Borough-Level Carbon Accountability: A Data-Driven Exploration of CO_2 Emissions in London

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Abstract – This study addresses the issue of global warming, focusing on borough level analysis of London's CO2 emission and its commitment to achieving net zero emissions by 2030. Emission is compared across 3 primary sectors: Domestic, Industrial and Commercial and Transport, including the population aspect. Preliminary trends emphasise the success in emission reduction efforts specifically in the domestic and industrial and commercial sectors, spatial distributions locating trends and comparison and use of linear regression models to predict future CO2 emissions levels, concluded with strategic recommendations to ensure London objectives are met.

1. Introduction

Global warming is caused by greenhouse gas emissions. Most notably, CO2 emissions (carbon dioxide). This is a problem that affects communities across the world. It is an urgent matter that deserves the attention of everyone, not just environmentalists. CO2 emissions have increased by more than 60% since 1990, across the globe [1].

Urban areas make up for about 70% of worldwide CO2 emissions from energy consumption. [2] London and its boroughs contribute significantly to CO2 emissions, with London ranked 16th in worldwide carbon footprint rankings. [3]. London is home to a population of over 8 million people and it is only poised to grow further, with global warming and climate crisis on the rise, London becomes a focal point for developing emission reduction strategies. The Mayor of London highlighted his commitment to reducing the emissions within the city by establishing a net-zero policy by 2030. [4]. Net zero policy is aimed at ensuring a balance between greenhouse gas emissions produced and greenhouse gas emissions taken out of the atmosphere. [5] Different boroughs in London exhibit different emission patterns, Recognising and comprehending these disparities are critical steps towards developing targeted and efficient emission reduction strategies.

This investigation intends to measure emissions across London. Studying relationships between the domestic, transport, industrial and commercial sectors, linkages between population increase and carbon emissions growth, and ultimately future CO2.

emission forecasts. Predictive linear regression analysis is used to forecast CO2 emissions to discuss London's ability to attain net-zero CO2 emissions by 2030, and suggestions of policies on specific sectors.

2. Analytical Questions

1. *Analysing and comparing the domestic sector to the transport, industrial and commercial sectors, respectively, for each borough*. What insights can be derived? from the patterns observed within these sectors.
2. *Evaluate the influence of population density on the overall CO2 emissions of each borough*. How does population density contribute to variations in emissions across different sectors? Is there a trend between population growth and emissions?
3. *Forecast future CO2 emissions*. What predictions and trends can be identified, and how can these insights steer emission reduction policies? From current trends will London achieve its net-zero target?

3. Data

For this analysis, two datasets were used. The first which was sourced from London Datastore [6], which contains CO2 emission data for all 33 boroughs in London and the fuels consumed by each, from 2010 - 2017. The second dataset containing population data of every borough from 2001 to 2050 sourced from [7]. LEGGI_Year equates to the year corresponding to the data in the row. The column KtCO2e refers to kilo tons of carbon dioxide equivalent. It is a unit of measurement used to express the amount of CO2 [8]. It is important to note that, while other greenhouse gases are present, this analysis will concentrate on their CO2 equivalent.

The second dataset aids in the understanding of the relationship between population growth over time encompassing population density within the London boroughs. The features that will be necessary to carry out this analysis task are.

- *'Borough'* labels and enables to perform spatial analysis within London
- *'LEGGI_Year'* allows to see trends over time as well as predict future trends,
- '*Sector'* gives insights into the different sources of emissions and comparisons between these sources.
- '*Fuel'* offers emission information sector specific.
- '*KtCO2e'* denotes total CO2 emitted.
- '*Population'* Provides population demographics and assess the impact of population over time against emissions
-'Square kilometres'- provides the size of each borough to make a per-unit area comparison.

The given variables will enable us to make sector comparisons for domestic, transport, industrial and commercial and their corresponding fuel types, assess the impact of population and forecast future KtCO2e levels. Additionally, London datastore shapefile was obtained from [9], and was used to construct choropleth maps to visualise the spatial distribution. Figure 1 illustrates the data types.

Figure 1

```
 #   Column                         Non-Null Count  Dtype
---  ------                         --------------  -----
 0   Borough                        4878 non-null   object
 1   LEGGI_Year                     4878 non-null   int64
 2   Sector                         4878 non-null   object
 3   Fuel                           4878 non-null   object
 4   KtCO2e                         4878 non-null   float64
 5   Population                     4878 non-null   int64
 6   Square_Kilometres              4878 non-null   float64
 7   Population_per_square_kilometre 4878 non-null  float64
```

4. Analysis

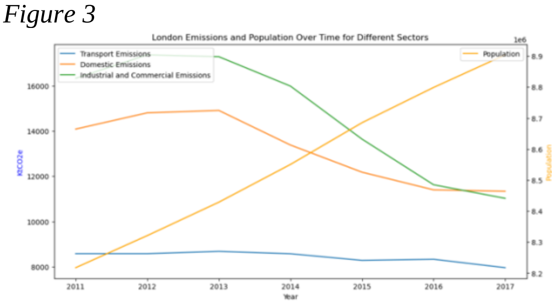
Initial data pre-processing was carried out. For the emission dataset, all missing values were removed, the missing values were observed not necessary for this analysis. There were no instances of duplicates, and all Borough names were ensured to be the same as the ones in the shapefile. As for the population dataset there were no missing values nor duplicates, the range of the data was also narrowed down to the time frame this analysis would capture (2010-2030). Finally, several columns that were not required were removed, the column names were altered to match those of the emission dataset, for swift merging. The merged dataset in the end had 4878 rows and 8 columns. Figure 2 shows how the final data frame appeared.

Figure 2

	Borough	LEGGI_Year	Sector	Fuel	KtCO2e	Population	Square_Kilometres	Population_per_square_kilometre
0	Barking and Dagenham	2017	Domestic	Electricity	72.537368	210513	36.1	5830.1
1	Barking and Dagenham	2017	Domestic	Gas	144.862242	210513	36.1	5830.1
2	Barking and Dagenham	2017	Domestic	Coal	1.931094	210513	36.1	5830.1
3	Barking and Dagenham	2017	Domestic	Oil	0.654757	210513	36.1	5830.1
4	Barking and Dagenham	2017	Domestic	Total	219.985461	210513	36.1	5830.1
...	...	...	...	...	...	...	...	...
4873	Westminster	2010	Transport	Railways diesel	3.634070	217187	21.5	10107.8
4874	Westminster	2010	Transport	Railways electric	64.715012	217187	21.5	10107.8
4875	Westminster	2010	Transport	Road Transport	258.608611	217187	21.5	10107.8
4876	Westminster	2010	Transport	Total	327.135007	217187	21.5	10107.8
4877	Westminster	2010	Total	Total	3212.433061	217187	21.5	10107.8

Before proceeding into the analysis, it is beneficial to look at the general trend among sectors for London. Looking at Figure 3, KtCO2e decreased gradually between 2010 and 2017. Each sector, shown in the graph key, saw a negative gradient. Domestic and industrial sectors saw the largest change while transportation seemed to stay relatively constant throughout. However, there was an early growth for industrial and commercial. By mid-2016, industrial and commercial plummeted just below domestic and narrowing the gap between transport. On the contrary Population linearly increased from 8.2 million in 2010 to 8.9 million in 2017. According to this primary analysis, the actions implemented for the industrial & commercial, and domestic sectors have been quite successful.

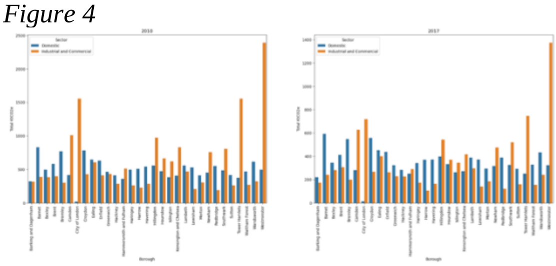
Figure 3



Domestic sector Vs Industrial and Commercial

Domestic sector and industrial and commercial sector are interrelated through complex supply chains. [10]. To visualise the comparison a bar plot was created to visualise the domestic and industrial and commercial sector. Data was filtered for 2010 and 2017 to make comparison, London removed to avoid skewing scale. The double bar plot was plotted as shown below in figure 4.

Figure 4

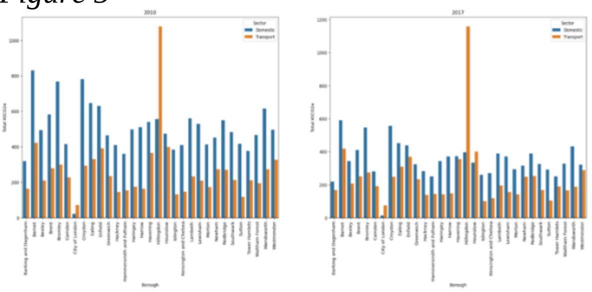


From first instance we notice the extreme spikes in 2010 being the orange bars which represent Industrial and Commercial. Boroughs such as Westminster' and 'City of London' stand out the most. As for the domestic sector the bars fluctuate comparatively less. Between 2010 and 2017, on average for London boroughs the domestic sector is higher than the industrial and commercial sector. Looking at the fuel types for both in more depth a scatter plot for all domestic and industrial fuel types was plotted, and with the use of Z-score set to three to identify these extremes. It was found that 'Barnet', 'Bromley' & 'Croydon' dominated the domestic sector, with the highest fuel type usage being 'Gas'. Between 2010 and 2017 the maximum which was outputted by 'Barnet' fell from 485 to 415 KtCO2e. As with industrial and commercial there was a distinct division of Boroughs that were significantly higher than the rest: 'City of London,' 'Tower Hamlets,' and 'Westminster,' with the highest being 2388.36 KtCCO2e in 2010 and this was 1373.15 KtCO2e by 2017, both emitted by the Borough of 'Westminster'. There was a slight similarity among industrial and transport and domestic emissions for most Boroughs the bars of the two sectors had a slight difference, this highlights that there is a correlation among transport and industrial and commercial sector.

Domestic and Transport Sector

Similarly for Domestic and Transport a bar plot was plotted as shown below.

Figure 5

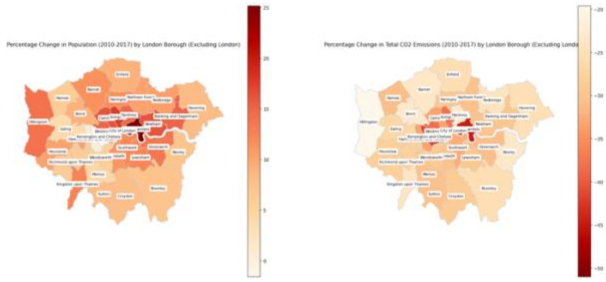


One first instance, the average domestic bars surpass the transport bars. However, the one key exception is the Borough of 'Hillingdon' and 'Hounslow. 'City of London' too but overshadowed by the others. Between 2010 and 2017 the margin between 'Domestic and 'Transport' has decreased significantly, we can assume that domestic measures taken in place were effective. Z score thresholds were set to three, to distinguish the extremes for the transport sector. It was shown that majority of transport emission arises from road transport, with 'Barnet',' Enfield' and 'Hillingdon' being the most. 'Hillingdon' and 'Hounslow' accounting for aviation, whereas 'Barnet' and 'Enfield' mostly accounted for road transport. When looking at the overall percentage change over the years 'Hillingdon', 'Hounslow' and 'City of London', where the only Boroughs to witness an increase in transport emissions since 2010.

Population and Emissions

To compare population growth and emissions. Population changes and emissions change was calculated since 2010 to 2017. These were visually displayed in a heatmap form for quick comparison. As population was on the increase for every borough except Kensington and Chelsea which faces a population decrease of -1.56%, the emission change for every sector was also decreasing. A spatial map was created as shown below.

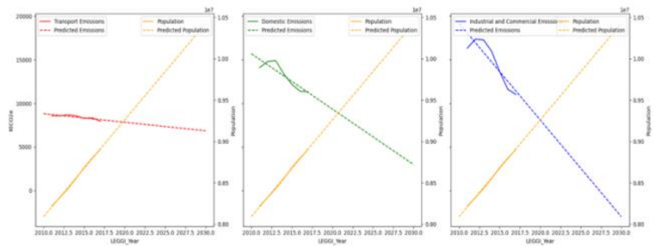
Figure 6



There was no obvious trend among population change, Pearsons correlation of population against emission was -0.4, indicating that there is in fact a negative relationship. It's evident that the higher percentage change in emission (decease) occurred within inner London region. As for population growth was also quite similar, population growth was highest among inner London too.

Prediction

Figure 7



Predictions for every sector was plotted as shown in the above figure. A 3-axis line graph was created. Linear regression models were built for both population and every individual sector. It seems that by 2030 both Domestic and Industrial and Commercial sectors will fall below Transport In order to validate the results mean squared error was calculated, which was as follows mean square error for transport = 15772.56, domestic = 393773, industrial and commercial 1108360.

5. Findings

Looking at the spatial distribution Boroughs with higher domestic usage seemed to be larger in terms of size such as Barnet, Croydon and Bromley which are among the top 5 largest boroughs, and it was more north and south of London which seemed to be dominant. One thing these boroughs had in common was a high population. In fact, in 2015 Bromley had the 6 highest population of 325,413 and had a higher-than-average per capita CO2 emissions for the domestic sector, approximately 1.9 tonnes per capita. [11]

Similarly for the transport sector, most emissions lie where the Borough size is larger, and population is greater. With road transport being the main factor, this includes private transport, with the introduction of London Congestion Charge in 2001 and later in 2017 London ultra-low emission zone (ULEZ) which recently expanded to cover Greater London, it seems the effect of these policies was not as effective as intended in fact across the UK, transport emissions have only decreased by 15% since 1990 , whereas total domestic fell by 48% in the same period [12]. The borough of 'Hillingdon', mainly accounted for aviation fuel type, due to it being the home of UK's largest and busiest airport. In 2020 it was reported Heathrow alone contributes 54.79% of the UK's total aviation CO2 emissions.[13]

The industrial and commercial sector primarily affects the economic aspect of every borough. Whilst emissions for each fuel type have fallen, there was a noticeable rise in waste and renewables. This could be because of insufficient data but can also be due to improved awareness and sustainability goals. It's clear that the industrial and commercial sector is dominated within the inner London. This could be clarified through the fact that these areas are business and financial districts with a high level of economic activity. In fact, at current rate Industrial and Commercial sector related carbon emissions are expected to fall below 0. With initial plans set to achieve net zero carbon by 2050, the Climate Change Committee suggested industrial emissions need to fall by over 90%. [14] From the obtained linear regression model this seems achievable at current rate by 2030.

When looking at the impact of population per square kilometres we can see that that population density is higher around inner London, there is a correlation that emissions per capita around inner London is higher, indicating that places with dense population have a higher emission per capita. Boroughs within inner London are smaller in terms of square kilometres, exemplify this trend.

Overall, the linear regression model suggest, emissions will fall linearly, and this falls in line with the target of net zero carbon for targeted for 2030. However, with the increase in expected population there needs to be a key focus on the Transport sector, as comparatively this sector had the lowest percentage change. A focus on incentivising cycling, public transport and car clubs/sharing would be necessary [15]. The recent expansion of ULEZ will play a part, as focus needs to be on the boroughs farther away from the centre, furthermore the aviation sector needs to be inspected as there was an observed growth. As for the domestic and transport sectors moving towards renewable energy sources seems to be growing and cost effective in the long run in fact every year Londoners spend an estimated £3.5bn on gas and electricity bills [16], this emphasises the potential of savings, with increased funding and introduction of schemes such as London power and Retrofit Accelerator , London takes a step closer to realizing its net zero target by 2030.

6. Wordcount

Section	Expected	Actual
Abstract	150	90
Introduction	300	254
Analytical Questions	300	96
Data	300	286
Analysis	1000	889
Findings, reflection, and further work	600	595
Total	2650	2210

7. References

[1] I. Tiseo, "Annual CO2 emissions worldwide 1940-2021," Statista, Jan. 03, 2023. https://www.statista.com/statistics/276629/global-co2-emissions/#:~:text=Global%20carbon%20dioxide%20emissions%20from

[2] M. Luqman, P. J. Rayner, and K. R. Gurney, "On the impact of urbanisation on CO2 emissions," npj Urban Sustainability, vol. 3, no. 1, Feb. 2023, doi: https://doi.org/10.1038/s42949-023-00084-2.

[3] Moran, D., Kanemoto K; Jiborn, M., Wood, R., Többen, J., and Seto, K.C. (2018) Carbon footprints of 13,000 cities. Environmental Research Letters DOI: 10.1088/1748-9326/aac72a.

[4] London Assembly, “Pathways to Net Zero Carbon by 2030 | LGOV,” www.london.gov.uk, 2023. https://www.london.gov.uk/programmes-and-strategies/environment-and-climate-change/climate-change/zero-carbon-london/pathways-net-zero-carbon-2030
[5]“London’s wider greenhouse gas impacts | London City Hall,” www.london.gov.uk. https://www.london.gov.uk/programmes-and-strategies/environment-and-climate-change/environment-publications/londons-wider-greenhouse-gas-impacts?ac-143249=143248
[6]“London’s consumption based greenhouse gas emissions 2001-2020 – London Datastore.” https://data.london.gov.uk/dataset/london-s-consumption-based-greenhouse-gas-emissions
[7]G. L. Authority, “Land Area and Population Density, Ward and Borough,” www.data.gov.uk, Aug. 20, 2021. https://www.data.gov.uk/dataset/a76f46f9-c10b-4fe7-82f6-aa928471fcd1/land-area-and-population-density-ward-and-borough (accessed Dec. 24, 2023).
[8] “Key climate terms,” City of London. https://www.cityoflondon.gov.uk/services/environmental-health/climate-action/key-climate-terms (accessed Dec. 24, 2023).
[9] “Statistical GIS Boundary Files for London – London Datastore.” https://data.london.gov.uk/dataset/statistical-gis-boundary-files-london
[10] Z. Wang, X. Wang, S. Peng, L. Ming, C. Cui, and B. Niu, “Interactions between households and industrial sectors in embodied carbon emission networks,” Journal of Cleaner Production, vol. 275, p. 123809, Dec. 2020, doi: https://doi.org/10.1016/j.jclepro.2020.123809
[11] “Bromley’s CO 2 Emissions: 2015 Performance Report CO 2 Emissions within the Scope of Influence of Local Authorities Sustainability Team 2 Bromley’s CO 2 Emissions: 2015 Performance Report,” 2017. Accessed: Dec. 24, 2023. [Online]. Available: https://www.bromley.gov.uk/downloads/file/1356/c02-emissions-local-authorities-2015-performance-report
[12]“Transport and environment statistics: 2023,” GOV.UK. https://www.gov.uk/government/statistics/transport-and-environment-statistics-2023/transport-and-environment-statistics-2023#:~:text=UK%20Statistics%20Authority.-(accessed Dec. 24, 2023).
[13]“Why Heathrow’s claim to be ‘Net Zero’ by 2050 is rubbish,” Teddington Action Group, Mar. 19, 2020. http://www.teddingtonactiongroup.com/2020/03/19/why-heathrows-claim-to-be-net-zero-by-2050-is-rubbish/#:~:text=Currently%20Heathrow%20operations%20produce%2020 (accessed Dec. 24, 2023).
[14]“London Power | London City Hall,” www.london.gov.uk. https://www.london.gov.uk/programmes-strategies/environment-and-climate-change/energy/london-power (accessed Dec. 24, 2023).
[15]F. Perry, “What ‘net-zero carbon’ really means for cities,” www.bbc.com, Sep. 23, 2020. https://www.bbc.com/future/article/20200922-how-london-could-achieve-net-zero-carbon-by-2050
[16]“London Power | London City Hall,” www.london.gov.uk. https://www.london.gov.uk/programmes-strategies/environment-and-climate-change/energy/london-power (accessed Dec. 24, 2023).