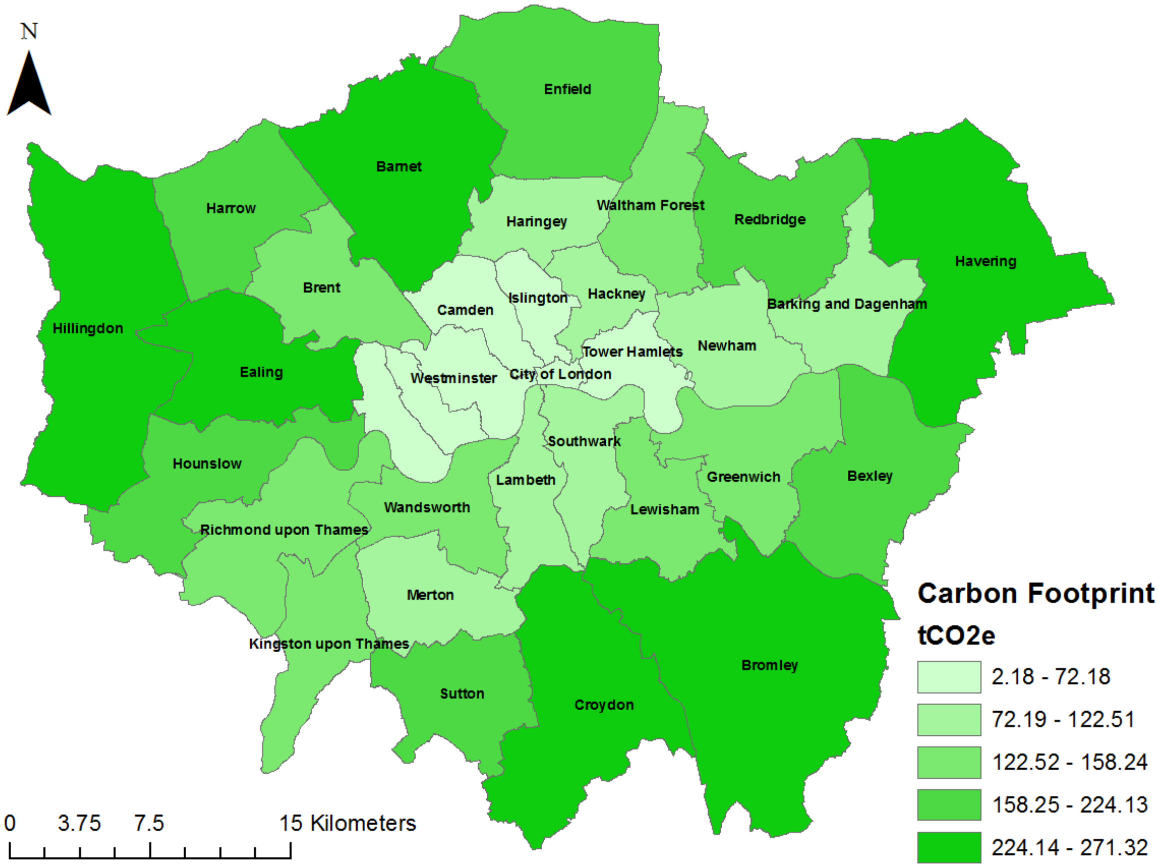

Figure 2: Daily commuting carbon footprint (intervals defined by quintiles) (*Data Source: ONS, 2011; GLA, 2016*)

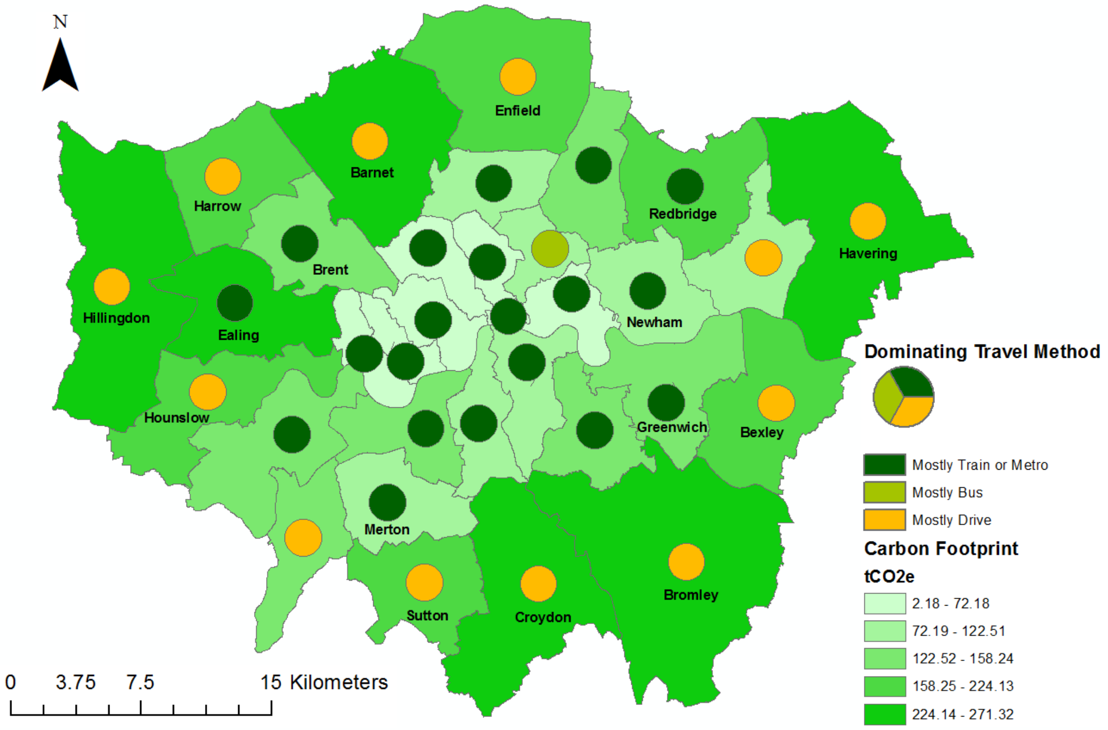

Figure 3: Dominating Travel Method by district (intervals defined by quintiles) (*Data Source: ONS, 2011; GLA, 2016*)

When mapping the share of active travel as a percentage of all commuting in London (Figure 4), it is once again evident how important city density is in terms of low carbon commuting. Between circa 7% and 30% of commuters use active travel across each of London's 33 local authority districts. Inevitably, the closer an individual lives to work then the more likely they are to walk or cycle. This is not to say that there are no workplaces outside of the city centre, but it should also be taken into account that the centre is likely to have not only a higher proportion of the city's employment but also a larger network of cycle lanes and pedestrian walkways when compared to suburban and peripheral areas.

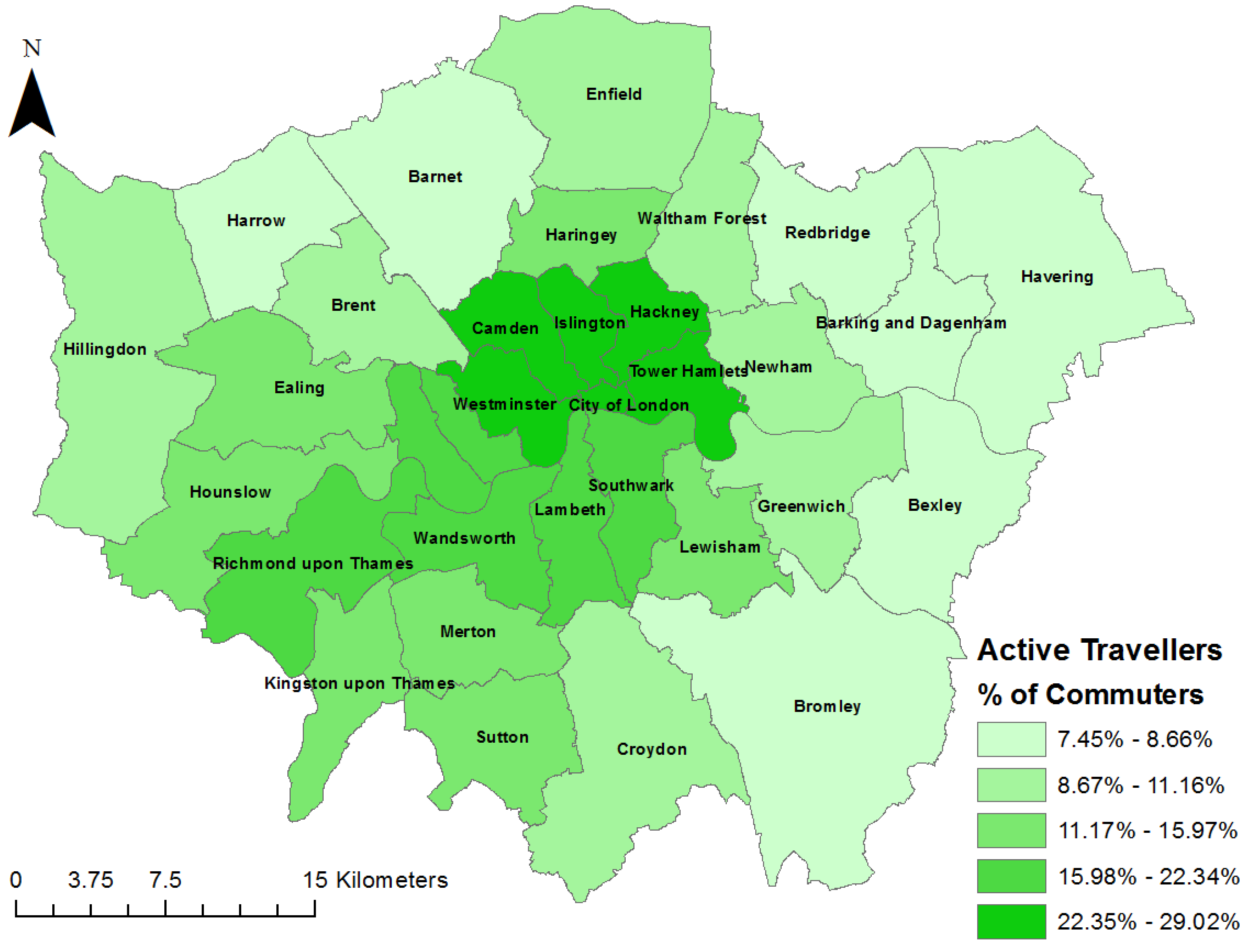

Figure 4: Share of active travellers as % of all commuters (intervals defined by quintiles) (*Data Source: ONS, 2011; GLA, 2016*).

Finally, Figure 5 presents the index of sustainable commuting. Westminster and the City of London share the best score of 98.1% in terms of sustainable commuting. Both of these districts are very central, and the largest segment of population commutes from within the 2-5km category. Other districts within the top 5 ranked areas include Islington with the lowest carbon footprint per capita, Hackney with the largest share of cyclists and walkers, and Tower Hamlets, which also benefits from short commutes.

The districts that fall into the bottom five ranked areas are those furthest away from the centre of London with the longest commutes. These are districts where driving is the dominant means of transport and associated emissions are very high. Among these districts is Havering, where over 40% of the commuting population travels between 10 and 30 km to employment on a daily basis.

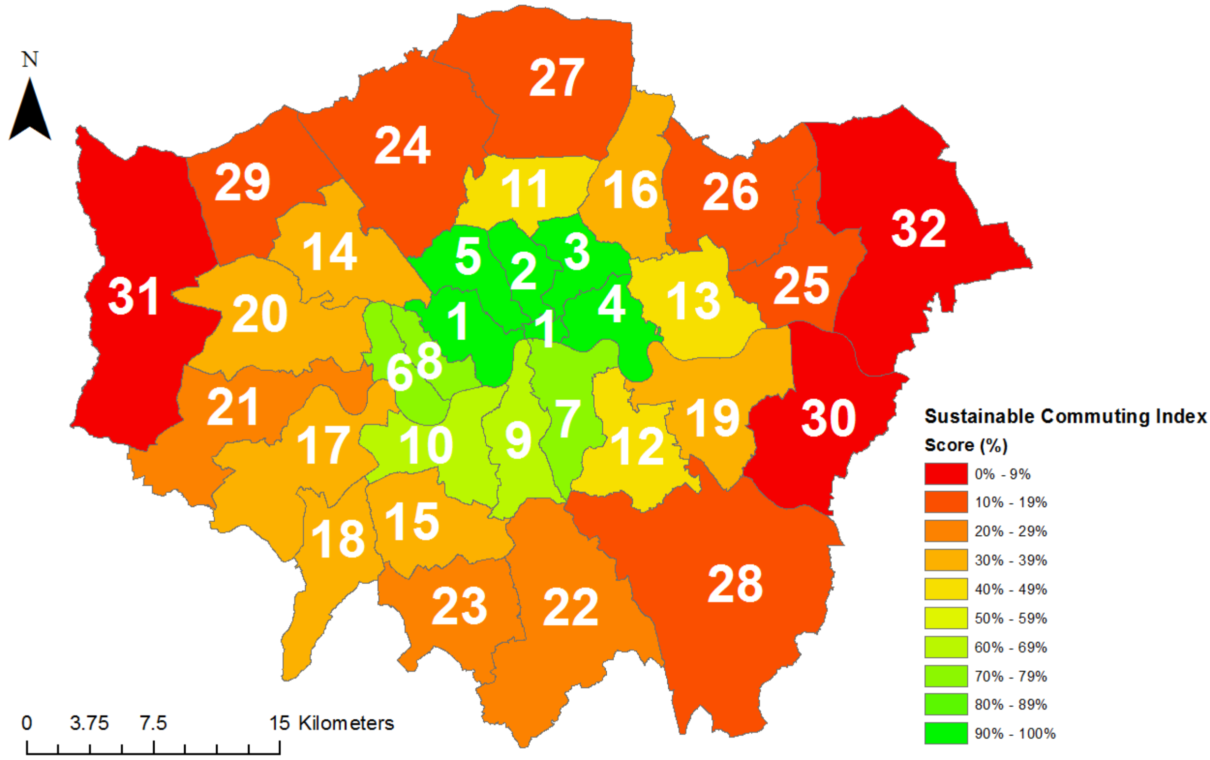

Figure 5: Sustainable Commuting Index (*Data Source: ONS, 2011; GLA, 2016*) (intervals defined by equal ranges) showing overall score and rank across all 33 London local authority districts (1 = best, 32 = worst).

Summary and policy implications

The data gathered and presented in this paper culminated in the creation of a sustainable commuting index. Statistical indices such as this have the potential to be used by decision makers to identify districts where emissions per capita are higher than desired and active travel rates lower than expected, and to support the implementation and prioritisation of improvement policies. These policies could involve promoting and providing more sustainable means of transportation such as electric trams and buses, platforms for car sharing, city bikes or cycling infrastructure. Strategies of this kind already exist in many cities and could be used to take forward London's 'Better Environment, Better Health' initiative (see e.g. GLA, 2013), a bespoke guide produced for each of London's 33 local authority districts describing the impact of seven environmental determinants on health outcomes, one of which is active travel and transport, and suggesting how these can be measured (London Climate Change Partnership, 2013).

Limitations

The creation of any composite index requires many decisions and hence has a degree of subjectivity. One core consideration in this paper was the choice of spatial unit ultimately leading to an analysis at the London local authority district level. Such a scale undoubtedly enables ease of comparison across the breadth of London's 33 districts, however, there is an appreciation that individual authorities may wish to repeat the process on a smaller spatial scale, particularly if adopted at the micro level within districts to support the 'Better Environment, Better Health' initiative. Given the open nature of this research, both of in terms of methods and data availability, replication is possible at any spatial resolution within districts, ranging from wards (largest unit) to output areas (smallest unit). It is also important to note that patterns presented in this report are aggregate patterns at the district level and are not necessarily representative of every individual. Interpreting such patterns incorrectly leads to committing the ecological fallacy and care is therefore recommended prior to policy implementation.

Due to lack of available data, this index grouped individual modes of transport under one emission range (both in terms of greenhouse gases and particulate matter) whereas in reality a difference will exist and this is likely to be more pronounced in private car travel. Some car commuters may travel by electric cars running on renewables, therefore reducing emissions down to almost zero whereas others may make use of older cars with far more polluting engines. Those with flexible working hours may also be able to commute by car outside of rush hour times, thus potentially emitting less due to reduced traffic congestion. Furthermore, different districts may typically own different types/ages of car and therefore basing calculations on a measure of affluence (such as deprivation) may lead to more nuanced results. Similarly, the category and grouping discrepancies of available data required the manipulation of "drivers" and "passengers" so that they could be separated into either full cars or lone drivers to match the given emission data categories. An alternative decision could have been made to ignore the category of "passengers" altogether, as the amount of drivers should cover the overall emissions. However, ignoring a whole section of commuters would also mean ignoring the impacts of potentially longer routes taken to accommodate passengers' needs, as well as ignoring the benefits of car-sharing (as opposed to each passenger driving their own car).

Although in this paper, 'working from home' was excluded from the carbon footprint of commuting, Shankleman (2014) considers whether working from home could actually have a bigger impact on the environment than, for example, commuting by electric car. One option would therefore be to re-calculate the index whilst taking into account the emissions associated with increased levels of domestic heating or cooling (assumed approximately 4 hours on average) that result from working at home, the impact of which the Carbon Trust (2014) estimates to be roughly 180 kg CO_2e annually. However, the argument in the study is that working from home reduces emissions (if the commute by car, bus or train is over 7, 11 or 25km, respectively), and as such is future consideration more so than a limitation per se of the existing index.

Conclusion

With growing populations, urbanisation and rising house prices, city commutes are becoming longer and more arduous. While there are people who are able to use carbon free modes of transportation, others have longer commuting distances and often have to opt for less environmentally friendly modes. In addition to reflecting social problems of inaccessibility and inequality, this produces greenhouse gas emissions and harms the environment, as well as citizens' health. These problems are very evident in London, where commuting distances and times are among the longest in Europe. Recognising the importance of reducing carbon emissions and their direct and indirect impacts as well as the benefits of active travel, the index put forward in this research was created using these two components of equal weight.

The index highlighted the positive relationship between city density and core urban centres with active travel and low carbon commuting, but also pinpointed areas of need, where emissions are high and commuting distances long. Although it has its limitations, the index represents a useful tool to quantify the commuting patterns of London's citizens, with the possibility of basing policy implications for positive change, sustainable development and transport service improvement on its output. The index lends itself to further analysis both at a finer spatial resolution and through more widespread adoption, given its open and replicable nature.

For completeness, the final tabular carbon footprint and sustainable commuting index results can be found in Appendix I of this paper (extended version of Table 4).

References

Boseley, S. (2016) *Benefits of cycling and walking 'outweigh air pollution risk' in cities*. Available at: https://www.theguardian.com/environment/2016/may/05/benefits-cycling-walking-outweigh-air-pollution-risk-cities (Accessed: 28 February 2018).

Bradshaw, J., Noble, M., Bloor, K., Huby, M., McLennan, D., Rhones, D. & Wilkinson, K. (2009), *A child well-being index at small area level in England*, *Child Indicators Research* 2(2), 201–219.

Carbon Trust (2012) *Carbon footprinting guide*. Available at: https://www.carbontrust.com/resources/guides/carbon-footprinting-and-reporting/carbon-footprinting/ (Accessed: 28 February 2018).

Carbon Trust (2014) *Homeworking: Helping businesses cut costs and reduce their carbon footprint CTC830*. Available at: https://www.carbontrust.com/media/507270/ctc830-homeworking.pdf (Accessed: 26 January 2018).

CEDAR (UKCRC Centre for Diet and Activity Research) (2013), *Evidence brief 4: Walking & cycling for transport: How promoting active travel can help meet the physical activity challenge*. Available at: http://www.cedar.iph.cam.ac.uk/resources/evidence/eb-why-active-travel-web/ (Accessed: 28 February 2087).

Chainey, S. P. (2008), Identifying priority neighbourhoods using the Vulnerable Localities Index, *Policing: A Journal of Policy and Practice*, 2(2), 196-209.

Goodman, A., Brand, C. and Ogilvie, D. (2012) 'Associations of health, physical activity and weight status with motorised travel and transport carbon dioxide emissions: A cross-sectional, observational study', *Environmental Health*, 11(1). doi: 10.1186/1476-069x-11-52.

GLA (Greater London Authority) (2013) *Better Environment, Better Health: London district of Havering*. Available at: https://s3-eu-west-1.amazonaws.com/londondatastore-upload/Better+Environment%2C+Better+Health+%28Havering%29.pdf (Accessed: 28 February 2018).

GLA (Greater London Authority) (2016) *Statistical GIS Boundary Files for London*. Available at: https://data.london.gov.uk/dataset/statistical-gis-boundary-files-london/resource/9ba8c833-6370-4b11-abdc-314aa020d5e0 (Accessed: 07 February 2018).

London Climate Change Partnership (2013), Better Environment, Better Health publications launched, Available at: http://climatelondon.org.uk/news/better-environment-better-health/ (Accessed: 05 March 2018)

London Data Store (2011), Data Downloads: 2011 Census, https://data.london.gov.uk/census/data/, (Accessed: 26 February 2017).

Lucy, L. and Burns, L. (2017), Devising a composite index to analyse and model loneliness and related health risks in the United Kingdom, *Journal of Gerontology and Geriatric Medicine*, 3, 1-10. Doi: 10.1177/2333721417714876

Morley, K. (2016) *Brits face longest commute to work in Europe*. Available at: http://www.telegraph.co.uk/news/2016/12/11/brits-face-longest-commute-work-europe/ (Accessed: 28 February 2018).

NHS Choices (2016) *Air pollution 'kills 40, 000 a year' in the UK, says report*. Available at: http://www.nhs.uk/news/2016/02February/Pages/Air-pollution-kills-40000-a-year-in-the-UK-says-report.aspx (Accessed: 21 November 2017).

ONS (Office for National Statistics) (2014), *2011 Census Analysis – Distance Travelled to Work*, Available at: http://webarchive.nationalarchives.gov.uk/20160105160709/http://www.ons.gov.uk/ons/dcp171776_357812.pdf

ONS (Office for National Statistics) (2015), *The English Index of Multiple Deprivation 2015 – Guidance*, Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/464430/English_Index_of_Multiple_Deprivation_2015_-_Guidance.pdf (Accessed: 28 February 2018).

ONS (Office for National Statistics) (2016), Travel to Work Areas, Available at: http://www.ons.gov.uk/ons/guide-method/geography/beginner-s-guide/other/travel-to-work-areas/index.html (Accessed: 28 February 2018).

Panter, J., Jones, A. & van Sluijs, E. (2008), Environmental determinants of active travel in youth: A review and framework for future research, International Journal of Behavioral Nutrition and Physical Activity, 5, 34, Doi: 10.1186/1479-5868-5-34

RCP (Royal College of Physicians) (2016) *Every breath we take: The lifelong impact of air pollution*. Available at: https://www.rcplondon.ac.uk/projects/outputs/every-breath-we-take-lifelong-impact-air-pollution (Accessed: 28 February 2017).

Saib, M.S., Caudeville, J., Beauchamp, M., Carré, F., Ganry, O., Trugeon, A. & Cicolella, A., (2015), Building spatial composite indicators to analyze environmental health inequalities on a regional scale, *Environmental Health*, *14*(1), 68. Doi 10.1186/s12940-015-0054-3.

Shankleman, J. (2014) *Does working from home grow your carbon footprint?* Available at: https://www.greenbiz.com/blog/2014/05/22/will-flexible-working-really-shrink-your-carbon-footprint (Accessed: 05 February 2018).

Thorpe, D. (2016) *Carbon emissions of travel modes*. Available at: http://www.sustainablecitiescollective.com/1084341/what-climate-impact-transport-infographic (Accessed: 28 February 2018).

UK Government (2016) *Greenhouse Gas Reporting - Conversion Factors 2016*. Available at: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2016 (Accessed: 02 February 2018).

Zachariadis, T., Ztziachristos, L. & Samaras, Z. (2001), The effect of age and technological change on motor vehicle emissions, Transportation Research Part D: Transport and Environment, 6(3), 221-227. Doi: 10.1016/S1361-9209(00)00025-0.

Appendix I: Final results for carbon footprints and sustainable commuting index

Rank	District	Ave. Carbon Footprint per capita ($kgCO_2e$)	Norm. Carbon Footprint per capita	Active Travel (% Total Commuters)	Norm. Active Travel	Sustainable Commuting Index
1	**City of London**	0.697	0.982	28.6%	0.981	**0.981**
1	**Westminster**	0.697	0.982	28.6%	0.981	**0.981**
2	**Islington**	0.663	1.000	27.9%	0.946	**0.973**
3	**Hackney**	0.779	0.938	29.0%	1.000	**0.969**
4	**Tower Hamlets**	0.712	0.974	26.7%	0.893	**0.933**
5	**Camden**	0.710	0.975	25.4%	0.834	**0.904**
6	**Hammersmith and Fulham**	0.866	0.891	22.3%	0.690	**0.791**
7	**Southwark**	0.860	0.895	21.7%	0.661	**0.778**
8	**Kensington**	0.820	0.916	19.5%	0.558	**0.737**
9	**Lambeth**	0.843	0.904	17.1%	0.446	**0.675**
10	**Wandsworth**	0.945	0.849	16.2%	0.408	**0.628**
11	**Haringey**	1.136	0.747	12.7%	0.242	**0.495**
12	**Lewisham**	1.191	0.718	11.4%	0.183	**0.451**
13	**Newham**	1.200	0.713	9.7%	0.104	**0.409**
14	**Brent**	1.394	0.610	11.2%	0.172	**0.391**
15	**Merton**	1.450	0.580	11.5%	0.189	**0.384**
16	**Waltham**	1.456	0.577	10.8%	0.153	**0.365**

17	**Richmond upon Thames**	1.966	0.304	16.0%	0.399	**0.351**
18	**Kingston upon Thames**	2.003	0.284	16.0%	0.395	**0.340**
19	**Greenwich**	1.548	0.527	9.7%	0.103	**0.315**
20	**Ealing**	1.741	0.424	11.4%	0.183	**0.304**
21	**Hounslow**	1.920	0.329	11.8%	0.203	**0.266**
22	**Croydon**	1.897	0.341	9.8%	0.110	**0.225**
23	**Sutton**	2.025	0.272	11.2%	0.174	**0.223**
24	**Barnet**	1.888	0.346	8.6%	0.052	**0.199**
25	**Barking and Dagenham**	1.981	0.296	8.7%	0.056	**0.176**
26	**Redbridge**	1.912	0.333	7.7%	0.009	**0.171**
27	**Enfield**	2.030	0.270	8.8%	0.061	**0.165**
28	**Bromley**	2.057	0.256	8.6%	0.053	**0.154**
29	**Harrow**	2.131	0.216	8.1%	0.031	**0.123**
30	**Bexley**	2.252	0.151	7.5%	0.000	**0.076**
31	**Hillingdon**	2.536	0.000	9.2%	0.080	**0.040**
32	**Havering**	2.472	0.034	8.0%	0.025	**0.030**