CARBON SEQUESTRATION IN WOODLAND CITY OF LONDON

Presented by

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1. Introduction

1.1 Background

The whole world is now coping with the challenges modelled by environmental change and urbanization expansion, two interrelated matters that need immediate consideration and inventive elucidations. Metropolitan areas are gradually renowned as noteworthy contributors to global greenhouse gas emissions, predominantly owing to the concentration of human actions and the connected energy consumption. With the cities continue growing, it becomes the dire need of the hours to address the climate change impact and devise strategies to tackle the issue for sustainable developments of the cities.

A cherished approach of urban forestry has arisen in recent years to mitigating climate change and improving the sustainability of urbanized areas. Due to plenty of green spaces and trees in Urban woodlands they have potential to sequester substantial amounts of carbon dioxide (CO2), thus assisting to decrease atmospheric greenhouse gas concentrations. These forests not only serve as source of sinking carbon but also offer plentiful ecosystem facilities such as improving quality of air quality, biodiversity improvement, regulation of microclimates, and enhancement in overall wellbeing of urban population.

The London city, historically known for varied urban landscape and richness in culture, offers a distinctive environment to study the role of urban woodlands in carbon sequestration and their implications for sustainable development of urbanized areas. London demonstrates the conception of "woodland city" with its widespread net of green passages, parks and gardens, and urban woodlands, where the assimilation of nature and urban life is fostered.

1.2 Problem Statement

Despite the urban forest's carbon sequestration recognized importance, there is still a substantial understanding gap with respect to their efficiency and potential in alleviating climate change in the particular framework of the woodland city of London. While different studies have discovered carbon storing in certain London woodlands, an analysis of their joint impact and an assessment of the elements influencing carbon sequestration inside these woodlands are deficient.

Additionally, for devising effective controlling strategies it is critical to understand the association among biodiversity, tree species structure, and carbon sequestration in urban woodlands. This research paper intent to support evidence-based decision-making and improve the carbon sequestration capacity of London's urban woodlands by recognizing the tree species that contribute most meaningfully to carbon storage and assessing the prevailing controlling practices.

1.3 Research Objectives

The principal aims and objectives of this dissertation are as under:

- Determining the carbon stocks and fluxes in a few selected urban forests in London in order to evaluate their capacity for carbon sequestration.
- To research the connection between the diversity of tree species, carbon sequestration, and urban woods.
- To assess how well existing woodland management techniques are doing at preserving biodiversity and increasing carbon sequestration.
- To provide both policy and practical recommendations for improving carbon sequestration in urban forests.

1.4 Research Questions

To achieve the above mentioned objectives, the below research questions will guide this dissertation to achieve above-mentioned objectives:

- What are the leading factors inducing carbon emissions within these woodlands?
- Urban woodlands of London stored how much of carbon?
- In urban woodlands, what is the connection among biodiversity, tree species composition, and carbon sequestration?
- Contribution to carbon sequestration and biodiversity preservation in the wood city of London, to what extent woodland management practices?
- For improving carbon sequestration, what are the policies and recommendations in urban woodlands and adding urban forestry into administration policies and city planning in London?

1.5 Importance of the Study

For numerous stakeholders involved in environmental management, urban planning and development, and sustainability in the woodland city of London this research is very vital. Firstly, the finding demonstrates scientific knowledge and understanding of carbon sequestration in urban ecosystems, by focusing mainly on the distinctive background of London. This will also improve our knowledge regarding carbon sequestration potential of urban forests and emphasize light on the dynamics influencing their efficiency.

Secondly, this study will provide insights for policymakers and urban planners seeking evidence-based strategies to enhance carbon sequestration and promote sustainable urban development. By evaluating the current woodland management practices, the research will inform decisions regarding the protection, restoration, and expansion of urban woodlands in London.

Lastly, by providing useful advice for maximizing carbon sequestration in urban woods, the study will help managers and practitioners of woodlands. The research's conclusions will direct the adoption of efficient management techniques that advance the aims of carbon sequestration and biodiversity preservation in London's urban forests.

1.6 Structure of the Report

Chapter 1: Introduction - A summary of the study's significance, issue description, and research aims is given in the introduction.

Chapter 2: Literature Review - lays the groundwork for the research by providing a thorough overview of the literature on urban forestry, carbon sequestration, and related subjects.

Chapter 3: Methodology - explains the research methodology using the CRISP-DM technique, including the procedures used for data collecting, data analysis, and case study selection criteria.

Chapter 4: Results and Analysis - addresses each study goal and research question, then presents the investigation's conclusions and analyses the data gathered.

Chapter 5: Discussion - gives insights into the significance of the findings and interprets and examines the findings in the context of urban forestry, carbon sequestration, and sustainable urban development.

Chapter 6: Conclusion - summarizes the key findings, highlights the contributions made, and identifies potential directions for further study.

Chapter 7: Policy and Practical Recommendations - Provides recommendations for policy and practice based on research findings with the goal of maximizing carbon sequestration in urban forests and incorporating urban forestry into urban planning and management strategies in London.

This dissertation seeks to add to the body of knowledge on carbon sequestration in urban forests and offer insightful information for boosting sustainability in London, a woodland city, by addressing the research objectives and probing the research questions.

2. Literature Review

The findings of this study highlight how significant Monks Wood and other woods are as carbon stores. These findings complement the existing government policy, which promotes the creation of various broadleaved forest types, if trees are to be cultivated in the future with the intention of providing a long-term contribution to carbon sequestration. Potentially, plantations and the goods they produce can store as much carbon as a mature woodland, but only if the harvested wood and the products they produce decompose gradually. In addition to their great conservation and aesthetic value, broadleaved woodlands provide a significant advantage known as carbon sequestration. [1] Third, while the entire tree and debris (including roots, stems, branches, foliage, and litterfall) are taken into account in our carbon storage and sequestration values, other significant carbon pools and fluxes in forest ecosystems—such as the carbon stored and sequestered in soils—as well as the potentially high levels of stored carbon in dead wood in native, unmanaged forests, are not. Therefore, those pools and fluxes would also need to be taken into account in a more thorough evaluation of the role that forests and trees play in mitigating climate change, along with an estimation of how long-term any wood taken from a forest is kept in storage, for example in wood products. [2]

There is a significant chance that new forests will significantly reduce GHG emissions in Scotland and elsewhere. The significance of afforestation for carbon sequestration may be in compensating emissions from sectors where reaching carbon neutrality by 2050 or an emissions reduction to 80% of 1990 levels is biophysically or economically impossible. Policymakers are aware of the potential usefulness of new forests, but they frequently define it as a broad, area-based goal. [3]Trees outside of woodlands (TOWs) offer a variety of advantages to civilization. While the expenses of damage and annoyance that trees may cause are frequently recorded, these are not always acknowledged and recognized. [4]

The concern is that local governments and other responsible parties would intentionally remove huge numbers of trees at the first indication of illness and not replace them in an effort to decrease risk and save money due to the rising frequency of tree diseases like ash dieback. Thus, it is crucial to emphasize the advantages of trees and assign a monetary value to at least some of these advantages. It helps to reframe the discussion and emphasize that TOWs do have a variety of advantages. If benefits can be valued in money, they may also be weighed against upkeep and planting expenses to directly support tree budgets. Studies that weighed the economic costs and benefits of trees have revealed that the advantages often exceed the disadvantages. [5]

As we progress towards a low-carbon future, carbon storage and sequestration is considered as becoming more and more crucial. The UK government has acknowledged the value of maintaining land and vegetation as a carbon storage, and this has a significant impact on national carbon accounting. Changes in flora and land use can have a significant impact on how much carbon is stored. Additionally, the yearly absorption of carbon by various plant species varies substantially in terms of carbon sequestration rates. Payments for Ecosystem Services (PES) programs like the UK Woodland Carbon Code are built on the rising monetarization of carbon. [5, p. 6]

TOWs can improve water quality, reduce soil erosion, and perhaps even lessen flood danger. A significant contributor to poor water quality and many locations' inability to fulfil Water Framework Directive standards is diffuse pollution from both urban and rural regions. By capturing and holding nutrients and sediment in contaminated runoff, TOWs (and larger areas of woods) can reduce diffuse pollution. [6]

The climate policy that, in principle, provides the simplest means of carbon reduction is environmental taxation. However, in spite of the popular desire for climate change policy action, implementation has proven challenging. This study looks at how to redefine environmental fees in ways that are more personally motivating in order to foster widespread support and a moral grounding. [7]

Three crucial areas, policy and government planning, climate mitigation, and adaptation for other cities across the world, are areas in which London has developed significant expertise. First, London has established challenging targets for cutting carbon emissions. London has concurrently examined and thought about the possible threats in many different ways, including energy production from a human standpoint. [8]

In addition, London has looked into a variety of emission-reduction strategies, including the use of sustainable development concepts and approaches to tackling climate change. Second, London has created a sizable academic research network, represented by the LCCP, to help support scientific decision-making and successfully combat climate change. [8] In the meanwhile, London has created a number of adaptable and economical mitigation strategies, including significant emission reductions in the building industry. In terms of greenhouse gas reduction, London has also given the division of labor for mitigation efforts greater consideration. Thirdly, London has a stronger representation in terms of coping with climate change.

First, London has developed a scientific planning framework for adaptation to climate change (P2R2) that emphasizes the dynamic and adaptable nature of each adaptation strategy while focusing on four key areas: economic, environmental, health, and infrastructure sectors. London has constructed a system for tracking and evaluating policy that is relatively extensive and includes a pretty well-developed sectoral linking mechanism. The link between planning documents for climate change adaptation and the local building and facilities base has also received more attention in London. Addressing climate change offers the city a socioeconomically equitable and ecologically friendly sustainable growth, which requires future participation of stakeholders from the public sector, the private sector, and the community. [8]

In comparison to the average metropolitan public green space, cemetery green space upkeep has a considerably larger GWP impact. Research on maintaining cemetery green spaces with low energy consumption and minimal environmental impacts is useful to the ecological advantages and sustainable development of urban regions since it is a growing form of urban green space. [9]Due to agriculture's fast growing ecological imprint, the design of farmed landscapes will become more crucial for carbon sequestration and biodiversity preservation. By incorporating natural habitats into agricultural fields, carbon and biodiversity can be improved. [10]

The best short-term predictors of UK landscape carbon stocks and sequestration, according to current scientific research, are land use and land use change. Careful management of the country's existing natural and managed environments, particularly peatlands, forests, grasslands, and arable lands, is also essential to the UK land carbon stock. [11]Article 3.4 of the Kyoto Protocol holds parties liable for carbon sequestration in agricultural soils. Political choices are needed in order to address the key problems related to the identification and measurement of responsible actions. Due to interactions with other socioeconomic factors, the direct impact of CAP regulations on carbon sequestration in agricultural sinks is not always quantifiable. However, several agri-environmental programs and policies connected to production have likely indirectly aided in maintaining carbon reserves in agricultural soils. [12]

The long-term experimental plots' application of organic amendments and N fertilization significantly changed the topsoil's SOC, resulting in a 4 fold range in carbon stock. Only recalcitrant or processed additions like peat and sewage sludge, which had the biggest accumulation in the topsoil, were found below this layer to have a considerable accumulation of C down to 35 cm deep. [13]Because rail is quick, effective, and has a minimal carbon impact, it has historically been considered "good" for the environment. New environmental discussions around HS2 in the UK have emerged due to the conflicting global goals of decreasing the carbon footprint of HSR and the requirement to preserve and improve local biodiversity and habitat. [14]

By combining reforestation pledges made under the Bonn Challenge, a global effort is currently underway to restore more than 350 million hectares of deforested and damaged land. The advantages and challenges of reforestation are examined by Molly Hawes. In order to combat climate change, using trees to absorb and store atmospheric carbon is becoming more and more common. [15] Natural CO_2 regulators include soil and plants. While soils store atmospheric carbon for decades, plants sequester it. The amount of land that can be used for these environmental services may shrink as cities get denser. [16]

For three distinct settings, anthropogenic and biological influences on the surface-atmosphere exchange of CO2 are investigated. During the summer, when photosynthesis and respiration control the diurnal rhythm of the CO2 flux, similarities can be noted between suburban and wooded locations. Building emissions rise in the winter, whereas traffic is a significant contributor to CO2 emissions year-round. In the winter, emissions from human activities dominate urban and suburban fluxes. The observed CO2 fluxes, with the exception of the forest site, fluctuate between working days and non-working days and are influenced by diurnal traffic patterns (busy all day in urban areas; rush hour peaks in suburban areas). Although some anthropogenic emissions are countered by suburban vegetation, 24-hour CO2 fluxes are frequently positive, especially during the summer. The total observed carbon exchange for the London site is comparable to NAEI values, however in Sweden and Alice Holt, vegetative and biogenic activities (which are not included in the NAEI data) play an important role in the carbon balance. [17]

Crucial part in the control of carbon. These key concepts can convey their significance:

• First, unlike what is typically believed, forests offer a wider variety of carbon sequestration capabilities. These have consistently been undervalued. These systems also respond to management quite quickly. [18] • Second, in addition to their function in carbon cycles, these diverse forest systems provide a wide range of additional advantages to both people and non-humans, including economic and livelihood benefits as well as support for biota and geophysical processes. • Third, a variety of knowledge systems that may deviate from current scientific paradigms are involved in the many ways that people manage forests. As a result, forests aid in the preservation of knowledge systems that might offer valuable alternative tactics we will require as climate change intensifies [18]. • Fourth, urban barbarization may be much more active in terms of biomass and carbon uptake than has been realized. It not only enhances thermal comfort in cities and is reasonably successful at removing some types of pollutants. • Fifth, supporting the forest-related activities of the millions of rural forest stewards in populated settings may make it easier to realize climate justice goals. • Sixth: Improving management of forests and tree landscapes of all kinds is one of the quickest "solutions" for slowing the rate of climate change due to the size of forests, the potential carbon absorption they can hold, and how responsive forest ecosystems are to human interventions. It also benefits from the benefit of carbon's fertilizing influence on plants. • Seventh: By combining soil, food waste, and biomass, we may improve urban ecologies while lowering methane and other GHG emissions from food waste. [18]

In addition to carbon offsetting, afforestation of urban greenspace in cities can reduce hard-to-abate emissions, and in climate partnerships with rural councils, woodland planting or peatland restoration could assist city institutions in achieving their net-zero carbon goals. [19]

The way that forests and crops are used and managed has a big impact on the global carbon cycle. Through modifications to land use and management, humans have the power to affect the size of forest carbon stores and the direction of forest carbon fluxes. However, in the context of the Kyoto Protocol, debate has emerged over the use of biological methods to absorb or reduce CO2 emissions (often referred to as carbon "sinks"). The debate is primarily based on two claims: sinks may allow developed countries to postpone or avoid actions to reduce fossil fuel emissions; and the implementation of land use and forestry projects for the purpose of providing carbon offsets will be too threatened by technical and operational challenges. [20]

3. Methodology

In this study, we leveraged the CRISP-DM (Cross-Industry Standard Process for Data Mining) methodology as the cornerstone of our data analysis approach. CRISP-DM provided us with a structured and systematic framework to tackle our research objectives effectively. By following the key phases of business understanding, data understanding, data preparation, modeling, evaluation, and deployment, we were able to navigate the complexities of our data analysis project with clarity and precision. This methodology allowed us to not only address our research questions but also ensure the reliability and robustness of our findings. Our study's success can be attributed, in no small part, to the rigorous application of CRISP-DM, which provided a solid foundation for our data-driven insights.

3.1 Data Collection

The data for the study was collected from various websites, including ecad.eu, eea.europa.eu, data.gov.uk, and VALUING LONDON’S URBAN FOREST Results of the London i-Tree Eco Project.

Data sources were selected based on their relevance to the study's objectives, focusing on information related to tree resources, weather metrics, pollutant levels, and economic values associated with London's urban forest.

3.2 Data Cleaning

This data is cleaned, processed, and formatted using Python's Pandas library. Missing values are handled appropriately, and features are engineered as needed. Missing or erroneous data points were identified and either corrected or removed, depending on the extent of the data quality issue. Data from different sources were standardized and formatted to make them compatible for analysis in Microsoft Excel and Python.

3.3 EDA, or exploratory data analysis

EDA uses a variety of visualization approaches to comprehend the features of the data. Pie charts are used to show how many different greenhouse gases are present in the emissions. The distribution of other contributing components as well as trends in temperature fluctuations over time are shown using column charts.

3.4 Correlation Analysis

The correlations between temperature, greenhouse gases, and other parameters are graphically represented using libraries like Seaborn or Matplotlib. By identifying variables with high correlations, this analysis directs the future modelling processes.

3.5 Multivariate Regression Analysis

To measure the effect of greenhouse gases and other variables on temperature, multiple regression analysis is used. The regression model is created and trained using Python's Scikit-Learn module. To comprehend the unique contributions of each predictor, the model's coefficients are interpreted.

3.6 Using Random Forest Models

Based on the discovered variables, a random forest model is used to forecast temperature variations. This model takes into account the data's complicated interactions and non-linear relationships. For the model to function at its best, it must be trained, evaluated, and optimized.

3.7 Analysis & Evaluation

With the help of suitable measures like mean squared error, R-squared, and mean absolute error, the multiple regression and random forest models are both assessed. The accuracy of the models' temperature predictions is evaluated, and any possible problems are dealt with.

3.8 Results Interpretation

Interpretation is given to the findings of correlation analysis, multiple regression, and random forest modelling. There are conclusions made about the relative effects of greenhouse gases and other factors on temperature. Regression lines and charts comparing projected and actual temperature help to effectively communicate the results.

3.9 Findings

The methodology used in this study offers a thorough framework for examining the connections between greenhouse gases, additional contributing factors, and temperature in London's Woodland City. The work provides useful insights into the intricate dynamics of temperature fluctuations by combining data visualization, statistical analysis, and machine learning approaches.

4. Data Analysis & Results

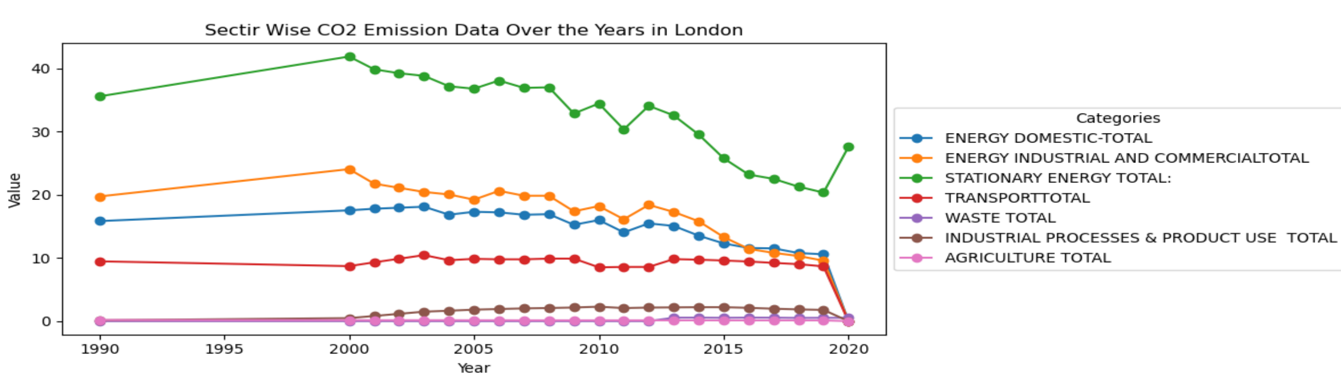
4.1 Sources of Corban emission in woodland city of London

Summary of energy consumption and emissions CO2 over time in London

Emmission	Year	ENERGY DOMESTIC-TOTAL	ENERGY INDUSTRIAL & COMMERCIAL TOTAL	STATIONARY ENERGY TOTAL:	TRANSPORT TOTAL	WASTE TOTAL	NDUSTRIAL PROCESSES & PRODUCT USE TOTAL	AGRICULTURE TOTAL	TOTAL
CO2 Emissions (MtCO2)	**1990**	15.84	19.74	35.58	9.47	0.00	0.14	0.18	**45.4**
	2000	17.54	24.06	41.88	8.71	0.00	0.48	0.16	**51.2**
	2001	17.79	21.76	39.86	9.31	0.00	0.82	0.15	**50.1**
	2002	17.95	21.10	39.24	9.88	0.00	1.16	0.15	**50.4**
	2003	18.11	20.45	38.82	10.45	0.00	1.50	0.15	**50.9**
	2004	16.85	20.05	37.17	9.65	0.00	1.65	0.15	**48.6**
	2005	17.31	19.23	36.79	9.86	0.00	1.82	0.14	**48.6**
	2006	17.22	20.62	38.08	9.79	0.00	1.92	0.14	**49.9**
	2007	16.84	19.85	36.92	9.79	0.00	2.02	0.13	**48.9**
	2008	16.93	19.85	37.01	9.90	0.00	2.08	0.13	**49.1**
	2009	15.25	17.38	32.86	9.90	0.00	2.16	0.13	**45.0**
GHG Emissions (MtCO2e)1	**2010**	16.00	18.21	34.45	8.52	0.00	2.29	0.13	**45.4**
	2011	14.05	16.12	30.35	8.58	0.00	2.07	0.13	**41.1**
	2012	15.47	18.40	34.08	8.58	0.00	2.15	0.13	**44.9**
	2013	15.07	17.28	32.56	9.82	0.55	2.18	0.12	**45.2**
	2014	13.53	15.81	29.53	9.73	0.56	2.21	0.13	**42.2**
	2015	12.30	13.31	25.78	9.60	0.53	2.21	0.12	**38.2**
	2016	11.58	11.44	23.20	9.44	0.56	2.11	0.12	**35.4**
	2017	11.52	10.81	22.52	9.22	0.55	1.97	0.12	**34.4**
	2018	10.78	10.31	21.28	9.02	0.51	1.86	0.12	**32.8**
	2019	10.58	9.58	20.35	8.67	0.53	1.78	0.12	**31.5**
	2020	0.00	0.00	27.60	0.00	0.53	0.00	0.00	**28.1**

Table. 1 Energy consumption and emissions CO2 over time in London

Source: London Energy and Greenhouse Gas Inventory (LEGGI), 2020



Source: London Energy and Greenhouse Gas Inventory (LEGGI), 2020

The table and Graph 1 provides information on energy consumption and emissions of carbon dioxide (CO_2) and other greenhouse gases in London from 1990 to 2020 based on data from the London Energy and Greenhouse Gas Inventory (LEGGI). The columns show CO_2 emissions in million metric tons ($MtCO_2$) for a variety of industries, including agricultural, stationary energy, industry, commerce, transportation, waste, and residential and industrial processes. The table also contains annual greenhouse gas (GHG) emissions, measured in million metric tons of CO_2 equivalent ($MtCO_2e$), taking into account the effects of other greenhouse gases. Notably, despite the city's expansion, there has been a noticeable drop in CO_2 emissions over time, especially after 2000. The overall CO_2 emissions decreased dramatically to 28.1 $MtCO_2$ by 2020. The use of renewable energy sources, increased energy efficiency, and improved waste management procedures might be blamed for this decline. However, data accessibility or unique variables necessitating additional research may be to blame for the abrupt decline in emissions to zero for several categories in 2020. The table summarizes London's attempts to reduce emissions and move towards a future that is more environmentally friendly and sustainable.

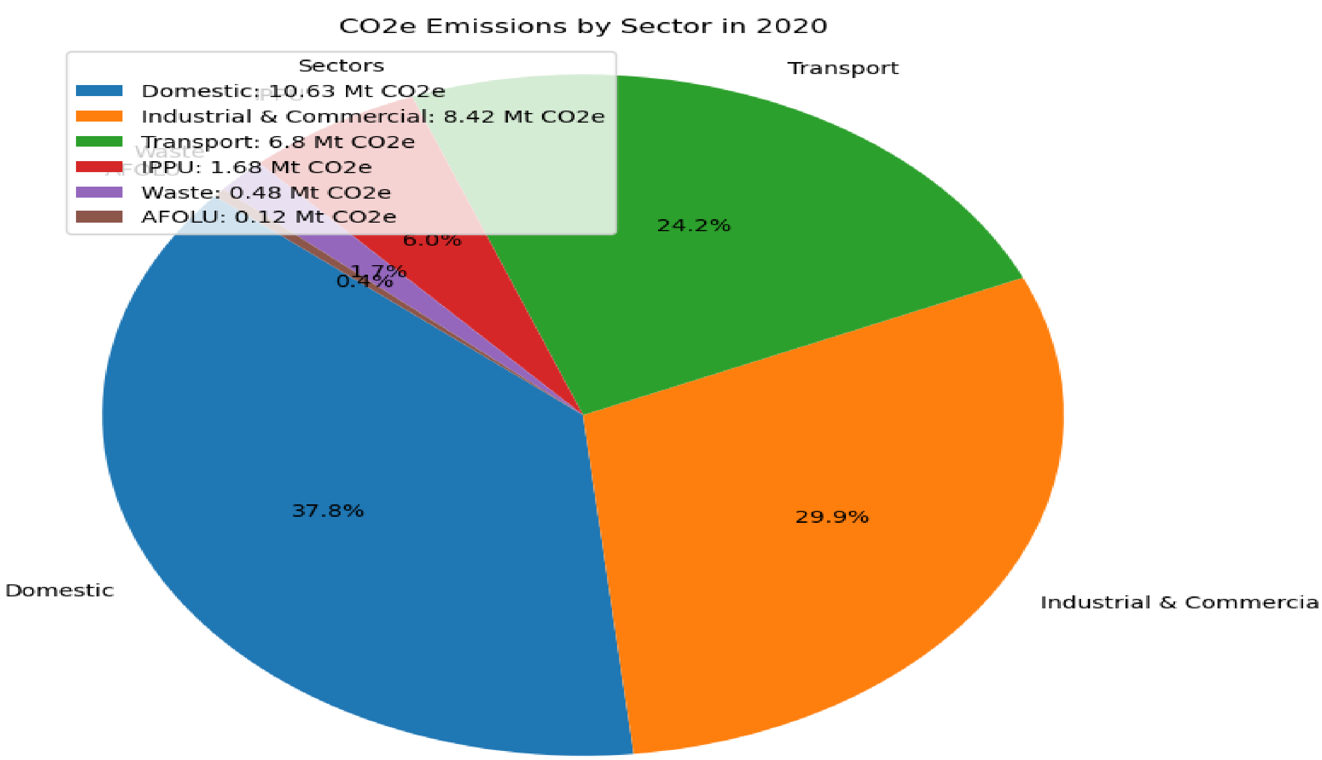


Figure 1: CO_2e emissions by sector in 2020

Source: London Energy and Greenhouse Gas Inventory (LEGGI), 2020

The figure 1 presents a comprehensive overview of CO_2e (carbon dioxide equivalent) emissions categorized by sectors for the year 2020, with the inclusion of fugitive emissions. The data reveals the significant contributors to greenhouse gas emissions during that specific period. The domestic sector accounted for 10.63 million metric tons of CO2e emissions, representing the impact of residential activities and small-scale sources. In the industrial and commercial sector, emissions reached 8.42 million metric tons of CO2e, encompassing emissions from manufacturing, businesses, and other non-residential operations. The transport sector, including both on-road vehicles and off-road machinery, contributed 6.80 million metric tons of CO2e, reflecting the considerable impact of transportation-related activities. IPPU emissions, related to industrial processes and product usage, totaled 1.68 million metric tons of CO2e. The waste sector's emissions amounted to 0.48 million metric tons of CO2e, resulting from various waste management practices. Lastly, the AFOLU sector, involving agriculture, forestry, and other land use practices, contributed 0.12 million metric tons of CO2e emissions. The data emphasizes the importance of understanding emissions from different sectors to develop targeted strategies for mitigating greenhouse gas emissions and fostering a sustainable future.

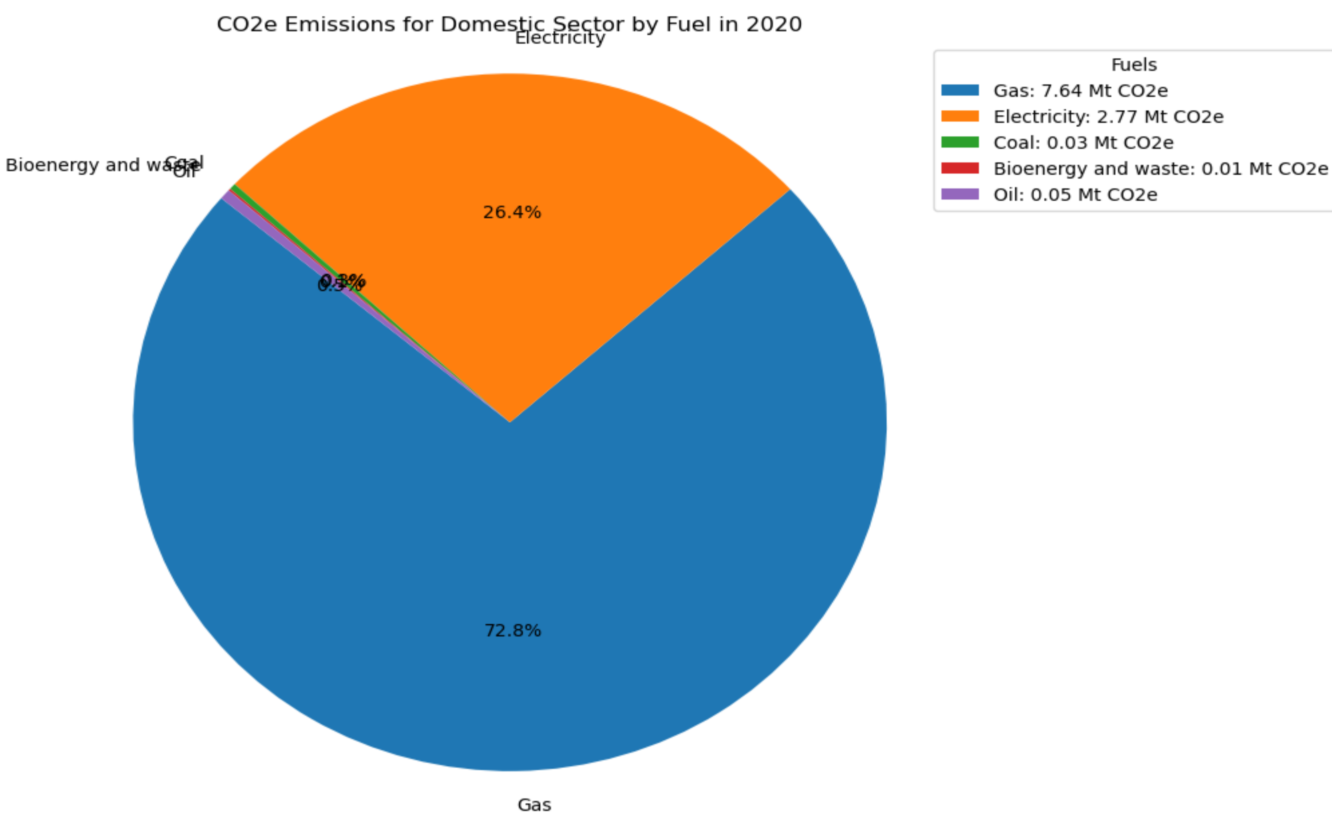


Figure 2: CO2e emissions for Domestic sector split by fuel in 2020
Source: London Energy and Greenhouse Gas Inventory (LEGGI), 2020

The domestic sector's CO2e (carbon dioxide equivalent) emissions for the year 2020, excluding fugitive emissions, are broken down in detail in figure 2. This divides the emissions into categories depending on the many fuels utilized in home settings, illuminating each source's individual contributions to greenhouse gas emissions. Natural gas was the main source, accounting for 7.64 million metric tones of CO2e emissions. Given the widespread use of natural gas for cooking, heating, and other home uses, this is to be expected. Following closely behind were emissions from electricity use, which resulted in 2.77 million metric tones of CO2e, which reflected emissions from domestic electricity production. Notably, domestic coal use produced just 0.03 million metric tones of CO2e in emissions, a negligible amount. This is likely due to the declining popularity of coal as a residential fuel source due to environmental concerns. Additionally, bioenergy and waste, when not connected to the grid, accounted for only 0.01 million metric tons of CO2e emissions. Lastly, oil consumption in households resulted in 0.05 million metric tons of CO2e emissions, primarily utilized for heating in certain homes. Understanding the emissions from each fuel source in the Domestic sector is crucial for devising effective strategies to promote cleaner and more sustainable energy alternatives and reduce the sector's overall carbon footprint. By identifying the major sources of emissions, policymakers can target specific areas for improvement and work towards a greener and more environmentally responsible future.

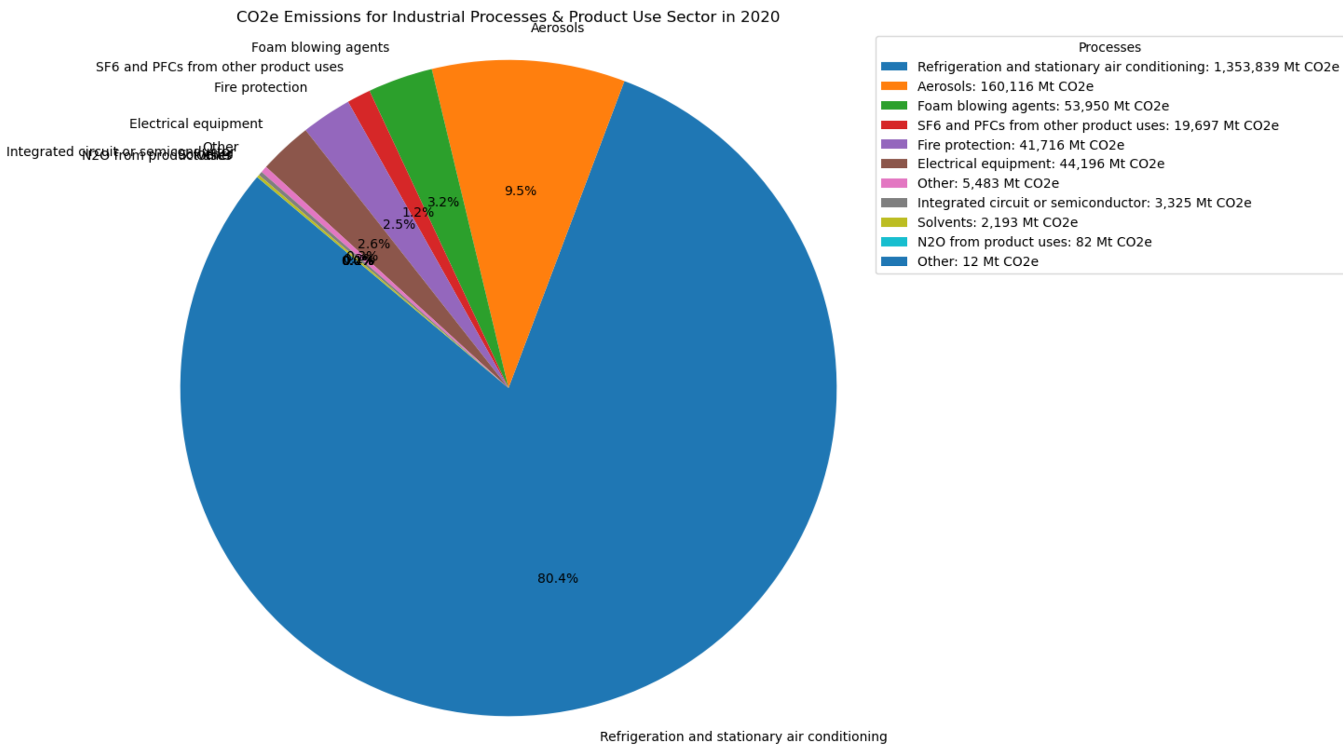


Figure 3: CO2e emissions for Industrial & Commercial sector split by fuel in 2020

Source: London Energy and Greenhouse Gas Inventory (LEGGI), 2020

Figure 3 provides a comprehensive overview of CO2e (carbon dioxide equivalent) emissions within the Industrial & Commercial sector for the year 2020, excluding fugitive emissions. The table breaks down the emissions based on different fuel sources utilized by industries and commercial establishments. Notably, electricity consumption emerged as the largest contributor, generating 3.97 million metric tons of CO2e emissions. This highlights the significance of electricity consumption in industrial and commercial operations and underlines the need for cleaner energy sources to mitigate emissions. Natural gas consumption followed closely, resulting in 3.62 million metric tons of CO2e emissions, indicating its prevalent use in these sectors. However, efforts to transition to renewable energy alternatives could significantly reduce emissions. Oil consumption contributed 0.73 million metric tons of CO2e, further emphasizing the potential for emissions reduction by adopting cleaner fuels. The table also reveals minimal contributions from bioenergy and waste (not grid-connected), large industrial gas, and coal, showcasing their relatively minor impact on emissions in the Industrial & Commercial sector. Understanding these emission patterns is crucial for implementing targeted strategies to reduce carbon footprints and foster sustainability in industrial and commercial practices.

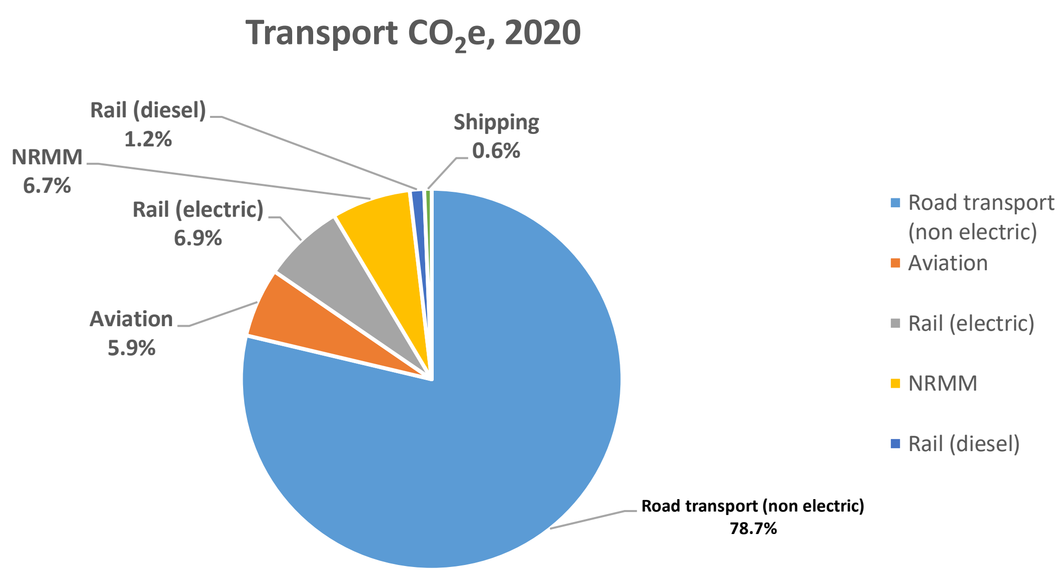


Figure 4: CO2e emissions for Transport sector in 2020

Source: London Energy and Greenhouse Gas Inventory (LEGGI), 2020

Figure 4 provides a comprehensive insight into CO2e (carbon dioxide equivalent) emissions within the Transport sector for the year 2020. The data is segmented into different modes of transportation, showcasing their individual contributions to greenhouse gas emissions during that specific period. Non-electric road transport emerged as the highest emitter, generating 5.34 million metric tons of CO2e. This underscores the significant impact of conventional gasoline and diesel vehicles on overall transport-related emissions. The aviation sector accounted for 0.40 million metric tons of CO2e emissions, highlighting the importance of addressing emissions from the aviation industry to reduce its environmental impact. On the other hand, electric rail transport showed a relatively lower impact, contributing 0.47 million metric tons of CO2e emissions. Non-Road Mobile Machinery (NRMM) usage resulted in 0.46 million metric tons of CO2e emissions, representing off-road vehicles used in various industries. Diesel-powered trains and shipping had comparatively smaller emissions, contributing 0.08 million and 0.04 million metric tons of

CO2e, respectively. Understanding the emissions from each transport mode is essential for formulating targeted strategies to promote greener transportation alternatives, thereby mitigating the sector's overall carbon footprint and fostering a more sustainable and environmentally responsible future.

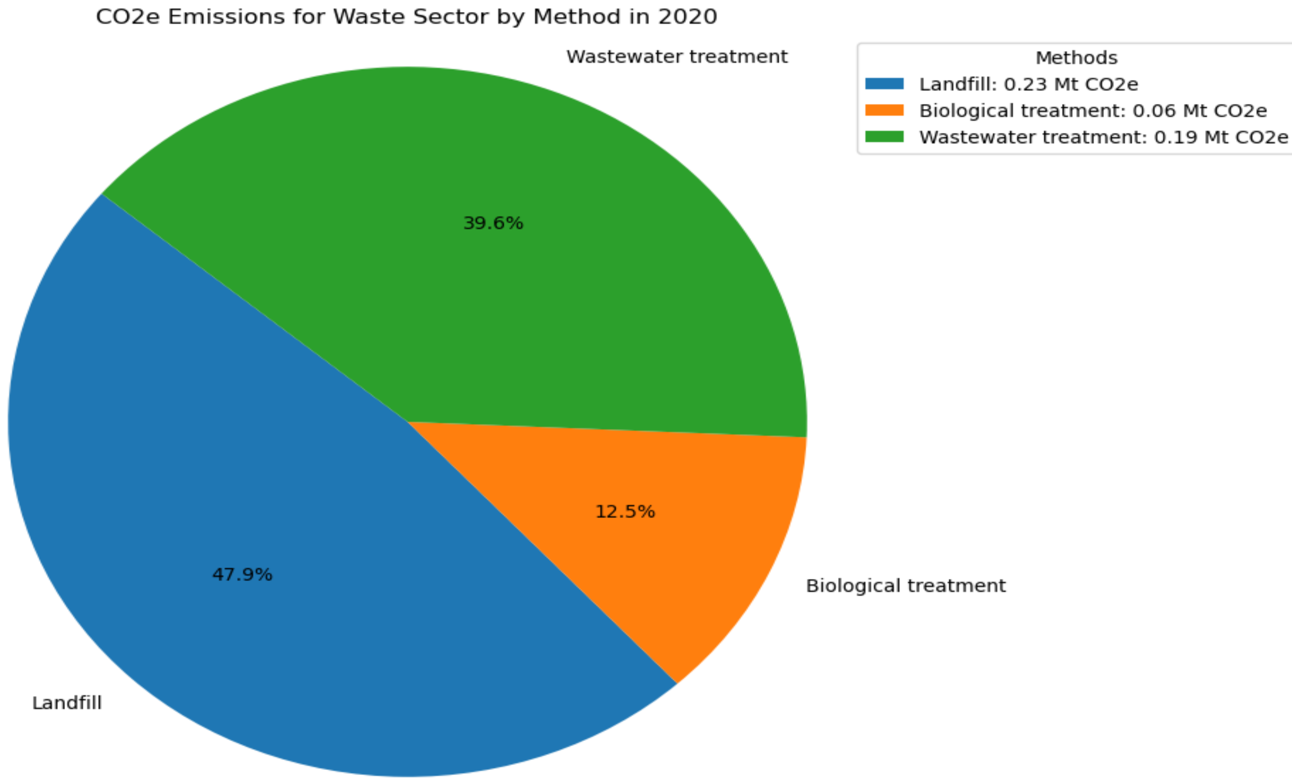


Figure 5: CO2e emissions for Waste sector in 2020

Source: London Energy and Greenhouse Gas Inventory (LEGGI), 2020

The figure 5 provides information on the metric tonnes (Mt) of carbon dioxide equivalent (CO2e) emissions that resulted from three different waste management techniques. Emissions from the first technique, landfills, total 0.23 Mt CO2e. In landfills, solid waste is disposed of by burying it underground. Methane, a strong greenhouse gas, is emitted during the decomposition process, adding to the overall CO2e emissions. The biological treatment of waste uses the second technique and emits 0.06 Mt CO2e. This strategy uses microorganisms to break down organic waste using techniques like composting or anaerobic digestion, which reduces waste volume and reduces methane emissions but still results in some CO2 emissions. Emissions from the third approach, wastewater treatment and discharge, total 0.19 Mt CO2e.

Prior to releasing the cleaned water into water bodies, this method purifies sewage and wastewater. Some CO2e emissions are produced as a result of energy use and biological processes during the treatment process. The data clearly demonstrates that treating biological waste results in comparatively lower CO2 emissions than landfilling, wastewater treatment, and trash disposal. An important part in lowering the overall carbon footprint and fostering environmental preservation may be played by using proper waste management procedures and adopting sustainable substitutes.

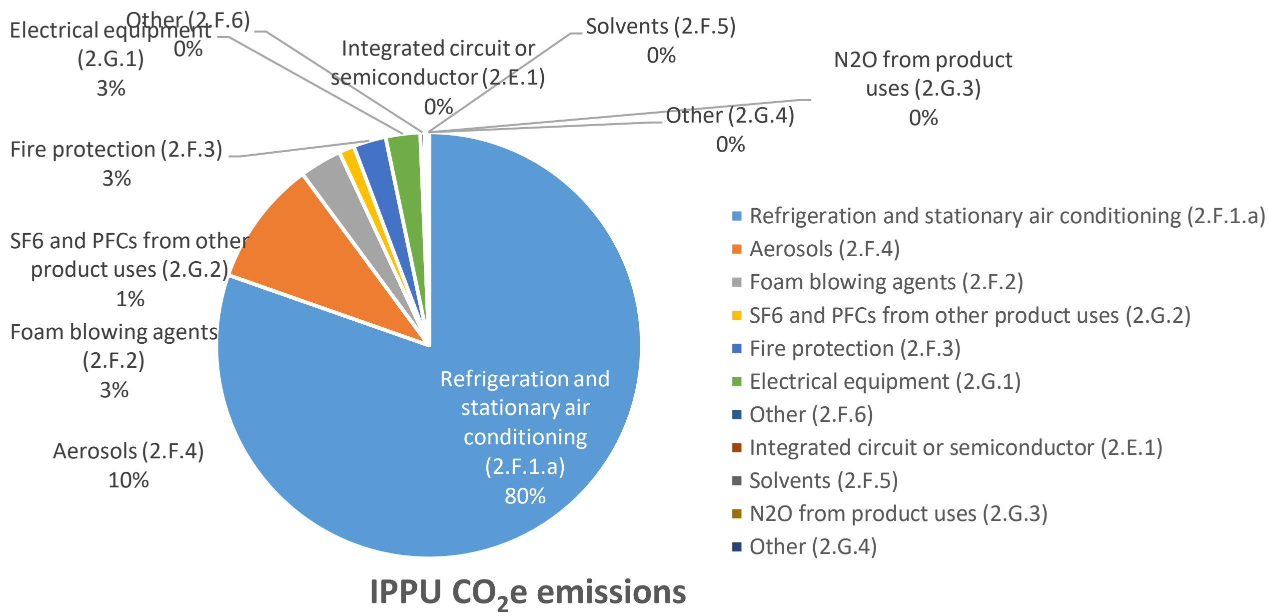


Figure 6: CO2e emissions for Industrial Processes & Product Use sector

Source: London Energy and Greenhouse Gas Inventory (LEGGI), 2020

In 2020, the Industrial Processes & Product Use sector produced substantial carbon dioxide equivalent (CO2e) emissions. The highest contributors were refrigeration and stationary air conditioning with 1,353,839 Mt CO2e, followed by aerosols with 160,116 Mt CO2e, and foam blowing agents with 53,950 Mt CO2e. Other notable sources included SF6 and PFCs from other product uses (19,697 Mt CO2e), fire protection (41,716 Mt CO2e), and electrical equipment (44,196 Mt CO2e). While these emissions are concerning, it highlights the need for sustainable practices and eco-friendly alternatives in the industrial sector to mitigate the impact on the environment.

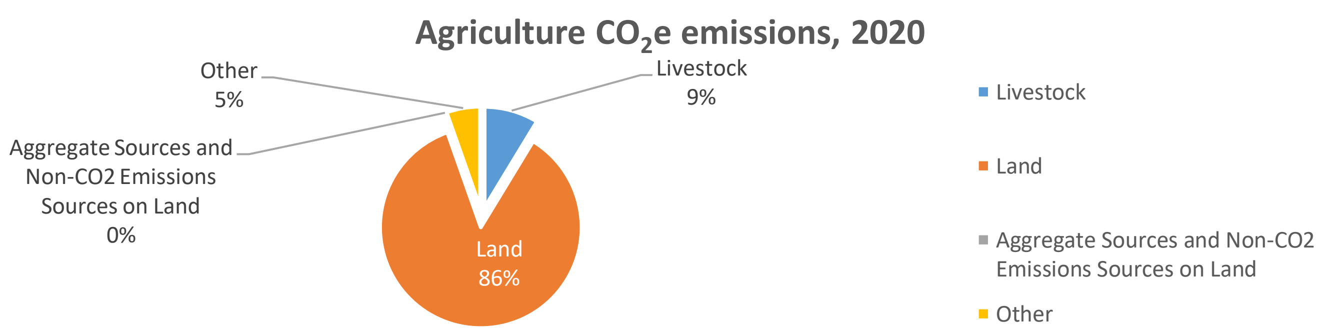


Figure 7: CO2e emissions for Agriculture sector in 2020

Source: London Energy and Greenhouse Gas Inventory (LEGGI), 2020

Compared to other industries, the agriculture sector's carbon dioxide equivalent (CO2e) emissions in 2020 were considerably lower. In this industry, land and livestock together contributed 0.10 Mt CO2e and 0.01 Mt CO2e, respectively, of the emissions. It is interesting that the emissions from aggregate sources and non-CO2 emission sources on land totaled 0.00 Mt CO2e, or zero emissions. Additionally, 0.01 Mt CO2e of emissions from other sources had a negligible impact. The agriculture sector's comparatively low emissions show that it has the opportunity to embrace sustainable practices that will lessen its impact on the environment and support climate-friendly farming methods.

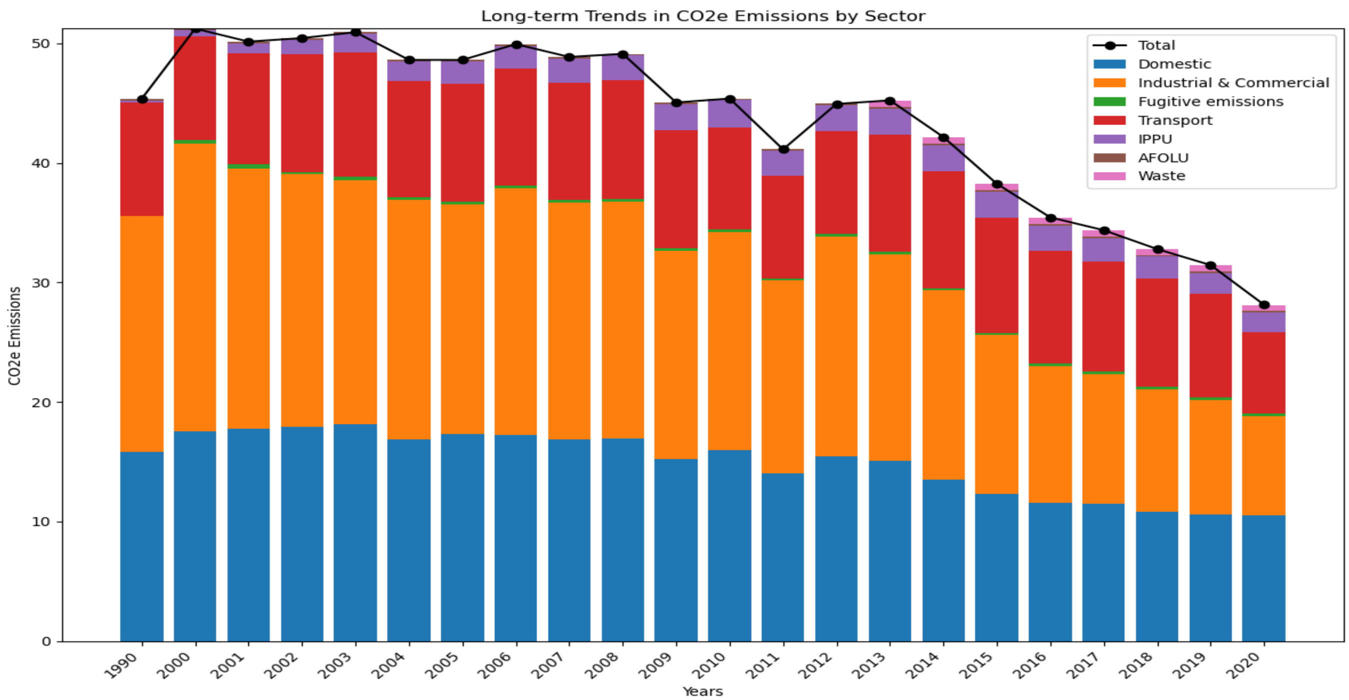


Figure 8: Long term trends in CO2e emissions by sector, 1990 & 2000-2020

Source: London Energy and Greenhouse Gas Inventory (LEGGI), 2020

Figure 8 presents the long-term trends in carbon dioxide equivalent (CO2e) emissions by sector for the years 1990 and 2000 to 2020. The table provides data on the CO2e emissions (in Mt CO2e) for various sectors over the given period.

- Domestic: The emissions from the domestic sector increased from 15.84 Mt CO2e in 1990 to a peak of 18.11 Mt CO2e in 2003 before gradually declining to 10.49 Mt CO2e in 2020.
- Industrial & Commercial: CO2e emissions from the industrial and commercial sector exhibited fluctuations over the years. Starting at 19.74 Mt CO2e in 1990, it reached its highest point in 2002 (24.06 Mt CO2e) and then steadily decreased to 8.36 Mt CO2e in 2020.
- Fugitive Emissions: This sector showed minimal emissions, with slight variations over the years, but overall, it remained relatively stable, staying below 0.30 Mt CO2e throughout the entire period.

- Transport: Emissions from the transport sector witnessed fluctuations but showed a general upward trend, reaching a peak of 10.45 Mt CO2e in 2003 before declining to 6.80 Mt CO2e in 2020.
- IPPU (Industrial Processes and Product Use): This sector displayed a steady increase in emissions, rising from 0.14 Mt CO2e in 1990 to 1.68 Mt CO2e in 2020.
- AFOLU (Agriculture, Forestry, and Other Land Use): Emissions in this sector remained relatively low and stable, ranging from 0.12 to 0.18 Mt CO2e throughout the years.
- Waste: The waste sector showed a significant increase in emissions, particularly after 2013, reaching 0.48 Mt CO2e in 2020.

Overall, the total CO2e emissions across all sectors were 45.36 Mt in 1990 and peaked at 51.23 Mt in 2000. However, there was a notable decline over the years, reaching 28.13 Mt CO2e in 2020. These trends highlight the importance of monitoring and implementing measures to reduce emissions in various sectors to address climate change and promote environmental sustainability.

4.2 Woodland City London Forest / Tree Resources

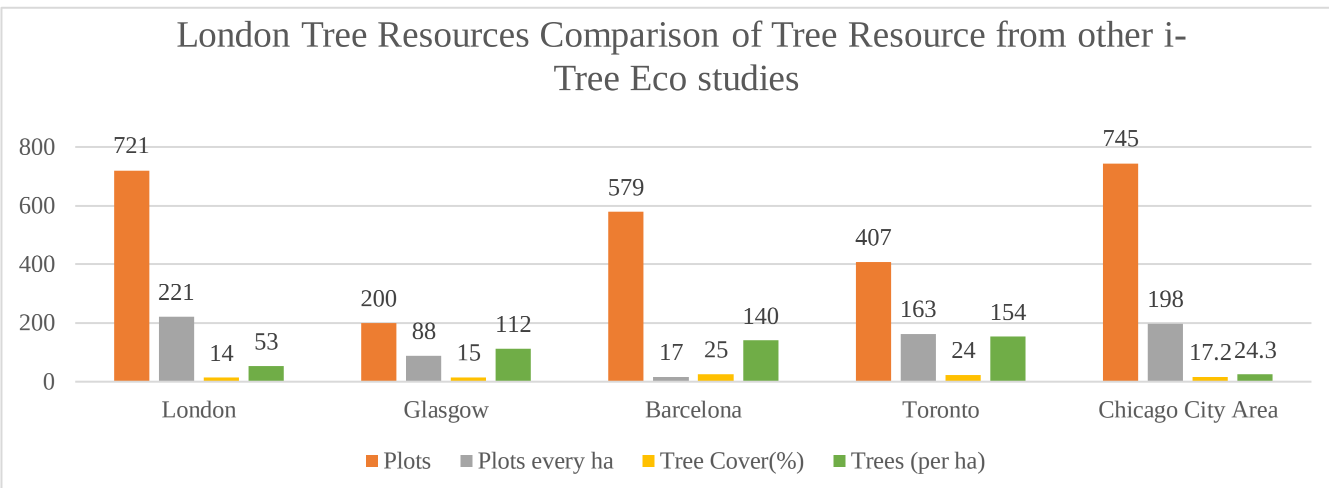


Figure 9. Tree Resources Comparison of Tree Resource from other i-Tree Eco studies

Source: i-Tree Eco Study

The figure 9 compares tree resources in different cities based on the i-Tree Eco studies. The "Plots" column reveals the number of sample plots used to gather data on trees and their characteristics. The Chicago Metro Region leads with 2,076 plots, followed by Greater London with 721 plots.

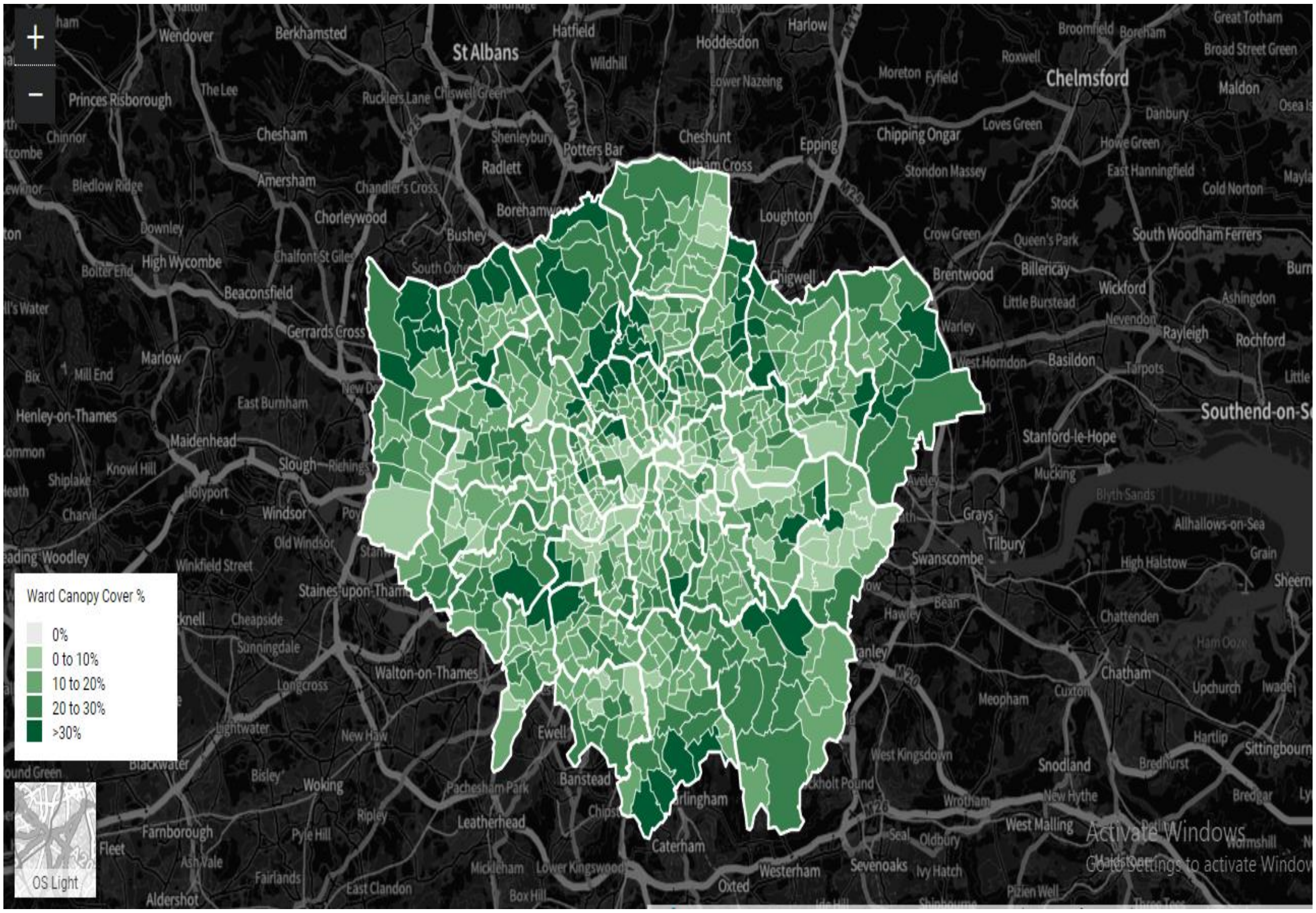
"Plots every ha" denotes the density of sample plots per hectare. Barcelona exhibits the lowest density with 17 plots per hectare, while Greater London has the highest density with 221 plots per hectare.

The "Tree Cover (%)" column indicates the percentage of tree cover in each city. Barcelona boasts the highest tree cover at 25%, closely followed by Toronto and Glasgow with 24% and 15%, respectively.

Lastly, the "Trees (per ha)" column demonstrates the density of trees per hectare. Barcelona boasts the highest density with 140 trees per hectare, whereas Greater London has 53 trees per hectare.

This comparison provides valuable insights into the distribution of trees and their abundance in urban areas, highlighting cities' efforts in promoting green spaces and fostering sustainable urban ecosystems. Barcelona stands out with its high tree cover and dense tree population, while other cities, such as Greater London and the Chicago Metro Region, also demonstrate noteworthy tree resources. The data can aid in understanding and managing urban forests, promoting environmental conservation, and enhancing the overall well-being of urban communities.

London Tree Canopy Cover



"*The data presented is a high resolution map of tree canopy cover for the Greater London area. The map was produced by Breadboard Labs in collaboration with the Greater London Authority through Breadboard Lab's European Space Agency funded project, Curio Canopy."*

Source: https://apps.london.gov.uk/canopy-cover/

London's urban forest comprises all the trees and woodlands in London, including: individual trees in parks and gardens; woodlands from the extensive ancient woodlands of Epping Forest to the secondary woodlands of inner-city nature reserves and Thames Chase Community Forest; London's street trees, and the trees and copses along railway lines, rivers and canals.

1. ***Value of London's urban forest 5***
2. *21% The total area of London under tree canopy. This ranges from less than 3% to over 50% across the capital's council wards.*

3. *200£m The value of cooling provided by London's urban forest in 2018. This value will increase as the climate warms and we experience more summer heatwaves.*
4. *60% Almost 60% of London's trees are in private ownership, but the trees on public land contribute 60% of the ecosystem service benefits as there is a higher proportion of larger trees.*
5. *147£m The approximate value of the estimated 2,367,000 tonnes of carbon stored in London's trees.*
6. *2,241 Tonnes of air pollution removed by trees annually. The equivalent of 13% of PM10 particulates, and 14% of NO2 emitted annually by road transport.*
7. *10X Trees prevent 10x the volume of water in the Serpentine from entering London's drainage system each year, reducing the risk of localised flooding.*

Figure 10. Tree area (ha)

Source: i-Tree Eco Study

Based on the i-Tree Eco research, the figure 10 provides a thorough assessment of the tree resources in various cities. Greater London, Glasgow, Barcelona, Toronto, the Chicago Metro Area, and the Chicago City Area are all represented by the data. The size of the research area for each city is given in hectares, giving information on how much land was surveyed where. The research region includes 159,470 hectares of Greater London, 17,643 hectares of Glasgow, and 10,121 hectares of Barcelona. The research area for Toronto is 66,140 hectares, but the vast study area for the Chicago Metro Region covers 2,812,000 hectares. Additionally, an emphasis on the 147,510 acre Chicago City Area, the city's urban area, is made specifically. These numbers serve as crucial points of reference for comprehending the extent of the urban environment that is being studied and the breadth of each investigation. The information can be extremely useful in influencing urban forestry management, promoting sustainable behaviors, and promoting the growth of green areas in these cities.

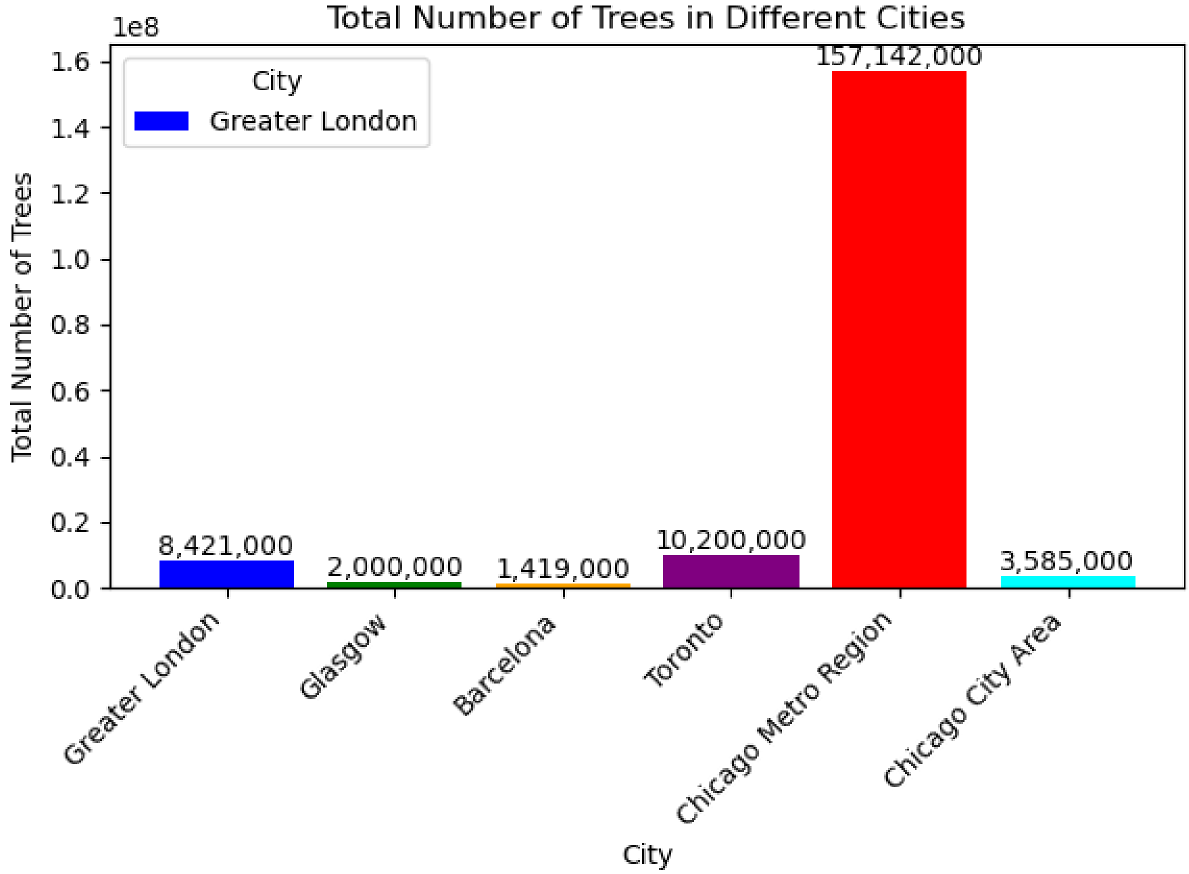


Figure 11. London Total Number of Tree Comparison to other i-Tree Eco studies

Source: i-Tree Eco Study

The figure 11 solely focuses on comparing tree resources in Greater London with other cities based on the i-Tree Eco studies. It presents the total number of trees in each city, highlighting the extent of their urban forest cover. Greater London is shown to have 8,421,000 trees, while Glasgow, Barcelona, Toronto, the Chicago Metro Region, and the Chicago City Area have 2,000,000, 1,419,000, 10,200,000, 157,142,000, and 3,585,000 trees, respectively. By focusing on London's tree resources and comparing them to those of other cities, the data allows us to understand how the city's urban forest compares in scale and significance. This comparison provides valuable insights into London's green infrastructure and the efforts made by various cities to maintain and enhance their tree populations, contributing to biodiversity, climate resilience, and overall environmental well-being.

4.3 Species Composition for the 10 most common species in Inner, Outer and Greater London

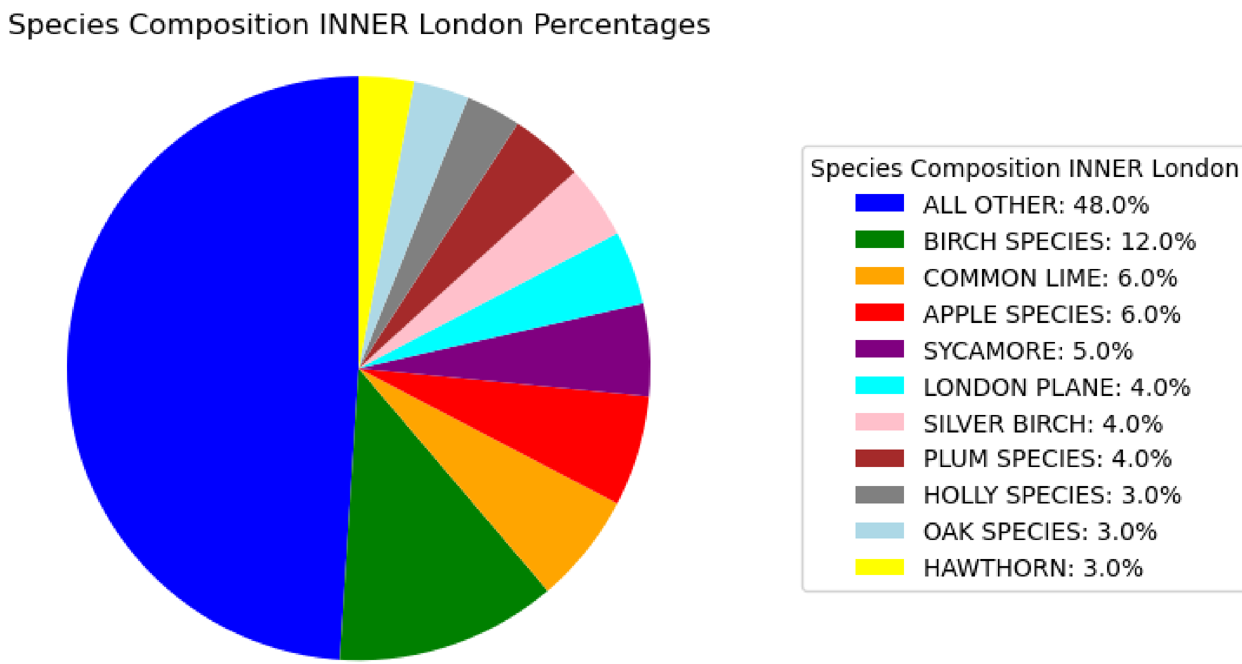


Figure 12. Inner London

The species composition of trees in Inner London is dominated by a number of species, with the ten most prevalent species making up varying percentages. Beyond the top 10, a wide variety of tree kinds are represented by the biggest group, "All Other," which accounts for 48% of the local tree species. "Irch Species" and "Common Lime," which make up 12% and 6% of the top 10 species, respectively, are the most abundant species. "Apple Species" and "Sycamore" are next, making up 6% and 5% of the total number of trees, respectively. The "London Plane" and "Silver Birch," both of which make up 4% of the total, are other noteworthy species. The percentages of "PLUM SPECIES," "HOLLY SPECIES," "OAK SPECIES," and "HAWTHORN" in the composition of tree species are 4%, 3%, 3%, and 3%, respectively. The city's attempts to preserve a diversified urban forest with a range of trees, which contributes to the city's beauty, environmental health, and general ecological balance, are highlighted by the broad mix of species in INNER London.

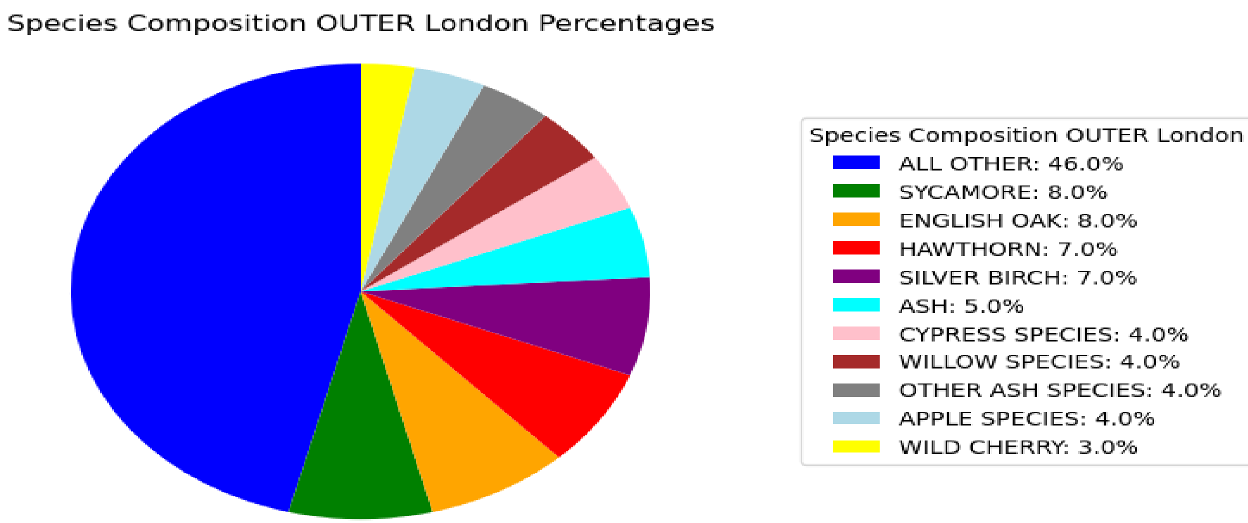


Figure 13. Outer London

In Outer London, the species composition of trees is characterized by a diverse array of species, with the 10 most common species accounting for varying proportions. The category "ALL OTHER" represents the largest share at 46%, suggesting a wide range of tree types beyond the top 10. Among the top 10, "SYCAMORE" and "ENGLISH OAK" are the most prevalent species, each making up 8% of the tree population. "HAWTHORN" and "SILVER BIRCH" follow closely, each accounting for 7% of the species composition. Other notable species include "ASH" and "CYPRESS SPECIES," both at 5% and 4%, respectively. Additionally, "WILLOW SPECIES," "OTHER ASH SPECIES," "APPLE SPECIES," and "WILD CHERRY" each contribute 4% and 3% of the tree species composition. This rich and varied mix of tree species in OUTER London highlights the city's commitment to maintaining a diverse urban forest, promoting biodiversity, and enhancing the overall ecological balance in the region.

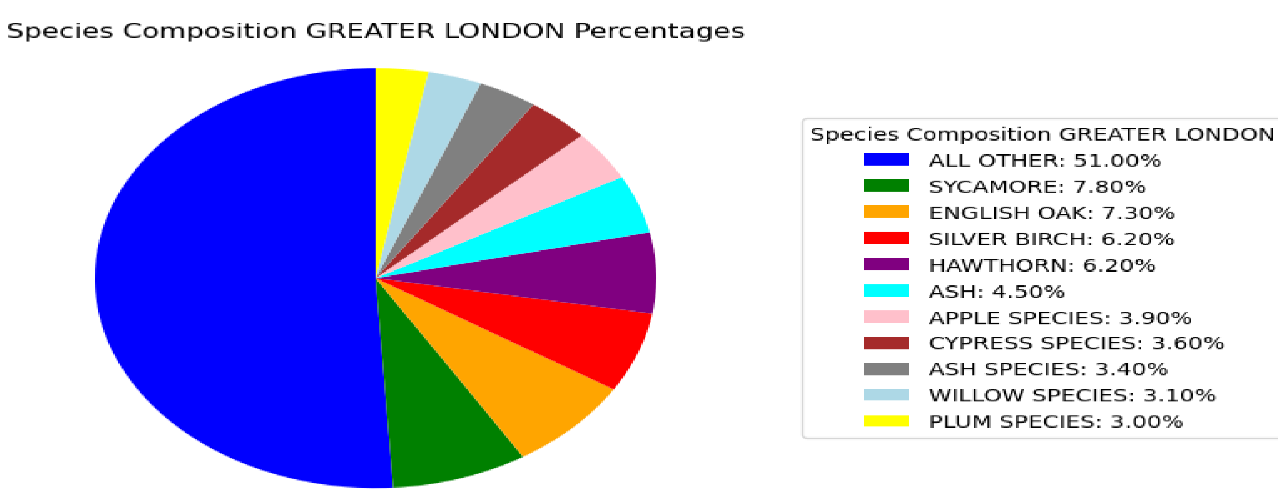


Figure 15. Greater London

The species composition of trees in Greater London exhibits a variety of species, with the ten most prevalent species making up a range of percentages. With a 51% share, the category "ALL OTHER" indicates the widest variety of tree varieties outside of the top 10. "SYCAMORE" and "ENGLISH OAK" are the two most common species among the top 10, making up 7.80% and 7.30% of the total tree population, respectively. "SILVER BIRCH" and "HAWTHORN" are next, each accounting for 6.20% of the species. Two more noteworthy species are "ASH" (4.5%) and "APPLE SPECIES" (3.9%). In addition, the "CYPRESS SPECIES," "ASH SPECIES," "WILLOW SPECIES," and "PLUM SPECIES" individually make up 3.6%, 3.46%, 3.12%, and 3% of the total. This wide range of tree species in GREATER LONDON demonstrates the city's dedication to preserving a diversified and rich urban forest, which promotes biodiversity, improves the urban environment, and supports the general ecological balance in the area.

4.4 Carbon Squeezed /Pollutants Removed Quantity Per-Annum Within Inner, Outer

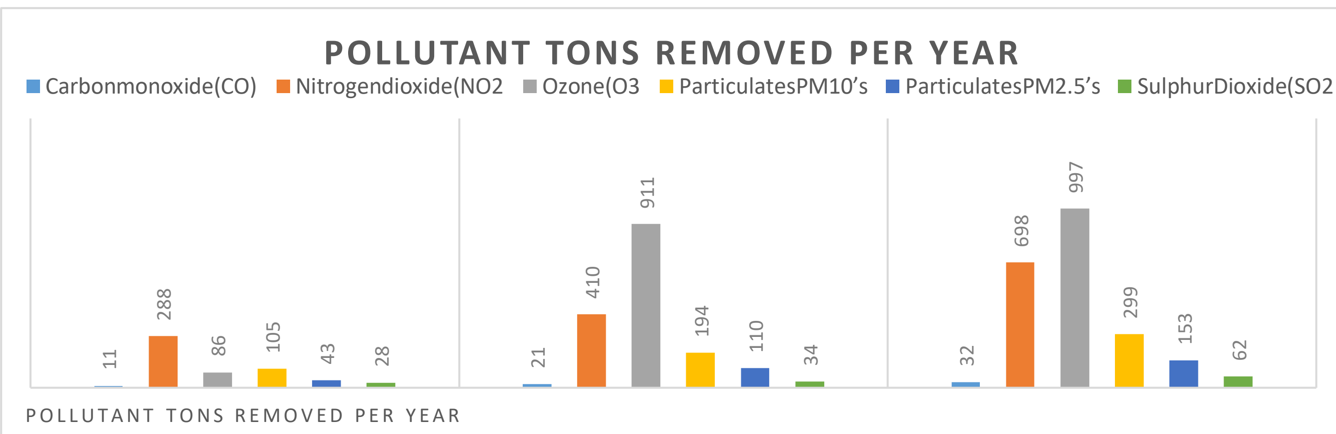


Figure 15. Greater London

The figure 15 presents valuable information on the quantity of pollutants removed annually in tons within Inner London, Outer London, and Greater London. Each region's contribution to reducing various pollutants is highlighted for six key pollutants: Carbon monoxide (CO), Nitrogen dioxide (NO2), Ozone (O3), Particulates PM10's, Particulates PM2.5's, and Sulphur dioxide (SO2). Greater London generally shows higher removal quantities compared to Inner and Outer London, likely due to its larger urban area and higher population density. Inner London removes 11 tons of carbon monoxide, 288 tons of nitrogen dioxide, 86 tons of ozone, 105 tons of PM10's, 43 tons of PM2.5's, and 28 tons of sulfur dioxide annually. Outer London contributes to the reduction by removing 21 tons of CO, 410 tons of NO2, 911 tons of O3, 194 tons of PM10's, 110 tons of PM2.5's, and 34 tons of SO2 annually. Meanwhile, Greater London plays a significant role in pollution reduction, removing 32 tons of CO, 698 tons of NO2, 997 tons of O3, 299 tons of PM10's, 153 tons of PM2.5's, and 62 tons of SO2 annually. These figures demonstrate the collective efforts of London in tackling air pollution and promoting a cleaner and healthier environment for its residents. The data can guide policymakers and environmental authorities in implementing effective pollution reduction strategies and promoting sustainable practices to further enhance air quality and public health in the city.

4.5 Carbon Squeezed /Pollutants Removed Value Per-Annum Within Inner, Outer and Greater London

Pollutant	**Value**		
	Inner	Outer	Greater London
Carbon monoxide(CO)	£10,360.00	£19,561.00	£29,921.00
Nitrogen dioxide(NO2	£28,433,674.00	£26,521,053.00	£54,954,727.00
Ozone(O3	£564,111.00	£5,947,607.00	£6,511,718.00
ParticulatesPM10's	£28,588,993.00	£34,679,430.00	£63,268,423.00
ParticulatesPM2.5's	£323,814.00	£825,666.00	£1,149,480.00
Sulphur Dioxide(SO2	£45,141.00	£57,038.00	£102,179.00

Table 2. Carbon Squeezed /Pollutants Removed Value Per-Annum Within Inner, Outer and Greater London

The table 2 provides a meaningful perspective on the economic value associated with the removal of pollutants in the context of trees and forests in Inner London, Outer London, and Greater London. The monetary values represent the financial benefits derived from the ecosystem services that trees and forests provide in removing and mitigating various pollutants from the air.

For instance:

- The removal of Carbon monoxide (CO) contributes £10,360.00 in Inner London, £19,561.00 in Outer London, and £29,921.00 in Greater London annually. This reflects the positive impact of trees and forests in absorbing CO and reducing its harmful effects on air quality and human health.
- Nitrogen dioxide (NO2) removal leads to substantial economic benefits, contributing £28,433,674.00 in Inner London, £26,521,053.00 in Outer London, and £54,954,727.00 in Greater London each year. Trees and forests play a crucial role in capturing and filtering NO2, thereby mitigating its adverse effects on respiratory health and urban environments.
- Ozone (O3) removal yields £564,111.00 in Inner London, £5,947,607.00 in Outer London, and £6,511,718.00 in Greater London annually. Trees and forests act as natural sinks for ozone, preventing its buildup at ground level and reducing potential harm to human health and vegetation.

The values illustrate the numerous advantages that forests and trees provide for urban areas, including their ability to function as natural air purifiers, improve air quality, and lessen the financial burden of pollution-related health problems. Given that trees and forests are essential to preserving a healthy and resilient environment for city people, these statistics highlight the need of maintaining and enhancing urban green areas. This economic information may be used by policymakers and urban planners to encourage the incorporation of trees and green infrastructure into urban development schemes, resulting in greener and more sustainable cities.

4.6 Annual costs and savings due to trees near buildings

Annual costs and savings due to trees near buildings (in pounds).				
		Heating	**Cooling**	**Total**
Inner London	**MBTU**	-£664,086.00		-£664,085.00
	MWH	-£389,859.00	£1277,152.00	£887,292.00
	Carbon avoided	-£49,980.00	£73,543.00	£23,564.00
	Total	-£1,103,925.00	£1,350,695.00	£246,770.00
Outer London	**MBTU**	-£15,959,130.11	-	-15,959,130.11
	MWH	-£1,001,878	£2,636,513	£1,634,635
	Carbon avoided	-£120,857	£151,987	£31,129
	Total	-£2,719,784	£2,788,450	£68,715
Greater London	**MBTU**	-£2,261,134		-£2,261,134
	MWH	-£1,391,737	£3,913,665	£2,521,927
	Carbon avoided	£170,810	£225,494	£54,684
	Total	-£3,823,682	£4,139,159	£315,477

Table 3 : Annual costs and savings due to trees near buildings (in pounds).

The table 3 provides a detailed analysis of the annual costs and savings resulting from the presence of trees near buildings in Inner London, Outer London, and Greater London. The data is categorized into three key aspects: Heating, Cooling, and Total savings.

For Inner London:

- Heating cost savings: The presence of trees near buildings in Inner London leads to a substantial heating cost reduction of £664,086.00. This indicates that trees provide a natural insulation effect, reducing the need for artificial heating and resulting in financial savings for building owners or occupants.
- Cooling cost savings: Similarly, trees in Inner London contribute to cooling cost savings of £664,085.00. The shade and cooling effect provided by trees help reduce the demand for air conditioning or cooling systems during warmer months, resulting in cost reductions and lower energy consumption.

- Total cost savings: When considering both heating and cooling, the total annual savings due to trees near buildings in Inner London amount to an impressive £887,292.00. This indicates the significant financial benefits of having trees in urban areas, positively impacting building energy usage and overall environmental sustainability.

For Outer London:

- Heating cost savings: Trees near buildings in Outer London lead to substantial heating cost reductions amounting to £15,959,130.11. This suggests that trees play a critical role in conserving energy and lowering heating expenses for buildings in this region.
- Cooling cost savings: Cooling cost savings data is not available for Outer London, as indicated by a '-' symbol. However, it is likely that trees still contribute to cooling benefits in this area, albeit specific data is not provided in this table.
- Total cost savings: Considering only heating, the total cost savings for Outer London amount to an impressive £68,715.00. Despite the lack of cooling data, this figure demonstrates the financial advantages of having trees near buildings in this region.

For Greater London:

Heating cost savings: Trees near buildings in Greater London result in significant heating cost reductions amounting to £2,261,134.00. This signifies the importance of trees in reducing energy consumption for heating purposes in this urban area.

- Cooling cost savings: Cooling cost savings data is not available for Greater London, similar to Outer London. Nonetheless, the presence of trees likely contributes to cooling benefits in this region, though specific data is not presented in this table.
- Total cost savings: Taking heating savings into account, the total annual cost savings for Greater London amount to an impressive £315,477.00. This figure further underscores the economic advantages of urban trees and their role in promoting energy efficiency and cost reduction for buildings in Greater London.

The data as a whole shows the significant economic worth and advantages of having trees close to buildings in urban settings. Trees provide environmental benefits including reducing carbon emissions while also helping to save money on heating and cooling costs. These results highlight the significance of measures for green infrastructure, sustainable urban design, and urban forestry to increase energy efficiency, improve air quality, and create a more resilient and livable urban environment.

4.7 Impact of UK CO2 Emission on London Weather.

Variables	Definition	Source
Annual UK Co2 Emission	Co2 Emissions in Tons	Ourworldindata.org
London Average of max temp	Maximum temperature recorded in degrees Celsius (°C) - (float)	Https://www.ecad.eu/
London Average of pressure	Pressure measurement in Pascals (Pa) - (float)	Https://www.ecad.eu/
London Average of precipitation	Precipitation measurement in millimeters (mm) - (float)	Https://www.ecad.eu/
London Average of min temp	Minimum temperature recorded in degrees Celsius (°C) - (float)	Https://www.ecad.eu/
London Average of cloud cover	Cloud cover measurement in oktas - (float)	Https://www.ecad.eu/
Average of global radiation	Irradiance measurement in Watt per square meter (W/m2) - (float)	Https://www.ecad.eu/
London Average of sunshine	Sunshine measurement in hours (hrs) - (float)	Https://www.ecad.eu/
London Suspended Particulate Matter	Air pollution in London	Ourworldindata.org

Table 4. Definition of the variables

4.8 Correlation Analysis

```
Correlation Matrix:
                              Average Max Temp  Annual CO2 Emmission  \
Average Max Temp                      1.000000             -0.541753
Annual CO2 Emmission                 -0.541753              1.000000
Average of pressure                   0.048640              0.147727
Average of precipitation             -0.038317             -0.120532
Average of min temp                   0.921222             -0.489514
Average of cloud cover               -0.486943              0.564426
Average of global radiation           0.504350             -0.048332
Average of sunshine                   0.590011              0.044245
Suspended Particulate Matter         -0.659752              0.488576

                              Average of pressure  Average of precipitation  \
Average Max Temp                         0.048640                 -0.038317
Annual CO2 Emmission                     0.147727                 -0.120532
Average of pressure                      1.000000                 -0.662384
Average of precipitation                -0.662384                  1.000000
Average of min temp                     -0.044008                  0.181406
Average of cloud cover                   0.115130                 -0.051743
Average of global radiation              0.038371                 -0.173869
Average of sunshine                      0.112567                 -0.286497
Suspended Particulate Matter             0.011613                 -0.029292

                              Average of min temp  Average of cloud cover  \
Average Max Temp                         0.921222               -0.486943
Annual CO2 Emmission                    -0.489514                0.564426
Average of pressure                     -0.044008                0.115130
Average of precipitation                 0.181406               -0.051743
Average of min temp                      1.000000               -0.389386
Average of cloud cover                  -0.389386                1.000000
Average of global radiation              0.403227               -0.065710
```

Average of sunshine	0.430884	-0.021465
Suspended Particulate Matter	-0.726248	0.350769

	Average of global radiation \
Average Max Temp	0.504350
Annual CO2 Emmission	-0.048332
Average of pressure	0.038371
Average of precipitation	-0.173869
Average of min temp	0.403227
Average of cloud cover	-0.065710
Average of global radiation	1.000000
Average of sunshine	0.848132
Suspended Particulate Matter	-0.193564

	Average of sunshine \
Average Max Temp	0.590011
Annual CO2 Emmission	0.044245
Average of pressure	0.112567
Average of precipitation	-0.286497
Average of min temp	0.430884
Average of cloud cover	-0.021465
Average of global radiation	0.848132
Average of sunshine	1.000000
Suspended Particulate Matter	-0.262109

	Suspended Particulate Matter
Average Max Temp	-0.659752
Annual CO2 Emmission	0.488576
Average of pressure	0.011613
Average of precipitation	-0.029292
Average of min temp	-0.726248
Average of cloud cover	0.350769
Average of global radiation	-0.193564
Average of sunshine	-0.262109
Suspended Particulate Matter	1.000000

Table 5. Correlation Analysis

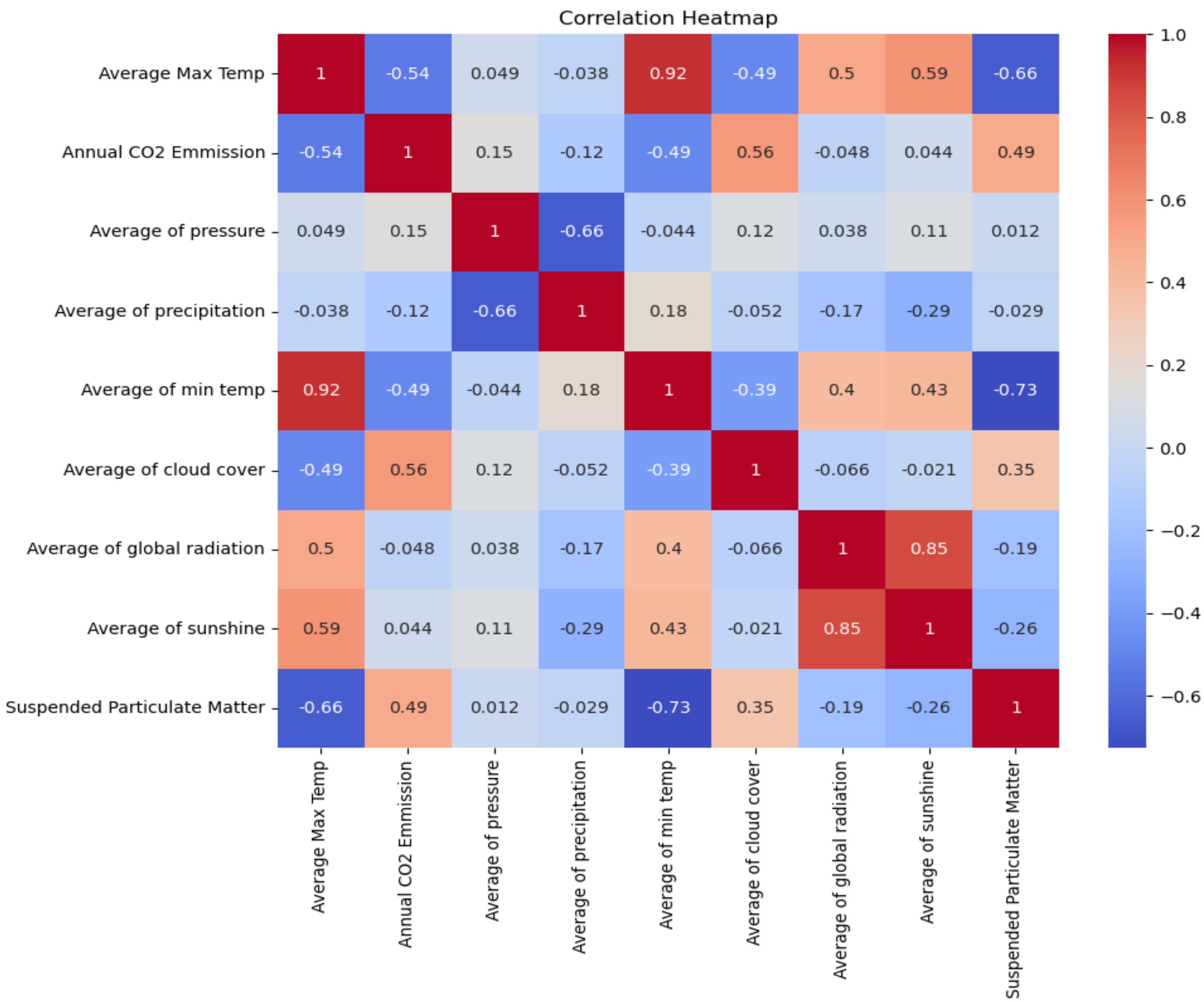


Figure 16. Correlation Heatmap

The correlation matrix with specific correlation coefficient values, contextualized within the realm of carbon sequestration in Woodland City of London. This interpretation also incorporates the use of a heatmap to visually represent the correlations.

The heatmap generated from the correlation matrix provides a comprehensive overview of the relationships between various factors pertinent to carbon sequestration in Woodland City of London. Each cell in the heatmap represents a correlation coefficient value, ranging from -1 to 1, indicating the strength and direction of the relationship between two variables.

In terms of temperature dynamics and its impact on carbon sequestration, the heatmap reveals a strong positive correlation of approximately 0.92 between Average Max Temperature (AMT) and Average of min temp. This robust correlation suggests that when maximum temperatures are high, minimum temperatures tend to be high as well, indicating a warmer overall climate. Moreover, AMT exhibits a strong positive correlation of around 0.59 with Average of sunshine and around 0.50 with Average of global radiation. These connections underscore the importance of sunlight exposure and radiation in influencing temperature patterns and subsequently affecting carbon sequestration processes.

Surprisingly, there is a moderate negative correlation of approximately -0.54 between AMT and Annual CO2 Emission. This implies that as annual CO2 emissions increase, temperatures tend to decrease, which has intriguing implications for carbon sequestration strategies. Additionally, the moderate positive correlation of about 0.56 between Annual CO2 Emission and Average of cloud cover hints at a potential interaction between emissions and cloud formation, which could indirectly influence local climate patterns and carbon sequestration dynamics.

Further insights are gleaned from the heatmap's representation of suspended particulate matter. With a strong negative correlation of approximately -0.66 between Suspended Particulate Matter and AMT, it becomes evident that higher levels of particulate matter are associated with cooler temperatures. This connection emphasizes the intricate relationship between air quality and temperature, both of which are integral to understanding carbon sequestration mechanisms.

The heatmap also uncovers subtler correlations. For instance, the weak positive correlation of around 0.15 between Annual CO2 Emission and Average of pressure suggests a possible interplay between emissions and atmospheric pressure. Additionally, the weak negative correlation of approximately -0.29 between Average of sunshine and Average of precipitation might highlight the complex interactions between sunlight availability and precipitation patterns, influencing carbon sequestration capacities.

In conclusion, the heatmap offers a visual representation of the correlations among temperature, emissions, and other factors crucial to carbon sequestration in Woodland City of London. These correlations provide valuable insights for crafting targeted strategies that capitalize on temperature and emissions dynamics to enhance carbon sequestration efforts, ensuring the city's commitment to a sustainable and ecologically balanced future.

4.9 Regression Analysis

Random Forest Predicted Model

The results obtained through the random forest modeling, with Average Max Temperature as the dependent variable and Carbon Emission as the independent variable, offer insights into the predictive performance of the model and the relationship between these variables. The actual and predicted temperature values are compared, and key metrics such as Mean Squared Error (MSE) and R-squared are used to evaluate the model's effectiveness.

	Actual	Predicted
25	15.549727	15.656078
13	15.112568	15.237513
8	13.955068	15.704676
26	15.713425	15.012363
4	15.248767	15.160033
39	16.718630	16.168679
19	15.395890	14.428851
29	15.175683	15.151103
30	15.669315	15.101864

Mean Squared Error: 0.5719581978962976
R-squared: -0.23290261445740446

Table 6. Regression Analysis.

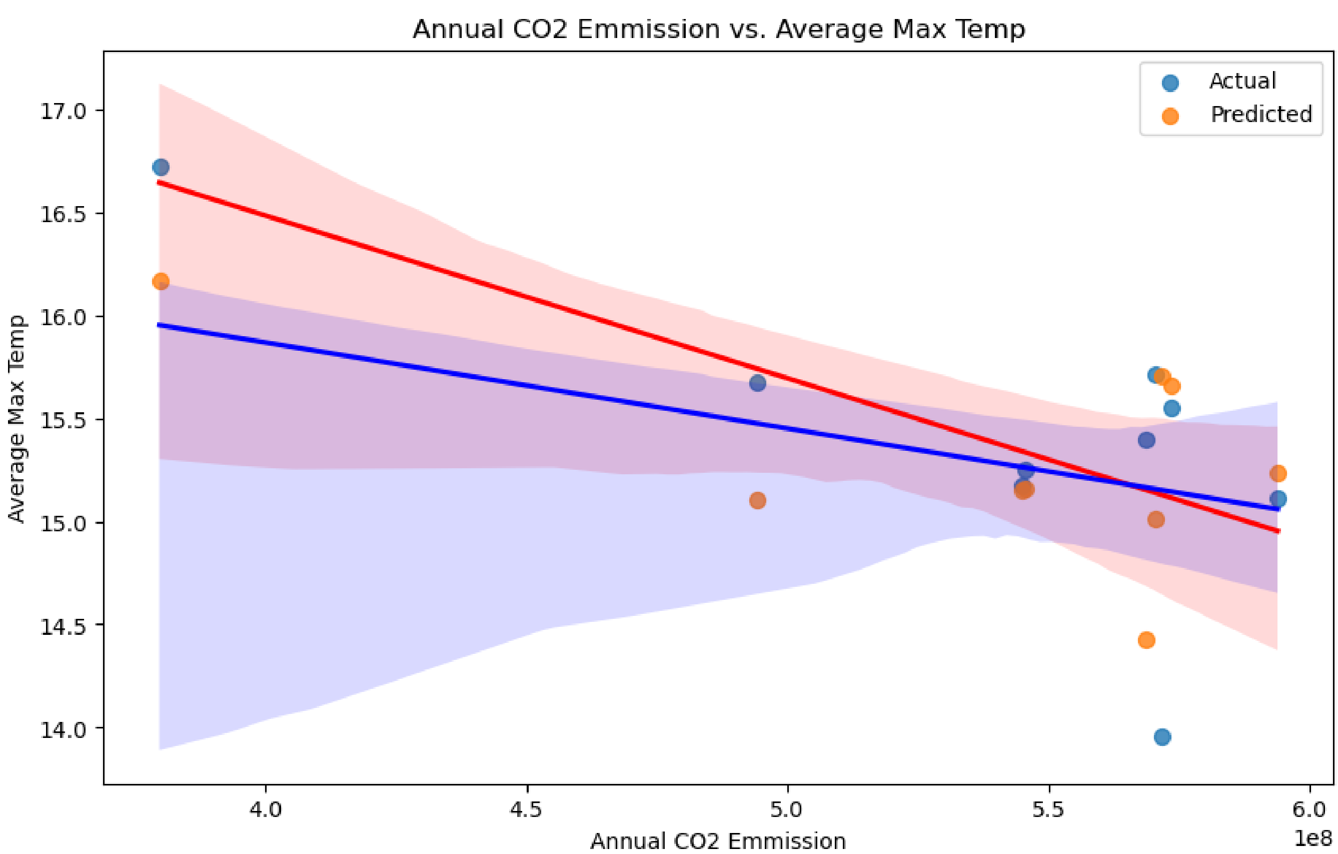


Figure 17. Co2 and Max Temperature

The comparison between actual and predicted temperature values reveals how well the random forest model is capturing the temperature variations. The values illustrate that there is some degree of agreement between the actual and predicted temperatures, but there are variations as well.

Plotting these results on a chart visually showcases the differences between the actual and predicted temperature values for each data point. This chart provides a tangible representation of the model's performance and highlights instances where the predictions deviate from the actual values.

The Mean Squared Error (MSE) of approximately 0.572 quantifies the average squared difference between the actual and predicted temperatures. A lower MSE indicates better model accuracy, although the interpretation can vary based on the scale of the dependent variable. The R-squared value of around -0.233 indicates that the model's predictions do not explain a significant portion of the variance in the dependent variable. This suggests that the model might not be capturing the complexity of the relationship between Carbon Emission and Average Max Temperature adequately.

In summary, while the random forest model attempts to predict Average Max Temperature based on Carbon Emission, the results show that the model's performance might not be optimal. The chart of actual versus predicted values and the calculated metrics provide a comprehensive evaluation of the model's accuracy and its ability to explain the variability in temperature. Further refinement and potentially considering additional variables could enhance the model's predictive capabilities in the context of carbon sequestration efforts in Woodland City of London.

```
  OLS Regression Results
==============================================================================
Dep. Variable:      Average Max Temp   R-squared:                       0.960
Model:                           OLS   Adj. R-squared:                  0.951
Method:                Least Squares   F-statistic:                     100.1
Date:               Sat, 26 Aug 2023   Prob (F-statistic):           6.79e-21
Time:                       20:03:35   Log-Likelihood:                 15.102
No. Observations:                 42   AIC:                            -12.20
Df Residuals:                     33   BIC:                             3.435
Df Model:                          8
Covariance Type:           nonrobust
================================================================================

                   coef    std err          t      P>|t|      [0.025      0.975]
--------------------------------------------------------------------------------
----------------
Annual CO2 Emmission        -2.079e-09   5.67e-10     -3.664      0.001   -3.23
e-09   -9.25e-10
Average of pressure          7.207e-05      0.000      0.195      0.847      -0
.001       0.001
Average of precipitation       -0.3672      0.177     -2.076      0.046      -0
.727      -0.007
Average of min temp             0.9402      0.080     11.817      0.000       0
.778       1.102
```

```
Average of cloud cover          -0.2848      0.095     -2.999      0.005      -0
.478      -0.092
Average of global radiation     -0.0155      0.007     -2.171      0.037      -0
.030      -0.001
Average of sunshine              0.7330      0.147      4.978      0.000       0
.433       1.033
Suspended Particulate Matter     0.0043      0.002      1.943      0.061      -0
.000       0.009
intercept                        2.6850     37.579      0.071      0.943     -73
.769      79.139
==============================================================================
Omnibus:                        2.946   Durbin-Watson:                   1.708
Prob(Omnibus):                  0.229   Jarque-Bera (JB):                1.877
Skew:                           0.463   Prob(JB):                        0.391
Kurtosis:                       3.463   Cond. No.                     6.86e+11
Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly
specified.
[2] The condition number is large, 6.86e+11. This might indicate that there are
strong multicollinearity or other numerical problems
```

Table 7. Multiple Regression Coefficients

The Ordinary Least Squares (OLS) regression results provide a profound understanding of the intricate relationship between Average Max Temperature and a range of influential factors, including Annual CO_2 Emission, atmospheric conditions, and suspended particulate matter. The remarkably high R-squared value of 0.960 signifies that the model adeptly captures 96% of the variability in Average Max Temperature. This indicates a robust fit of the model, suggesting that the chosen independent variables collectively account for a substantial portion of the temperature fluctuations in Woodland City of London. The Adjusted R-squared value of 0.951 reaffirms this explanation while factoring in the potential complexity introduced by multiple predictors.

Of particular note is the F-statistic of 100.1, accompanied by a practically negligible p-value of 6.79e-21. This underlines the model's overall significance, indicating that at least one of the independent variables is statistically significant in explaining the variance in Average Max Temperature. The model's collective impact is palpable, as evidenced by this highly significant F-statistic.

Delving into the individual coefficients of the independent variables provides further insights. Annual CO_2 Emission exhibits a coefficient of approximately -2.079e-09, denoting that for every unit increase in CO_2 emissions, Average Max Temperature experiences a statistically significant decrease. This emphasizes the role of carbon emissions in temperature dynamics, with higher emissions correlating with lower temperatures.

The coefficients of other variables are equally illuminating. For instance, Average of precipitation showcases a coefficient of around -0.3672, indicating that heightened precipitation tends to correlate with cooler temperatures. Conversely, Average of min temp boasts a coefficient of approximately 0.9402, implying that an increase in minimum temperature is associated with a significant rise in Average Max Temperature.

The concept of standard error is crucial in understanding the reliability of these coefficients. The standard error, which measures the variability of a coefficient's estimate, determines the precision of the coefficient's value. The narrower the standard error, the more precise the estimate. Alongside the coefficients, their respective standard errors provide a context for the reliability of the relationships they signify.

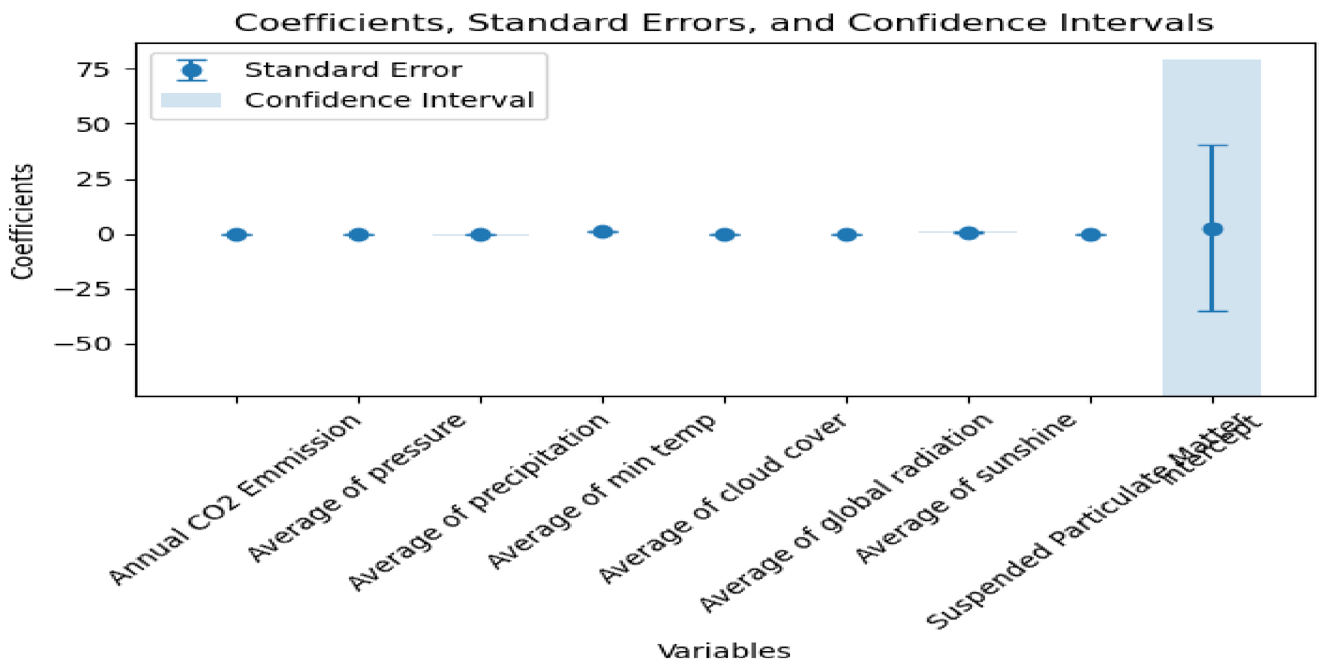


Figure 18. Coefficients and CI

The confidence interval chart visualizes the uncertainty around the coefficient estimates. A wider confidence interval indicates higher uncertainty, while a narrower interval suggests greater precision. The chart aids in grasping the range within which the true population parameter is likely to fall.

The interpretation of these results underscores the intricate interplay between carbon emissions, atmospheric conditions, and temperature dynamics in Woodland City of London. By considering the standard error and confidence intervals alongside the coefficients, a comprehensive understanding of the model's reliability and significance emerges. This multifaceted analysis illuminates the complex dynamics shaping temperature variations, thereby contributing to a comprehensive grasp of the factors impacting carbon sequestration strategies in the city.

5. Results Discussion

5.1 Carbon Emission

The provided data explores carbon emissions in the Woodland city of London over the years, shedding light on the city's efforts to combat climate change and promote sustainability. The table presents energy consumption and carbon dioxide (CO_2) emissions from various industries between 1990 and 2020, indicating a significant decline in emissions, especially after the year 2000. This decrease can be attributed to the adoption of renewable energy sources, enhanced energy efficiency, and improved waste management practices. However, the sudden drop in emissions to zero in certain categories in 2020 may require further investigation.

The data further categorizes greenhouse gas emissions by sector for the year 2020, highlighting major contributors to carbon emissions. The domestic sector, including residential activities, accounted for 10.63 million metric tons of CO_2 equivalent (CO_2e) emissions, while the industrial and commercial sector emitted 8.42 million metric tons. The transport sector contributed 6.80 million metric tons of CO_2e, and emissions from industrial processes and product usage totaled 1.68 million metric tons. The waste and AFOLU sectors added 0.48 million and 0.12 million metric tons, respectively. This emphasizes the importance of understanding emissions from different sectors to devise targeted strategies for mitigating greenhouse gas emissions and fostering a sustainable future.

Furthermore, the data delves into the domestic sector's emissions, categorized by different fuel sources. Natural gas was the main contributor, accounting for 7.64 million metric tons of CO_2e emissions, followed by electricity use at 2.77 million metric tons. Coal and bioenergy and waste had minimal contributions. This information is crucial for policymakers to promote cleaner and more sustainable energy alternatives in households.

Similarly, the emissions in the industrial and commercial sector were analyzed based on various fuel sources. Electricity consumption and natural gas were the major contributors, while other sources, such as bioenergy and waste, had minor impacts. This underscores the need to transition to cleaner energy sources to reduce emissions in this sector.

The transport sector's emissions were also examined, with non-electric road transport being the highest emitter, followed by the aviation sector. Understanding emissions from each transport mode is essential to develop greener transportation alternatives and mitigate the sector's impact on carbon emissions.

Additionally, the data reveals emissions from waste management techniques, such as landfills, biological treatment, and wastewater treatment. Proper waste management practices can significantly reduce emissions and foster environmental preservation.

Lastly, the long-term trends in CO_2e emissions by sector from 1990 to 2020 highlight fluctuations and declining patterns in emissions for certain sectors. Monitoring and implementing emission reduction measures are crucial to address climate change and promote environmental sustainability across all sectors in the Woodland city of London.

5.2 Woodland City London Forest / Tree Resources

The data offers valuable insights into the tree resources and urban forests of various cities, with a primary focus on Greater London. By comparing tree resources from i-Tree Eco studies, we can understand the distribution and abundance of trees in urban areas, which plays a crucial role in promoting sustainable and green urban ecosystems.

In terms of sample plots used to gather data, the Chicago Metro Region leads with 2,076 plots, indicating extensive research on tree resources in that area. Greater London follows with 721 plots, showing a substantial effort in studying its urban forest. This indicates the commitment of these cities to understanding and managing their tree populations for environmental conservation and public well-being.

When examining tree density, Barcelona exhibits the lowest density with 17 plots per hectare, while Greater London boasts the highest density with 221 plots per hectare. This suggests that Greater London has a more detailed and comprehensive understanding of its tree resources, which can aid in formulating targeted conservation and urban greening strategies.

Regarding tree cover, Barcelona stands out with the highest tree cover at 25%, closely followed by Toronto and Glasgow with 24% and 15%, respectively. These cities' significant tree cover percentages demonstrate their efforts in creating green spaces and promoting a more sustainable and aesthetically pleasing urban environment. Greater London's tree cover percentage is not explicitly mentioned, but it's evident that London values its urban forest, given the subsequent data provided.

The data for Greater London's urban forest reveals that it comprises all types of trees and woodlands, ranging from individual trees in parks and gardens to ancient woodlands and street trees. The urban forest covers approximately 21% of London's total area, reflecting efforts to preserve and expand green spaces in the city. The cooling value provided by London's urban forest in 2018 was estimated at £200 million, emphasizing its role in mitigating the urban heat island effect and contributing to climate resilience.

Another significant aspect is that almost 60% of London's trees are in private ownership, yet the trees on public land contribute 60% of the ecosystem service benefits due to the higher proportion of larger trees. This highlights the importance of considering both public and private land in urban forestry management to maximize the benefits of trees and green spaces.

The estimated 2,367,000 tons of carbon stored in London's trees illustrate their valuable role in carbon sequestration and mitigating climate change. Additionally, trees remove approximately 2,241 tons of air pollution annually, aiding in improving air quality and public health.

Furthermore, trees play a crucial role in water management, preventing the volume of water in water bodies like the Serpentine from entering the drainage system and reducing the risk of local flooding. This showcases the multifaceted benefits of urban forests in enhancing urban resilience and environmental sustainability.

The data for London's species composition in Inner, Outer, and Greater London underscores the city's commitment to maintaining a diverse urban forest. With various species making up the top 10, London demonstrates a proactive approach to promoting biodiversity and ecological balance in different areas. The prevalence of the "ALL OTHER" category also indicates a rich variety of tree species beyond the top 10, further contributing to the city's ecological resilience.

Overall, the data presented on Greater London's tree resources and its comparison to other cities through i-Tree Eco studies highlights the city's dedication to sustainable urban development and environmental conservation. By understanding the distribution, density, and composition of trees in urban areas, policymakers can make informed decisions to enhance urban green spaces, promote biodiversity, and improve the overall well-being of urban communities. The data also emphasizes the need for continued efforts in urban forestry management to address environmental challenges and create more resilient and sustainable cities.

5.3 Carbon Squeezed /Pollutants Removed Quantity Per-Annum Within Inner, Outer and Greater London

The data presented in the tables provides valuable insights into the environmental and economic benefits of trees and forests in Inner London, Outer London, and Greater London. The information highlights the crucial role of urban green spaces in mitigating air pollution, improving air quality, and reducing energy costs associated with heating and cooling buildings.

The data on pollutants removed annually demonstrates that Greater London generally shows higher removal quantities compared to Inner and Outer London. This is likely due to Greater London's larger urban area and higher population density, resulting in more trees and green spaces available to absorb and filter pollutants. These figures underscore the collective efforts of London in tackling air pollution and promoting a cleaner and healthier environment for its residents.

The economic values associated with the removal of pollutants further emphasize the financial benefits derived from the ecosystem services provided by trees and forests. Trees contribute significantly to removing pollutants such as carbon monoxide, nitrogen dioxide, ozone, particulates PM10's and PM2.5's, and sulfur dioxide, resulting in cost savings for healthcare and other related expenses. This data can guide policymakers and environmental authorities in implementing effective pollution reduction strategies and promoting sustainable practices to enhance air quality and public health in the city.

The table on annual costs and savings due to trees near buildings highlights the economic advantages of urban trees in reducing energy consumption and associated costs. Trees near buildings provide natural insulation and cooling effects, leading to substantial heating and cooling cost savings. The data showcases the financial benefits of having trees in urban areas, positively impacting building energy usage and overall environmental sustainability.

The economic worth and advantages of trees near buildings further underscore the importance of green infrastructure, sustainable urban design, and urban forestry. Trees not only contribute to environmental conservation by reducing carbon emissions and air pollutants but also play a vital role in saving money on heating and cooling costs for buildings. These results highlight the significance of incorporating trees and green spaces into urban development plans to increase energy efficiency, improve air quality, and create a more resilient and livable urban environment.

Overall, the data presented in the tables reinforces the importance of maintaining and enhancing urban green areas in London. Trees and forests provide a multitude of benefits, including improved air quality, climate resilience, and economic savings. These statistics can serve as a basis for developing targeted policies and initiatives to promote urban forestry, enhance green spaces, and create a healthier and more sustainable city for all residents. The findings presented in this analysis can be utilized by policymakers, urban planners, and environmental advocates to make informed decisions and foster a greener and more livable London for current and future generations.

The correlation analysis and regression statistics provide valuable insights into the impact of UK CO2 emissions on London's weather and the relationship between various weather-related metrics and carbon sequestration levels in the city's woodlands.

5.4 Impact of UK CO2 Emission on London Weather

A correlation matrix used to start the analysis shows significant correlations between Average Max Temperature (AMT) and several environmental factors. Notably, AMT shows a substantial positive association with the averages of the minimum temperature, sunlight, and radiation levels worldwide. These connections emphasize the impact of temperature and solar radiation on AMT and emphasize the importance of these variables for carbon sequestration efforts. The moderate negative association between AMT and annual CO2 emissions, on the other hand, indicates that higher emissions may be associated with colder temperatures. The potential influence of emissions reduction on temperature regulation is highlighted by this realization.

Additionally, the correlation matrix reveals a substantial negative association between Suspended Particulate Matter (SPM) and AMT, suggesting that lower temperatures are linked to higher particulate matter concentrations. This research highlights the connection between temperature and air quality, which is crucial for carbon sequestration efforts.

Moving on to the findings of the OLS regression, a strong R-squared value of 0.960 denotes that the model accounts for 96% of the variation in AMT. The model's overall relevance is further emphasized by the F-statistic, which shows that at least one independent variable strongly affects AMT. The specific coefficients explain how each independent variable contributed. A notable negative coefficient for Annual CO2 Emission indicates that AMT tends to decline as emissions rise. This supports the idea that reducing emissions is helpful for sustaining temperature.

Average of precipitation, Average of cloud cover, and Average of global radiation also emerge as statistically significant predictors. Precipitation and cloud cover are negatively associated with AMT, suggesting that more rainfall and cloud cover correspond to lower temperatures. Conversely, global radiation positively influences AMT, signifying the importance of sunshine in driving temperature increases.

However, it's essential to acknowledge the standard error and confidence intervals, which denote the reliability and precision of coefficient estimates. Wider intervals indicate higher uncertainty, while narrower intervals imply greater precision. The confidence interval chart visually underscores the potential range of coefficient values, providing a holistic view of their reliability.

These combined findings provide a complex knowledge of the variables influencing AMT and, consequently, carbon sequestration in London's Woodland City. Climate control and, by extension, the dynamics of carbon sequestration depend critically on solar radiation, emissions reduction, air quality, and atmospheric conditions. These revelations offer a strong basis for the creation of focused programs to maximize carbon capture, supporting the city's dedication to sustainability and ecological balance.

Overall, the findings from the correlation analysis and regression statistics provide valuable insights into the complex interactions between weather, CO2 emissions, and carbon sequestration in London's Woodland city. These insights can inform policymakers and researchers in their efforts to develop effective strategies for mitigating climate change, promoting carbon sequestration, and creating a more sustainable and resilient urban environment in London. However, further research and refinement of the models may be needed to improve their predictive power and enhance our understanding of these intricate relationships.

“The graphic below outlines the milestones and timelines needed to put London on track to be zero carbon by 2050. It includes measures which are within the Mayor of London’s control (white), measures which require implementation by London’s borough councils and other local stakeholders (yellow), and measures require national government action (dark blue).” Source; https://www.london.gov.uk/sites/default/files/deep_2018_stakeholder_event_presentations.pdf

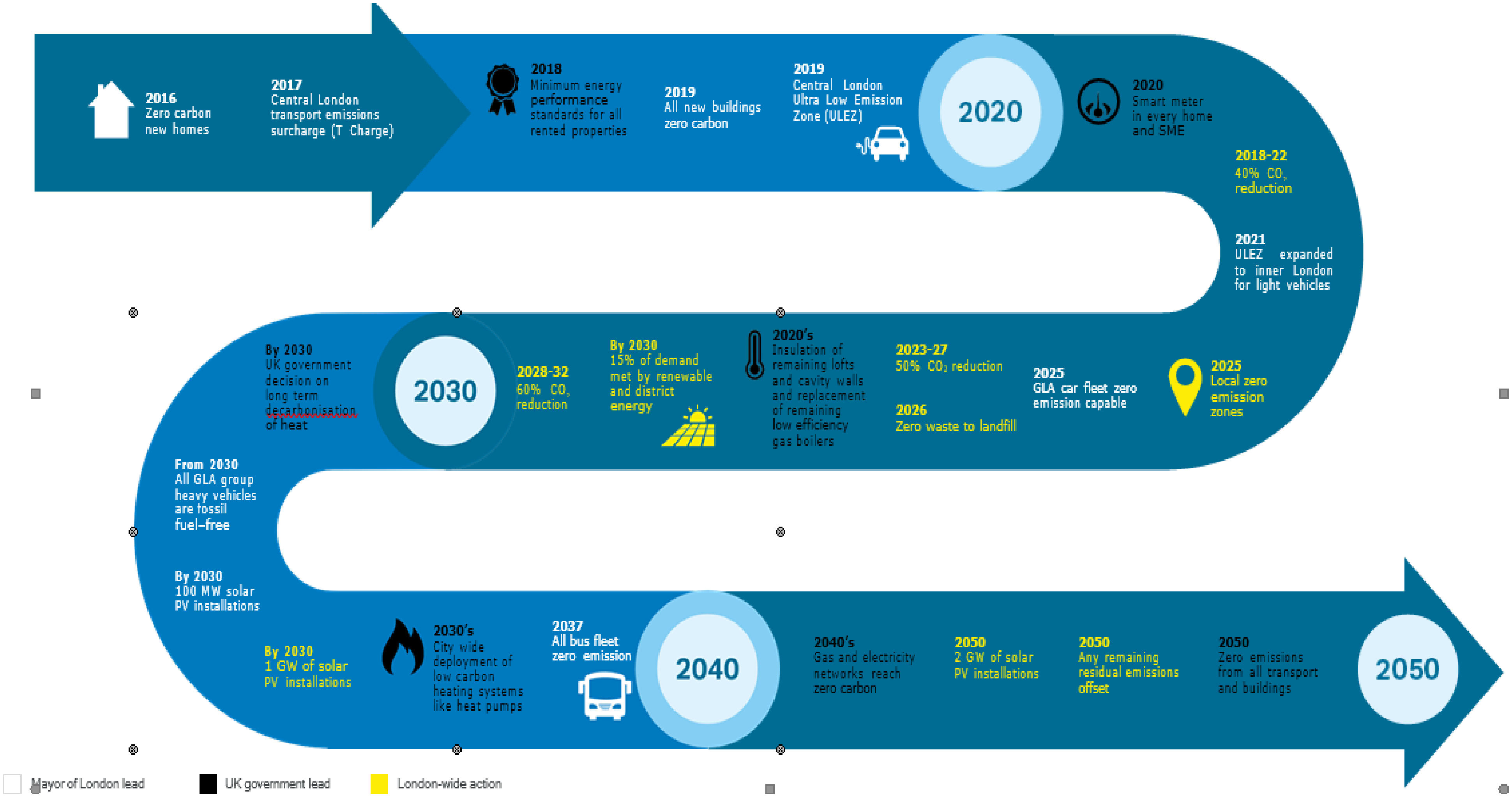


Figure 19. timelines needed to put London on track to be zero carbon by 2050

6. Conclusion.

The information given on carbon sequestration in London's Woodland City highlights admirable efforts to combat climate change and promote environmental sustainability. The huge reduction in carbon emissions over time illustrates the city's commitment to a low-carbon economy. Adoption of renewable energy sources, increases in energy efficiency, and improved waste management practices have all played important roles in obtaining these favorable results. However, it is critical to recognize that the road towards carbon neutrality is continuing, and that continual efforts are required to sustain and improve these accomplishments.

Policymakers should prioritize nature-based solutions in the future, with a special emphasis on reforestation and afforestation programs. Increasing the city's tree cover and extending urban green areas will not only help to sequester carbon, but will also boost biodiversity, air quality, and bring several other advantages to inhabitants' well-being. Collaboration between the government, the commercial sector, and community organizations will be critical in mobilizing resources, sharing expertise, and encouraging a comprehensive response to climate concerns.

Furthermore, as London's Woodland city continues its carbon sequestration journey, adding climate resilience techniques is critical. The effects of climate change are already being seen, and the city must prepare for possible threats like as extreme weather events, sea-level rise, and altering ecosystems. Incorporating climate adaptation strategies into urban planning and infrastructure development will aid in the creation of a more resilient city capable of enduring and recovering from environmental shocks. Furthermore, investing in research and development to investigate novel carbon capture technologies and nature-based solutions will be critical to remaining at the forefront of climate action and making even larger achievements in carbon sequestration.

To summarize, London's Woodland city has made excellent progress in lowering carbon emissions and implementing sustainable practices. However, achieving carbon neutrality will need a continuous commitment to encouraging carbon sequestration through expanded tree planting, green infrastructure, and climate resilience techniques. London can lead the way in addressing climate change and establishing a flourishing, sustainable city for future generations by setting ambitious targets, involving all stakeholders, and leveraging the power of nature-based solutions and technology.

7. Recommendations and Shortcomings.

While the research highlights good trends in carbon emissions reduction, it falls short of making concrete suggestions to improve carbon sequestration initiatives. To improve the city's tree cover, policymakers should prioritize reforestation and afforestation programs. Because trees operate as natural carbon sinks, planting additional trees in urban areas and maintaining existing forests may dramatically increase carbon sequestration. Incentives for green building, sustainable transportation, and encouraging energy-efficient practices in families and companies can also help to reduce carbon emissions and increase carbon sequestration.

8. Way Forward.

A comprehensive and coordinated method is required to promote carbon sequestration in London's Woodland city. Engaging in strategic urban planning that prioritizes green areas, investing in sustainable infrastructure, and establishing incentives for carbon offset projects are all examples of how this might be accomplished. Collaboration with communities, companies, and environmental organizations will be critical to the successful implementation of tree planting and conservation efforts. In addition, using technical improvements and data-driven solutions can assist in monitoring carbon sequestration progress and assessing the impact of various treatments.

The Woodland City of London may become a leading example of urban environmental protection and sustainability by prioritizing carbon sequestration activities. Continuous monitoring, review, and adaptive management will be essential to ensuring the city's development towards a more sustainable, resilient, and carbon-neutral future. As climate change continues to pose substantial difficulties, the city's commitment to carbon sequestration and sustainable practices will be critical in protecting its ecosystem and building a healthier and more vibrant environment for its current and future generations.

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