UNIVERSITY of STIRLING

Case Study 2 - Leveraging Data Science to Improve Transport Efficiency and Accessibility in Scotland

Name- Jeet Parashar

Student Number- 3459046

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Executive Summary

This dissertation explores the differences in bus transportation between Edinburgh, as an urban case, and Stirling, as a rural case. The objectives were to identify service gaps in bus accessibility, track changes in residents' satisfaction levels in service over time, assess the integration of bus services with cycle hire docking stations, analyze changes in cycle hire demand, and gauge how all these factors contribute towards achieving Scotland's Net Zero 2045 target. The study utilized open data sets, including NaPTAN bus stops, the Public Transport Indicator, NextBike trip data, and emissions records. These datasets were preprocessed in Power Query and analyzed in Power BI to produce visualizations including maps, graphs, and overlays. The findings indicate a pronounced urban-rural gap: Edinburgh has 2,479 bus stops distributed within the city, as compared to Stirling, where 970 are located and a majority of the countryside has only 1 or 2. Data on satisfaction levels between 2005 and 2025 demonstrates Edinburgh's higher, stable satisfaction levels above 80% while Stirling was lower and more volatile, plunging to 49% in the year 2020. The integrated study indicates a singular concentration of NextBike stations around the city center and university campus, with a distinctive secondary concentration around certain bus stops, suggesting an absence of last-mile connections for non-motorized CW users boarding buses in the outer suburban and rural zones. Demand data demonstrates a rapid decline in privately hired cycle trips for the years of 2022 and 2024, chronicling a decrease from 0.38 million to 0.09 million. Demand for bus services post COVID-19, although still suppressed as compared to the pre-pandemic levels, has shown an upward trajectory. Emission statistics illustrate the fact that the transport sector in Scotland is the largest emitter of greenhouse gases, estimated to constitute 31.7% of the total emissions in the year 2022. Meanwhile Stirling has the highest per capita CO2 emissions due to excessive automobile dependency, which are 40% above the average. The contribution of the current study is to bridge the local access gap identified in the study, by showing a 20-year gap in user satisfaction, integration neglect between bus and cycling services, and the use of multiple data sources in Power BI to aid conversations around NTS2 and Net Zero 2045. Considering these findings, this dissertation suggests that Stirling Council extend bus and cycle hire services further out of the city center, that Transport Scotland allocates more monitored rural funding and satisfaction tracking, and that Net Zero policies incorporate electric buses, integrated bus-bike ticketing, and fare incentives alongside employer sponsorship. In summary, the research illustrates that advancing Scotland's transport and climate objectives would require, in addition to rural communities having cleaner vehicles, an increased effort to more equitable access, greater integration, and bolstered support to rural areas.

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Chapter -1

1.1 Background

The availability of public transport is crucial for mobility within urban areas as well as the countryside. It influences the ease with which a person can access jobs, education, health facilities, and participate in social activities. With the capability of accommodating 2,479 bus stops, the capital city of Scotland, Edinburgh, is helped a lot by the public transport network which provides bus and tram as well as light rail facilities. In 2019, bus transport accounted for 74% of public transport usage (*Scottish Transport Statistics 2024 | Transport Scotland*). Despite the importance of buses, they have a lot of problems to resolve, such as decline in support as well as geographic inequalities in service accessibility. (Scottish Transport Statistics, 2024)

The public transport network is quite unevenly distributed, which clearly reflects the under provision of bus services in the countryside. Take for instance, Edinburgh and the rural city of Stirling. Edinburgh has a capital city advantage which makes the public transport network a lot better than Stirling. Apart from having 970 bus stops, Stirling has a bus system that is poorly serviced, unreliable, and under connected to other transport facilities.

The National Transport Strategy 2022 highlights some of the key issues that Scotland faces which include reducing inequality and sustainable and inclusive transport (National Transport Strategy (NTS2) Transport Scotland, 2022h). However, according to the consultation Stirling Council Sustainable Mobility Strategy 2023 , residents of the outer areas reported being disconnected from the bus services, experiencing unreliable and expensive bus services and having no services during evenings and weekends. Such situations aggravate social exclusion, foster the reliance on private cars, and obstruct climate goals of Scotland. (Stirling Council)(National Transport Strategy (NTS2), p6, 2022**.)**

From an environmental perspective, transport remains the largest emitting sector, accounting for 36% of Scotland's greenhouse gas emissions (*Chapter 13 - Environment | Transport Scotland*). The reason is said to be Stirling's heavy reliance on Fossil Fuel Transport while travel to Stirling. This is believed to be the reason on why Stirling's transport emission is so high. (Stirling Council). only serves to accentuate the problem. This highlights the need for enhanced bus services and greater accessibility to public transit as means of achieving social justice and reducing emissions.

1.2 Rationale

Accessing public transport is not simply a means of getting from point A to point B; it also involves social justice, potential economic advancement, and protection for the ecological system. Buses are the most popular mode of public transport in Scotland, accounting for 74% of total public transport use in 2023-24. Unfortunately, this dependence is not evenly distributed, as there are glaring inequities in accessibility to services between urban centers such as Edinburgh and the rural countryside of Stirling. (*Scottish Transport Statistics 2024 | Transport Scotland*)

This dissertation adopts a case study methodology in contrasting Edinburgh (urban) and Stirling (rural) to shed light on the urban rural disparity in bus access. The justification for this study rests on three interlinked and interdependent sets of problems:

i. *Satisfaction Gap*
The results of the Public Transport Indicator Dataset clearly indicate that in respect to public transport, satisfaction is markedly higher in large urban areas 68% satisfied in 2022 as compared to 40% - 42% in remote rural areas.This data indicates that whereas Edinburgh has strong coverage of buses, demand in the rural parts of Stirling is poorly satisfied, poorly integrated, and results in lower customer satisfaction and greater access deficit. (*Public Transport | Transport Scotland*)

ii. *Accessibility Gap*
A full 30% of the population in remote rural areas reports no bus stop within a 15-minute walk of their house, with half of those reporting no available bus service (Transport Connectivity for Remote Communities in Scotland, p15)

iii. *Integration Gap with Active Travel & Multi Model Transport*
The National Transport Strategy Monitoring and Evaluation 2019 Baseline Report has identified the reduction of socio-economic disparities and the improvement of system sustainability as the primary targets of the strategy (National Transport Strategy (NTS2) Transport Scotland, 2022h). The Power BI integration overlay of Stirling's NextBike stations and bus stops reveals a significant gap in integration. Most bike stations in the bus and bike stations of the city centre and the university have no associated bus stops, which makes intermodal transfer cumbersome. Such integration gaps severely curtail last mile connectivity and diminish the efficacy of multi-modal transport offered in Stirling. (. (National Transport Strategy (NTS 2), 2022)

iv. *Transport Emission*
In the year 2019, the most recent year available, Scotland's greenhouse gas emissions were comprised of 36% Transport (including international shipping and aviation) emissions which includes international shipping and even aviation (*Chapter 13 - Environment | Transport Scotland*)

Stirling Higher Emission: Stirling's transport CO2 emissions are currently 40% above the Scottish average. (Sustainable Mobility Strategy, p7, 2025)

Net Zero Target: Scotland legislated for a net zero by 2045 target and because of this, transport and travel transport emissions must be reduced. Increasing the accessibility of buses, along with support of the above targets, will encourage a shift from private cars and an increase in cycling and bus usage.

1.3 Aim

This dissertation sets forth to primarily conduct a comparative study on the Public Transport Accessibility within Edinburgh city and Stirling town about bus services, user satisfaction, multi modal transport, environmental considerations, and recognizing accessibility gaps and suggesting interventions within the context of Scottish transport and greenhouse gas emissions. This dissertation seeks to compare the accessibility of public transport in Edinburgh and the Stirling town. More precisely, the dissertation focuses on bus services, user satisfaction, cycling in bus transit, intermodal transit, and the peripheral impacts of the environment (*Chapter 13 - Environment | Transport Scotland*). The focus is to develop an access inequality and environmental degradation factor access disparity problem and siloed recommendations in alignment with the transport and climate policy of Scotland, particularly the National Transport Strategy (NTS 2), 2022 and the Net Zero 2045 commitment (National Transport Strategy (NTS2) Transport Scotland, 2022h). This aim has been translated within a framework of objectives. The report 'Scottish Transport Statistics 2024' notes that transport is the largest source of emissions in Scotland, accounting for 31.7% of the country's emissions in 2022 (*Scottish Transport Statistics 2024 | Transport Scotland*). Buses are rather significant in this, with Scotland accounting for 14% of total bus emissions in the UK, which is disproportionate to the population. Although buses are more efficient in comparison to cars, the lack of adequate bus service coverage in regions such as rural Stirling means that a larger portion of the population still depends on cars, hence increasing overall emissions. This demonstrates that the case for improving bus services is not simply about providing better transport options, but also about strategically helping Scotland in reducing emissions and achieving the Net Zero target by 2045.

1.4 Objective

This dissertation aims to maintain focus on the accessibility of transport across the urban–rural divide while adding methodological rigor by integrating the concepts of accessibility, integration, satisfaction, demand, and environmental impact. Using NaPTAN open data, the study demonstrates the spatial distribution and frequency of bus stops within Edinburgh and Stirling, thus illustrating the direct contrast of accessibility in urban and rural settings.

The second group focuses on evaluating the Public Transport Indicator Dataset derived from the Scottish Household Survey to analyze gaps in the perceived quality of services from the urban and rural populations' satisfaction trends and equity concerns.

The district level analysis was conducted on Stirling public transport bus stop location dataset (660) to determine bus service gaps, inadequacies, or absences, often referred to as 'bus deserts', which illustrate the rural provision gaps in accessibility.

The analysis on the integration of multiple modes of transport evaluates the spatial overlay of Stirling bus stops and NextBike docking stations to assess the extent to which cycling provides last mile connectivity. Usage patterns for bus, bicycle, and cycle hire demand are examined between 2022 and 2024 with the help of Combined NextBike 2022,2024 Dataset and the bus

dataset, focusing on developments on urban plus rural areas (*Scottish Government Riaghaltas na H-Alba Gov.scot*, 2021).

The research evaluates the role of transport, and in particular buses, in the total greenhouse gas emissions of Scotland based on Emissions Datasets (ENV0201,13.2, 13.3, 13.4 tables) and seeks to relate this to the urban rural imbalance, meanwhile considering the country's climate goals, including Net Zero 2045.

Demand trends for buses, bicycles, and cycle hire are analyzed across 2022 to 2024, providing insights into changing usage patterns in both urban and rural areas.

The research evaluates the role of transport, and in particular buses, in the total greenhouse gas emissions of Scotland based on secondary emission datasets and seeks to relate this to the urban rural imbalance, meanwhile considering the country's climate goals, including Net Zero 2045.

Drawing from the conclusions of the findings, the dissertation will put forward strategies focusing on emissions mitigation, improving accessibility, integration, and increasing passenger satisfaction while providing proof of their efficacy and ensuring alignment with the National Transport Strategy 2022 and support sustainability objectives. National Transport Strategy (NTS2), 2022

Chapter - 2

2. Problem Exploration & Analysis

This chapter addresses the crucial challenges concerning the accessibility of bus transport in Scotland, focusing on the contrasting context of urban Edinburgh and rural Stirling. There is a stark gap in the user experience at a national level: "*Satisfaction with public transport was lowest in rural and accessible rural areas 40% to 42% respectively contrasted with a satisfaction rate of 68% for those living in large urban areas"* (*Public Transport | Transport Scotland*). Disparities noted in the Sustainable Mobility Strategy, 2025, reported that residents in outlying settlements frequently experience unreliable, infrequent, and pricey bus options, with almost no service on evenings and weekends (Stirling Council). Guided by these insights, this dissertation utilizes open datasets, along with Power BI visualizations, to analyze five interconnected problems. It addresses bus stop accessibility, satisfaction with services, integration with active travel, demand trends, and emission. Previous reports, to a great extent, indicated averages. This report focuses on the micro aspects of the problems to form a comprehensive framework highlighting the evidence justifying the need for sensitive targeted measures.

In a similar fashion, this dissertation demonstrated deep analysis of open datasets and visualizations identifying several problems concretely. Using Edinburgh Bus Stop Dataset (620), Stirling public transport bus stop location dataset (660), and Data Zone Accessibility Dataset, I realized that Stirling, having a total of 970 bus stops, suffers from bus stop distribution inequity. Numerous neighborhoods, for instance, Argaty and Ashfield, have only one or two bus stops, creating a lack of bus stops. Review of Public Transport Indicator dataset

isolating long term trends revealed that while Edinburgh satisfaction rates were above 80% for many years, Stirling has suffered severe dissatisfaction and collapsed as low as 49% in 2020 and has not recovered (Transport and Travel in Scotland, 2022).While Integrating and analyzing NextBike Dataset 2022, NextBike Dataset 2024, and NextBike Dataset 2025 demonstrated that NextBike docking stations are largely in the city center and University campus, leaving the majority of bus stops poorly connected to cycling facilities for last mile connectivity. Demand analysis of Combined NextBike 2022,2024 combined dataset and cycle hire data indicate concerning trends in cycle hire activity stagnation (0.38M trips in 2022 to 0.09M in 2024) and slower bus recovery in Stirling, indicative of limited resilient, sustainable transport shifts. From Emissions Datasets (ENV0201,13.2, 13.3, 13.4 tables) of Scotland Greenhouse emission dataset, it was reconfirmed that transport is the highest emitter in Scotland with 36% of greenhouse gas, as well as the country's major emitter.

2.1 Accessibility of Bus Stops

The basis of transport equity has many elements, including accessibility. Stirling has 970 bus stops, as does Edinburgh, with 2,479 bus stops, but there is a striking difference in accessibility. Some of the rural settlements have very few bus stops which seriously restricts the ability of the residents to get to work, school, or use the available services.

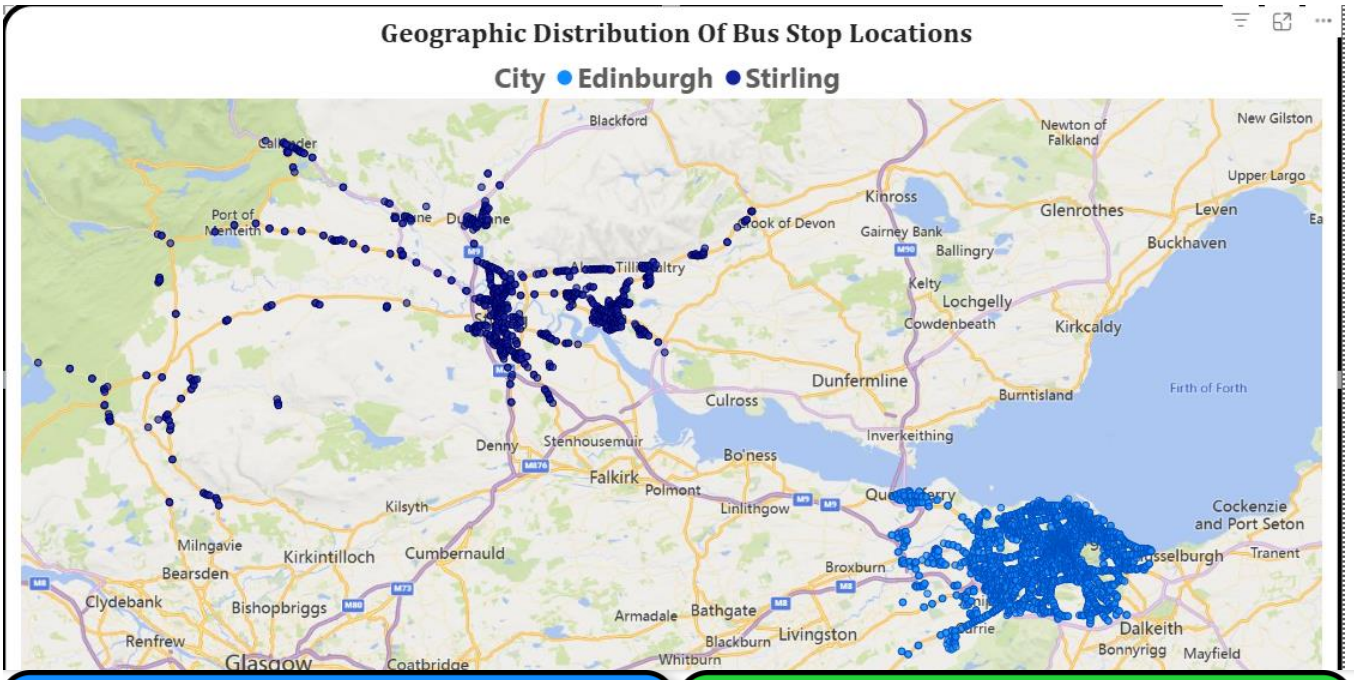

Figure 2.1.1 Geographic Distribution of Bus Stop Locations

Figure 2.1.2 Bus Stop Count

Analysis Conducted

In my attempt to map the density of bus stops within the region, I relied heavily on the resources of derived Edinburgh Bus Stop Dataset(620), Stirling public transport bus stop location dataset (660), and Data Zone Accessibility Dataset. For Edinburgh, the stops are evenly spaced across all the neighborhoods, with higher clusters densely populated around the central regions and along the main corridors. As for Stirling, the accessibility is quite patchy. Settlements of Argaty, Ashfield, and Kilmahog, for instance, have only one or two stops, resulting in very low provisions of accessibility. Even though the dataset in these stop less areas doesn't accurately represent the areas with zero bus stops, the data still demonstrates nearby neighborhoods, so called “Bus Deserts”, and the peripheral neighborhoods having very low accessibility.

Supporting Evidence

In its survey of the Scottish rural population, 30% of rural persons in Scotland do not have a bus stop within a 15-minute walk, and this confirms the situation noted in Stirling (*Public Transport | Transport Scotland*) (Laird and International Transport Forum, 2020c)In the same way, Stirling Council’s Draft Sustainable Mobility Strategy (2023) consultation showed that many residents in these outer settlements consider themselves “disconnected” from the bus network, and this was especially the case during the evenings and weekends (Stirling Council)

Insight

The evaluation of bus stop accessibility undertaken for Edinburgh and Stirling unequivocally demonstrates the rural–urban disparity in public transport service provision. The study, which used cleaned datasets alongside Power BI visualizations, assessed the bus stops in both areas in terms of density, distribution and distribution across neighborhoods.

In the case of Edinburgh, the dataset used contained 2479 bus stops which were geographically evenly spread across the city. The visual representations demonstrated that almost all the residential region was within proximity to at least one bus stop and that multiple stops were available to several neighborhoods. This resulted in the passengers having multiple options, thus reducing the walking distance to the stops, making public transport much more efficient for the commuters. The visualizations illustrated that the system was not only extensive, but also well integrated, providing ample access in the urban and suburban areas of the city along with the surrounding areas to popularize public transport.

In stark contrast to the previous case, Stirling had only 970 bus stops which were also scattered in an unbalanced manner. Central Stirling and Bridge of Allan had many clustered stops but rural dominions surrounding villages like Argaty, Ashfield, Kilmahog and Balmaha had only one or two stops. The Power BI density maps also showed these areas, alongside many others, to be severely underserved or not served at all.

2.2 Satisfaction With Bus Services

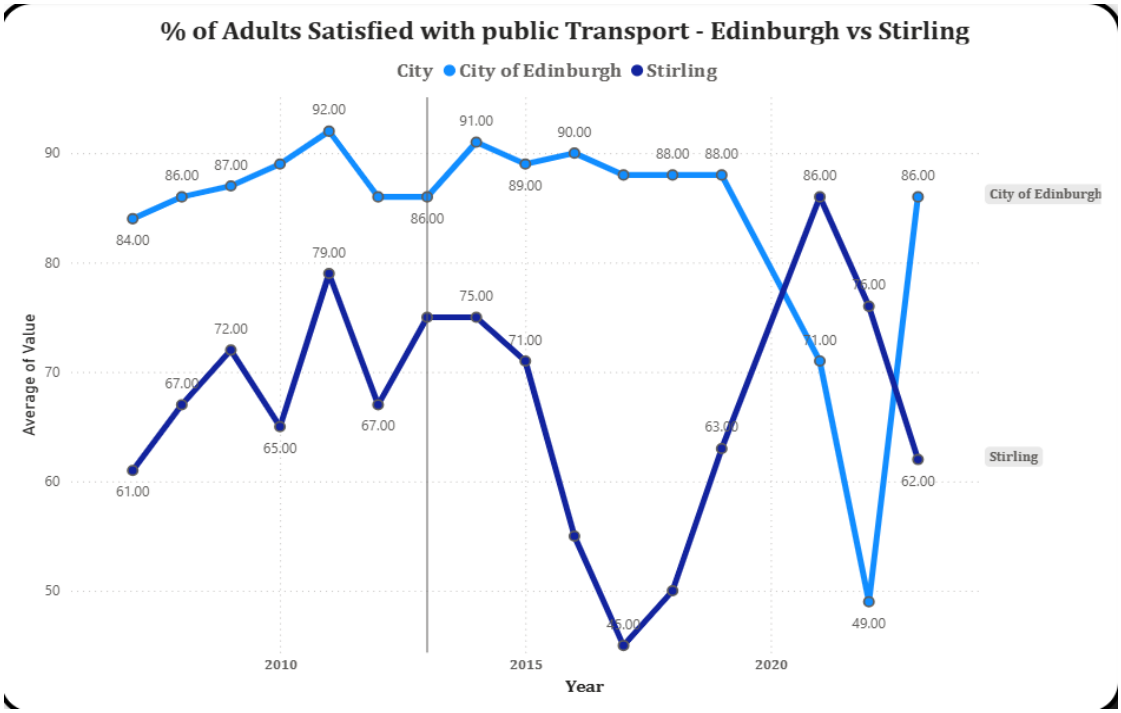

Figure 2.2.1 - %Adults satisfied with public transport

Analysis Conducted

I have constructed a line chart that measures the Public Transport Indicator time series (2005-2025) and compares Edinburgh (urban) to Stirling (rural). The chart indicates that Edinburgh's initial satisfaction score soared and maintained the same level for most of the period; 84% in 2005, a peak of 92% in 2011 and mid to upper 80's until 2018. During the pandemic, Edinburgh's score dropped to approximately 49% in 2020 and recovered to 71% in 2021 and 86% by 2023. Certainly, Edinburgh demonstrates a strong baseline satisfaction score and a visible V-shape recovery after COVID-19.

In contrast, Stirling demonstrates a much more volatile pattern. Satisfaction increased from approximately 61% in 2005 to 79% in 2011 but then dropped drastically to 45% in 2017 and 55% in 2020. Although there was a short rise to the mid 80's in 2021, that was the peak as satisfaction fell to 62% by 2023. The instability further supports the results of your dissertation. Customers in rural areas with sparse bus services experience low service quality and highly variable public feedback over time.

The local findings corroborate national evidence. According to Transport Scotland, the level of satisfaction with public transport is much greater in large metropolitan areas than in rural and remote regions 68% of respondents in 2022 in large urban areas as compared to 40–42% in remote/accessible rural areas (*Public Transport | Transport Scotland*) confirming the urban-rural gap that visual shows. The most recent monitoring also demonstrates that the pattern continues, with 72% satisfaction in large urban areas as compared to 47% and 46% in remote and accessible rural areas in 2023 (*Public transport | Transport Scotland*, no date d).

Supporting Evidence

The nationally gathered evidence has greatly influenced the analysis of the line chart findings. As highlighted in the report Transport and Travel in Scotland 2022, “Large Urban areas had 68 per cent satisfaction rate while Accessible Rural areas and Remote Rural areas had 42 per cent and 40 per cent satisfaction, respectively, which indicates disparity.” Transport and Travel in Scotland 2022. Differences in satisfaction in Edinburgh and Stirling support the urban-rural satisfaction divide. Edinburgh satisfaction levels remained high and consistent while Stirling faced more variable and lower satisfaction levels. The trend holds in the results from 2023 satisfying levels in Large Urban areas were higher (72%) versus Rural areas (just 46–47%) (*Public transport | Transport Scotland*, no date d).The cumulative evidence corroborates the qualitative data in the dissertation, providing definitive proof that the bus services in rural locations like Stirling are of lesser quality and greater disparity than those offered in urban centers like Edinburgh.

Insights

The line graph illustrates the difference between the urban and rural customer's satisfaction with the bus services. Customer satisfaction in Edinburgh remained relatively high, being above 80% throughout, while in Stirling, the graph showed much more volatility, with sharp drops and an inability to reach the former satisfaction levels. The difference, which at times is over 40%, is alarming and demonstrates the deep level of disadvantage rural customers face. The issue of being permanent is indicative of service provision patterns. The data implies that there is very little designed effort to serve the bus transit needs of rural areas which are more unreliable than the urban ones.

2.3 Integration with Active Travel

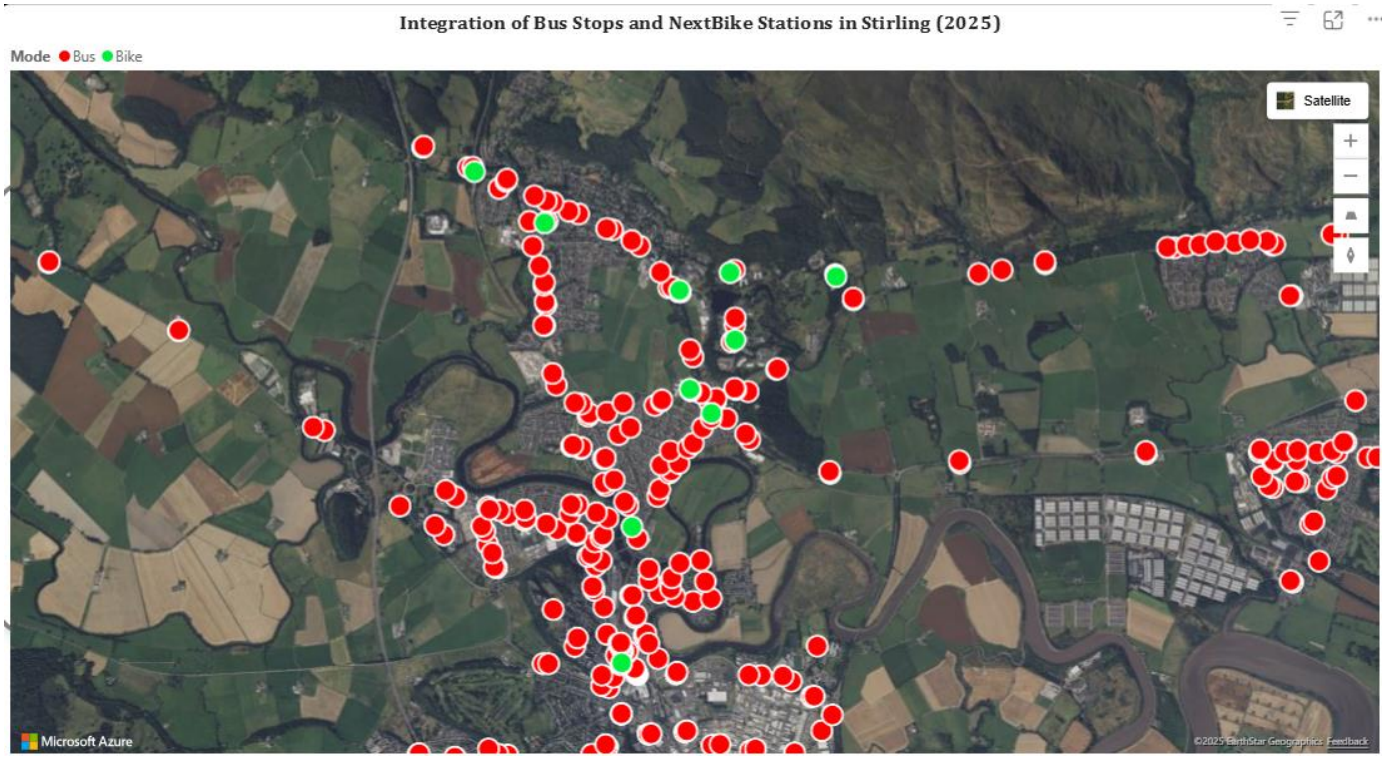

Figure 2.3.1 Integration of Bus Stops and Next Bike Stations in Stirling(2025)

Analysis Conducted

Having scrutinized the documents NextBike 2022 dataset, NextBike 2024 dataset and NextBike 2025 dataset, I superimposed the locations of NextBike docking stations with bus stop locations. The analysis showed that cycle hire stations are predominantly positioned within Stirling city center and the University campus, with a nearly total absence from suburban and rural areas. This means that most bus stops are poorly linked to cycling facilities, giving rise to significant last mile connectivity gaps.

Supporting Evidence

The visual indicates that the NextBike stations in Stirling are primarily located in the central areas of the city and in and around the University Campus. Coverage is sparse or absent in the suburbs and rural areas. This underlines the issues identified in the Cycling Framework for Active Travel 2030(Transport Scotland, 2023g) which aspires for “walking and cycling to be the most popular choice for everyday short journeys,” but relies heavily on safe access to the public transport system (Transport Scotland, 2023g). The absence of bus stops next to cycle hire facilities in Stirling starkly illustrates the extent to which the current system fails to realize this vision, resulting in

rural dwellers remaining reliant on private vehicles, while also restricting options for sustainable, multi-modal travel.

Insight

We should consider the troubling ‘double disadvantage’ identified in the study on Stirling. In particular, the peripheral areas tend to have poor bus access. For instance, while the core areas of Stirling and the Bridge of Allan have several stops, many other rural settlements only have one or two stops. This makes daily commutes by bus almost impossible. As a result, people living in these areas either have to walk long distances to reach the bus stops or are highly constrained in their travel options.

Worse still, the situation is exacerbated by the absence of active transport connections, particularly cycling. In other cities, like Edinburgh, cyclists are in great part catered for by the buses. A case in point is bike-sharing schemes, such as NextBike, which offer functional integration at the ends of the route, enabling users to access bus stops or to continue their trips after disembarking from a bus. In stark contrast, Stirling experiences a bus-NexBike intersection which is minimal. Analysis performed using the Power BI overlays revealed that many bus stops are far from docking stations, which makes cycling and bus travel an impractical combination.

This leads to a unique form of disadvantage. Many neighborhoods do not even have a bus service, and do not have any other form of public sustainable transportation to connect them. People living in those poorly serviced areas become even more reliant on private motor cars. This creates social inequity and counters Scotland’s aims of emission reduction and sustainable mobility.

2.4 Demand Trends and Behavior

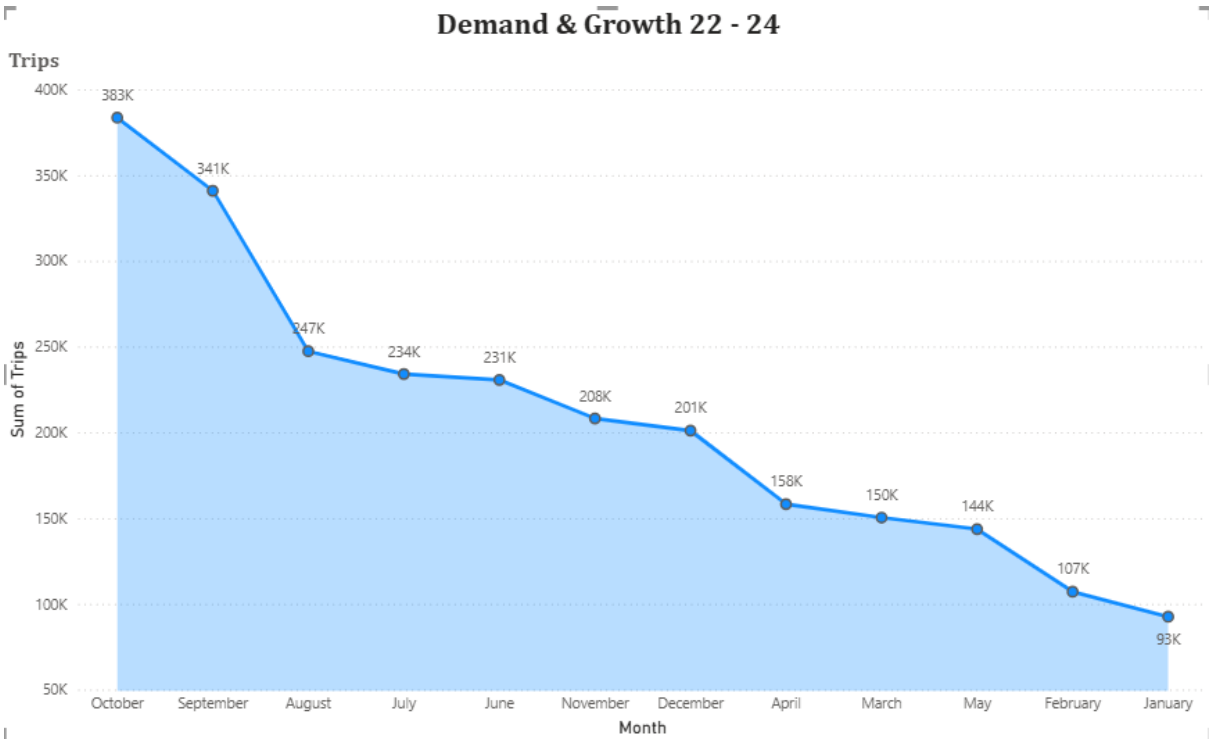

Figure 2.4.1 Demand & Growth 22-24

Analyses Conducted

With respect to shifts in demand for different modes of transit from 2022 to 2024, I visualized the information in Combined NextBike 2022,2024 and NextBike 2022, NextBike2024, NextBike 2025. Demand for bus services seems to have recovered, albeit remaining well below, particularly in the case of Stirling, the level of demand pre-COVID. Use of cycle hire services seems to have contracted, from 0.38M trips in 2022 to 0.09M in 2024; moreover, extensive dependence on central docking stations such as Albert Place and the marked underuse of peripheral docking stations is notable.

Provide Supporting Evidence

From the perspective of the graph, there seems to be a drop in cycle hire trips from altitudes of around 0.38 million in the year 2022 to 0.09 million in the year 2024. This drop aligns with the national travel patterns. The report on Transport and Travel in Scotland 2022 states that as of 2022, a considerable segment of the everyday traversing was still far from the pre-pandemic stakes. The data for 2022 indicates that on average an adult made for himself 1.52 trips in a day unlike in 2019 where the average was 1.94

trips, evidenced a fall in the appetite to travel on a day-to-day basis. The same report indicates that bus usage declined as well with the average bus trips made per person decreasing from 0.14 in the year 2019 to 0.10 in the year 2022 (*Public Transport | Transport Scotland*). This confirms that the pandemic created a sharp break in travel behaviour, which is still affecting both buses and cycle hire today. The most recent figures in the Scottish Transport Statistics 2024 show that bus journeys have not entirely been restored. While the total number of passengers rose by 13% in 2022 - 2023 to 334 million bus journeys, that number is still 31% lower than the figures of 2007 - 2008 (*Scottish Transport Statistics 2024 | Transport Scotland*).This lack of full recovery corroborates the situation in Stirling, whereby the demand for cycle hire continues to plummet and bus services have yet to revert to pre-pandemic service levels. Collectively, this data suggests that the decrease in NextBike trips is not an isolated occurrence, but rather part of a wider pattern regarding demand for transport in Scotland. It further adds to the understanding that, in the absence of improved bus services as an active travel option, there is little hope for Stirling and similar rural locations to achieve modal shift to sustainable transport.

Insights

The analysis indicates that bus use in Scotland has begun recovering post-pandemic. However, this use still sits far below the historical peak; for instance, in the case of 2023-2024, bus use still sits approximately 31% lower than 2007-2008. This lack of recovery in use is experienced even more so in Stirling, where the levels of satisfaction and use appear to be fluctuating and low. In stark contrast, the cycle hire usage has plummeted from 0.38 million trips in 2022 to 0.09 million trips in 2024, with most of the trips being boarded from main stations such as Albert Place. The unutilized peripheral docking stations indicate a lack of active bus- cycling integration and active travel options for individuals living beyond the city center. This suggests a concerning trend where rural regions are more poorly served, and their options are more poorly connected, increasing their reliance on cars. This hampers Scotland's aspirations for socially just, and sustainable mobility.

2.5 Transport and Emissions

In Scotland, car use on rural roads is one of the main contributors to greenhouse gas emissions, as car travel has remained the highest mode of emissions transport.

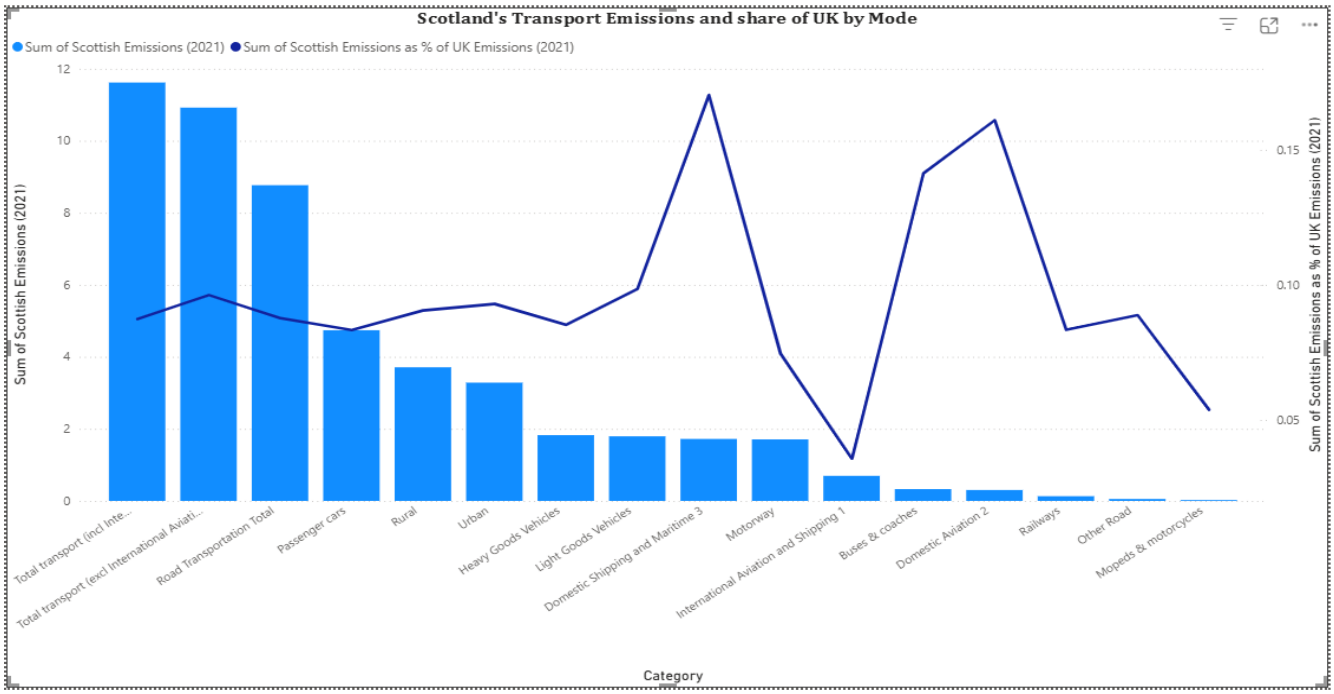

Figure 2.5.1 Scotland's Transport Emissions and share of UK by Mode

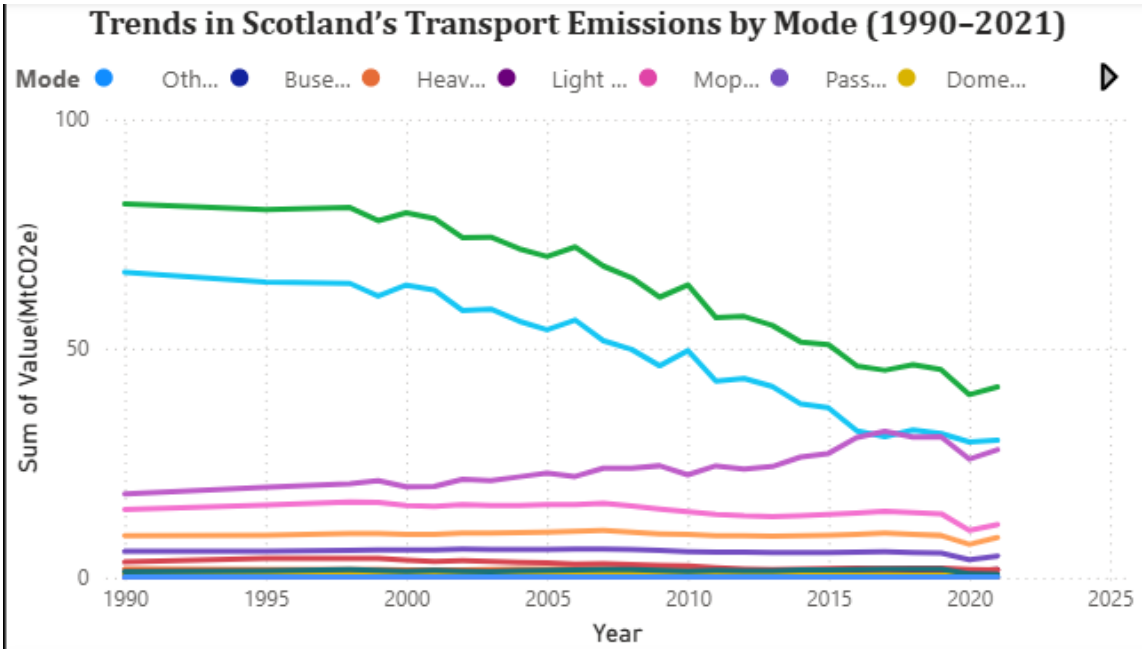

Figure 2.5.2 Trends in Scotland's Transport Emissions by Mode (1990-2021)

Analysis Conducted

After examining the files Emissions Datasets (ENV0201,13.2, 13.3, 13.4 tables)
, I was able to assess Scotland's Greenhouse gas emissions from 1990 to 2021. From the graph, while total emissions have reduced in the majority of the areas, transport sector remains one of the biggest emitters. Within transport, it is road traffic, and in particular cars, which predominates. Cars' emissions have reduced by approximately 17% over the period from 2006 to 2021 due to engine technologies, and yet the vehicle remains the most emitting vehicle in Scotland. The transport sector has demonstrated that is has the lowest rate of decarbonisation of any other in Scotland. Hence, its proportion of Scotland's emissions has increased over the years.

Supporting Evidence

It is evident through the data that transport is at the heart of the emissions conundrum facing Scotland. The Scottish Transport Statistics 2024 - Environment states that "in 2022 Scotland's Transport (including international aviation and shipping) was responsible for 13 million tons of carbon dioxide equivalent (mtCO2e) and 31.7% of Scotland's total net emissions. Road transport alone is responsible for almost 70% of this total (*Scottish Transport Statistics 2024 | Transport Scotland*)

Insight

Based on the data I have compiled on rural Stirling, even though the shifting of vehicles to electric is necessary for decarbonizing transport, if accessibility as well as rural integration is not improved, the car dependency will persist, thus negating the effectiveness of emissions reduction.

Chapter-3

3. Methodology

3.1 Introduction

This section outlines the research method used to investigate the differences and gaps in the accessibility and use of bus transport in Edinburgh (urban) and Stirling (rural). As guided by the questions of the dissertation focus, how public transport services are spaced, how accessibility varies in regions, and the implications of such disparities for sustainable transport and equity of access are analyzed in detail.

This chapter starts with an explanation of the types of data that were collected, including bus stop datasets and other data using accessibility and satisfaction indicators for public transport as well as public transport emission data that were acquired from open data portals. Each of the data collections was subjected to a thorough cleaning and preparation process using Power Query where the data was in the schema harmonized by removing duplicates and nulls, type formatted and spatial validated to achieve a high level of accuracy and consistency.

It also includes considerations such as the ethical use of data, which was public, available, and anonymized along with what was done to ensure reliability and validity by comparing the findings with the official statistics as well as consistency in the data management processes.

This particular chapter on methodology provides the framework and the rigor of the dissertation, demonstrating how the research was carried out in a manner that is valid, reproducible, and meets the criteria set out for the level of research. It critically examines the processes undertaken to ensure that they are rational, organized, and able to provide insightful contributions to transport policy and planning in Scotland.

3.2 Research Design

This dissertation examines Edinburgh as its bus transport urban-example, and Stirling as the rural counterpart. The chosen regions portray the disparity in bus supply, which is the problem underlying the dissertation. Edinburgh is serviced by a highly dense, integrated bus network that in principle reaches every corner within urbanized limits while Stirling, especially its rural villages, exhibit under provision with the network containing merely one or two stops. The high disparity between the two regions provides opportunities to study matters of accessibility, transport equity, and sustainable mobility.

The case study design was backed by three supporting factors. The first is the socio–spatial disparity which provides a strong rationale for analyzing inequities in the provision of public transport. The second is the ability to study multiple dimensions simultaneously: physical accessibility (distribution and density of bus stops), satisfaction (using Public Transport Indicators), Integration (relationship between bus stops and NextBike docking stations), Demand (changes in transport usage over time), and emissions (transport supply in the context of national targets for carbon reduction). The third is the variety of data in the case study that includes the descriptive (e.g. maps, density, time series trends) and the Exploratory (bridging the findings to the broader issues of transport equity and climate policy).

3.3 Data Sources

Eight main datasets were used and grouped by theme:

Accessibility

i. Edinburgh Bus Stop Dataset (AtcoCode620) (*Download stop data by local authority - NaPTAN - DfT*)
ii. Stirling public transport bus stop location dataset (Atco Code660) (*Scottish Government Riaghaltas na H-Alba Gov.scot*, 2021)
iii. Data Zone Accessibility Dataset (*Scottish Government Riaghaltas na H-Alba Gov.scot*, 2021)

Satisfaction

i. Public Transport Indicator Dataset (*Public Transport*, 2025)
ii. NextBike 2022,2024,2025 Dataset (Cycling Activity Data 2022,2024,2025).
iii. Combined NextBike 2022,2024 Dataset

Demand

i. Combined NextBike 2022,2024 Dataset and (Power BI integrated Bus and Cycle Hire Datasets)

Emissions

Emissions Datasets (ENV0201,13.2, 13.3, 13.4 tables) (*Transport energy and environment: data tables (ENV)*, 2025c).

All datasets were free and came from reliable government or official sources.

3.4 Data Cleaning and Preparation

3.4.1 Edinburgh Bus Stop Dataset (620)

The Edinburgh bus stop dataset was sourced from NaPTAN (National Public Transport Access Node) which provided records of bus stops in the city. The dataset contains stop names, unique identifiers, and geospatial coordinates (latitude and longitude). As the dataset is, it has duplicates, inconsistent formatting and blank spaces which must be addressed in order to maintain credibility in the analysis.

All cleaning was done on Power Query in Power BI. First, the schema was checked and corrected. Latitude and longitude coordinates were stored as decimal values, while the identifiers StopID, ATCOCode, and the neighborhood were incorrectly classified as text fields. Ensuring uniformity within fields prevents errors during mapping and joins later

on in the analysis. Use of the StopID in conjunction with latitude and longitude ensured that no stop was counted more then once during the deduplication process. As with the deduplication process, rows with null or missing latitude/longitude values were removed, as they were unable to be mapped, thus, used in the accessibility calculations.

Standardization was also important, namely to adjust stop names to remove superfluous characters, unify case sensitivity, and expand shortened forms (for instance, “Opp.” to “Opposite”). Neighborhood names were also converted to Title Case and standardized to remove superfluous spaces. This subsequently made the dataset comparable with Stirling’s dataset later in the analysis. The stop count was also cleaned and validated to 2,479 bus stops, which was aligned with Transport for Edinburgh figures, and became the point of reference for subsequent visualizations.

Revised for analysis were the following fields: StopID, StopName, Latitude, Longitude, and Neighborhood. This optimized dataset size enhanced refresh speed in Power BI, and ensured the file retained the key elements of greatest importance. Overall, this cleaned dataset served as the urban benchmark in relation to Stirling’s bus provision.

Cleaning & Preparation Steps (Tool: Power Query)

a. Schema & types: Ensured Latitude/Longitude had Decimal Number values; StopID, ATCOCode, and Neighborhood were Text fields.
b. Removed duplicates: Removed exact duplicates based on (StopID, Lat, and Long.
c. Null values: Rows with no Lat/Long values that can’t be mapped were removed.

Standardization:

- Eliminated stoppages and excessive spaces, edited upper and lower casing, and uniformed common abbreviations for bus stops names.
- Standardized and modified Neighborhood names to Stirling conventions Title Case with no extra spaces for later intercity comparisons.
- Quality Check: After cleaning, the total count for stops validated at 2,479 (anchor metric for later joins/visuals).
- Shaping for Analysis: Preserved only the analysis components (StopID, StopName, Latitude, Longitude, and Neighborhood) to alleviate model size and enhance refresh intervals.

3.4.2 Stirling public transport bus stop location dataset (660)

Using Excel Power Query, data cleaning and preparation was done cautiously on file 660 "Stirling public transport bus stop location dataset" to enhance its correctness and its feasibility for further analysis. The base data for the dataset was bus stops coordinates and identification numbers, which initially were organized by geocoding bus stops to the neighborhoods in the Stirling Council Area. This spatial connection was necessary for the assessment of accessibility to the bus stops located in urban and

rural areas. In the construction of the data model, fields of latitude and longitude were formatted to Decimal Number to facilitate spatial mapping and distance calculations, and therefore, were classified as Decimal Number. The other fields of StopID and Neighborhood were classified as Text fields to retain their categorical data structure. Then, data quality assessment was performed in which duplicate StopIDs were eliminated and records with null coordinate values were removed in order to ensure integrity of analysis. The dataset was then clustered by neighborhood to compute the number of bus stops which enabled the analysis of service provision across Stirling and identified areas of very low provision, such as Argaty, Ashfield, Kilmahog, and Balmaha which were found to have only one or two bus stops.

The profiling set the groundwork for determining disparity in accessibility throughout the center of Stirling, as bus stops were closely located, compared to distant villages that were poorly serviced. Following the cleaning procedure, the total bus stops in Stirling city was found to be 970, which corroborates with the estimates from the council, indicating the data set's accuracy and completeness. Other bus stops data verification included tracking geographic coordinates of minimal and maximal latitudes and longitudes which validated that all bus stops were positioned within Stirling's envisaged geographic borders and that there were no geographic outliers. This meticulous approach to data compilation and validation ensured that the data was trustworthy for the use in Power BI visualizations and accessibility analyses. This also serves as evidence of the underlying spaced data used to investigate the imbalance of public transport available in the countryside and urban areas.

Cleaning & Preparation Step (Tool: Power Query)

a. Stirling Bus Stop Coordinates and Neighbourhood Assignments.
b. Schema and types of Lat/Long as Decimal Number, StopID, and Neighbourhood as Text.
c. Removed duplicates from StopID and nulls from coordinate
d. Counting and profiling: Grouped by Neighbourhood to calculate Stop Count and used it for identifying very low provision area.
e. The total stop count as per verification simplifies to 970.
f. For the data validation Minimum and maximum latitude and longitude were checked and all the coordinates fell under the expected geographic boundaries of Stirling and no outliers were found.

3.4.3 Data Zone Accessibility Dataset

The insights offered by the Data Zone level records highlighted the ability for public transport access across Stirling, although substantial work done in Power Query was still necessary in order to ensure the dataset was both clean, and sufficiently compatible with the bus stop dataset. The first step was column filtering, in which only the constituents necessary for the analysis were retained—namely, DataZoneID, FeatureName/Neighbourhood, and the selected access indicators—while extraneous columns and incomplete rows were eliminated, thus streamlining the dataset. In order

to ensure uniformity across various datasets, the FeatureName/Neighbourhood field was standardised to fit the naming norms applied in the Stirling bus stop dataset in order to enable proper referencing and merging. The Data Quality Control steps highlighted the existence of duplicate DataZoneIDs and records with missing IDs or labels that could not be mapped, these were purged in an attempt to work with only relevant and non duplicated records. In order to preserve integrity, the DataZoneID field was intentionally configured as Text to make sure it aligned with the corresponding dimension table and allowed joins without errors downstream in the workflow. Thereafter, a left join was performed with the Stirling bus stop dataset by Neighbourhood in a one to many relationship, where each data zone was able to acquire the associated provision of bus stops within its boundaries. This combination allowed a robust zone level understanding of accessibility, which filled the gap between the neighbourhood level service provision and the wider data zone constellation. This enhancement enabled a more sophisticated understanding of the spatial variations in bus stop provision across Stirling.

Cleaning & preparation (Tool: Power Query)

a. Column Filtering: Cleared entire rows for the access indicators that were not relevent to the analysis DataZoneID, FeatureName/Neighbourhood, relevant access indicators.
b. Standardisation: Standardized the FeatureName/Neighbourhood to conform to the Stirling naming used in the stop's dataset.
c. Duplicates & nulls: Removed DataZoneID duplicate rows, filtered resist zones that had no ID and a mappable label.
d. confirmed DataZoneID is Text and matches the dimension table to maintain the integrity of the join.
e. Left joined with Stirling bus stops by Neighbourhood (one-to-many) to form a zone level perspective for the provision of stops

3.4.4 Public Transport Indicator Dataset

During the period of 2005 to 2025, the Public Transport Indicator dataset 's portion of public transport satisfaction trend analysis for the cities of Edinburgh and Stirling was pivotal, to say the least. Without this dataset, it would not have been possible to visualize the satisfaction levels of both cities on a single chart and, for more than two decades, perform their side-by-side comparison. For the analysis of the Public Transport Indicator dataset, significant steps were 'cleaning and transforming the data. The first step involved filtering the initial data set to include only the relevant criteria to the project, which was the bus transport satisfaction indicator, since it aligned with the dissertation's focus on bus accessibility. The next step involved determining the data type of the Year field, which was changed to a whole number, and interpolation was carried out to populate the Year data ranging from 2005 to 2025. This was important in preserving a cross-sectional time series dataset. Many of the original tables were

infeasible for time-series analyses due to containing an excess of columns in relation to rows. The data were maintained in a long format which was unpivoted and standardized to the following four fields: Year, Area, Indicator, and Value. This restructuring format allowed each satisfaction response to be placed into a list format for easier aggregation and enhancement in Power BI. Further data set refinement consisted of the deletion of null values, empty cells, deletion of non-necessary symbols, and values which could potentially compromise interpretation. As an ultimate step, the Value column which represented the percentage satisfaction with each year's bus services was cross checked for all the years mentioned, with all the dataset records. The satisfaction percentage of the respondents lower with bus services was set to zero, which cleans, consistent, cross checked, and precise across the board, the dataset records also standardized the dataset records. This dataset works as the solid core for producing comparative data which is cross checked for all the years mentioned, with all the dataset records and analyzes the levels of relative satisfaction with public transportation. This also demonstrates the variation with urban and rural areas over time up to the year which is mentioned for Stirling and Edinburgh.

Cleaning & preparation (Tool: Power Query)

a. Indicators of satisfaction with public transportation in Edinburgh and Stirling for the years 2005-2025 have been assessed and visualized on the same chart.
b. Cleaning & Preparation (Tool: Power Query)
c. For the class of data that is related to public transport satisfaction and the only relevant scope indicator was the bus indicator.
d. Type of the year field changed to whole number and filled the gaps that were present in dataset to ensure the dataset remain continuous from 2005 – 2025
e. Any tables that contained more columns than rows in the unpivoted arrangement were set within the list format (Unpivoted) of (Year, Area, Indicator, Value).
f. Removed nulls and outliers, empty cells, unnecessary symbols that were present in the dataset.
g. A check was conducted to ensure that “Value” refers to the percent satisfied indicator in each year.

3.4.5 NextBike 2022,2024,2025 Dataset

The datasets corresponding to 2022, 2024, and 2025 from NextBike contain critical information about cycling and biophysical docking stations in Stirling, such as the number of trips taken and docking stations used. This information was most useful to study the public transport and active travel fundamental framework and evaluate the bus-bike last mile connectivity along with the docking stations. To ensure comparability between years and compatibility to other transport datasets, data cleaning and preparation such as alignment in Power Query was done. The first step in the process was setting up the structure and corresponding data types: StationID and StationName

were assigned as Text, Date/Year as Date or Whole Number, and Trips were entered as Whole Number. To enable comparisons between years, StationID and StationName were modified so that the same physical docking station could be identified reliably in 2022, 2024 and 2025 records, even when data provided differed due to naming or ID formats. At the aggregative level, the raw trip data was simplified and consolidated to present total annual trips for each station, along with additional monthly aggregates for periodical analysis. This was done with the construction of a special Stations table containing unique StationID records along with corresponding geographical latitude and longitude coordinate values for easy mapping with GIS systems and layers. Negative values on trip counts or duplicated rows were deemed implausible and were removed through intensive outlier and sanity checks. Only plausible values were retained after this process. The cleaned dataset was then merged spatially with Stirling's bus stop dataset, which made it possible to conduct a multilayered analysis of multimodal accessibility. In the final step on Power BI, visual overlays were constructed where NextBike docking stations and bus stop points were plotted at the same time to analyze possible synergies and gaps in last-mile connectivity. The results of this analysis identified the point s where public transport Cycle hire accessibility and strengthened the evidence base for the recommendations to support the Sustainable Mobility Strategy 2025

Cleaning & Preparation (Tools: Power Query)

a. Schema & types: StationID = Text, StationName = Text, Date/Year = Date/Whole Number, Trips = Whole Number.
b. Station ID standardization: Normalized IDs and names so the same station can be tracked across years.
c. Aggregation level: Aggregated raw trips into annual totals per station and monthly if needed for seasonality
d. Created a Stations table with unique StationID, Lat/Long for mapping and overlay with bus stops.
e. Outlier/sanity checks: Flagged improbable values (e.g., negative counts, obviously duplicated rows) retained only plausible rows.
f. Integration with bus stops (spatial):
g. Visual overlay in Power BI: bus stop points vs NextBike stations to inspect last-mile connectivity in Stirling.

3.4.6 Combined NextBike 2022,2024 Dataset

The Combined NextBike 2022, 2024 which was titled to provide a longitudinal view on rental bike demand for Stirling. The two source files, Nextbike 2022 dataset and Nextbike 2024 dataset, for each of the years provided independent tables worth dataset, along with the metadata for the recorded and associated trips. In Power Query, each of the independent tables was merged to form a cohesive dataset for comparative analysis across the years. The first step for the combination of two files is preparation, which in this case was the schema. The naming convention for the years was unified. For example, StationID and Station Name, as well as Year and Trips, were synonymously

defined to ensure that the same variables were headers and equally formatted. Data types with StationID as an element of Text was enforced along with Year, which was a Whole Number, for StationID to ensure the identification is preserved in an alphanumeric way which enables filtering for chronology, and Trips defined as a Whole Number to enable ease of aggregation. The two annual datasets were consolidated and unified into a single dataset containing records of the years 2022 and 2024 which preserved the same format structure within Power Query. Attention during this stage of the process was given to the treatment of null values. Records with missing entries containing the StationID or with missing entries containing '0' Trips were deleted to maintain a dataset with only authentic and accurate demand counts. Another important step pertained to the alignment of stations within the years under study. Some stations were associated with different entries or had minimal changes to their names and so were merged and standardized to their StationID so that the same docking station was consistently represented within the two years under consideration. Assimilation of the different data sources was subjected to scrutiny for the purposes of integrity. Potential duplicates and validation were done on the layer of datasets constructed datasets to the source files of the years. The resulting set of trip counts was checked with the supplied total values of approximately 0.38 million trips in the year 2022 and 0.09 million trips for the year 2024 to assure the dependability of the dataset constructed. Protected in this manner was a longitudinal dataset of integrity reliable for study with direct comparisons for cycle hire demand access for different years that formed the basis for the study of Stirling's active travel behaviour and usage patterns integrated with multimodal transport data accessible for the area.

Preparation and Cleaning (Tool: Power Query)

a. Harmonisation of the schema: Naming conventions for the fields in the annual files was unified (for example, StationID, StationName, and Year, Trips).
b. Data types: StationID was deemed to be Text, Year as Whole Number, and Trips as Whole Number.
c. Appending: The files corresponding to the years 2022 and 2024 were combined in Power Query to produce a single cohesive table.
d. Dealing with null values: Values such as missing StationID and zero Trips were eliminated so as to possess accurate counts.
e. Alignment of stations: The duplicate stations for every year were matched with the StationID for the purpose of standardisation.
f. Checking of duplicates: The combined file was compared to the individual year files, which contained roughly 0.38 million trips in 2022 and 0.09 million trips in 2024, to ensure that the counts were accurate.

3.4.7 Emissions Datasets (ENV0201,13.2, 13.3, 13.4 tables)

The datasets on emissions (ENV0201, 13.2, and tables 13.3 and 13.4) between 1990 and 2021 provided statistics on sectoral split and transport mode for Scottish

greenhouse gas emissions. These datasets were particularly relevant for linking public transport accessibility to broader sustainability goals, for instance, Scotland's legally binding net-zero target by 2045. In these datasets, the first step was to scope the analysis which was done by filtering the raw data to emissions relevant to transport and its sub-modes (road, rail, domestic aviation, and shipping) and excluding irrelevant sectors such as agriculture and industry. After the relevant subset was retrieved, the next step was unit normalisation. To ensure comparability, all records were converted into a standard unit of kilotons of CO_2 equivalent ($ktCO_2e$) which was the norm, especially when values in different tables were in different notations. Appropriately tidying the datasets in Power Query involved focusing on long format datasets for Emissions_$ktCO_2e$ with Year and Sector/Mode titles. This made them ready for year-on-year comparisons and easy visualisation. ENV0201 and tables from 13.2 to 13.4 were treated as a coherent long series and stacked tables to form the integrated table for time series analysis to consolidate various transport and sector emission perspectives from the separate tables. Derived measures were created such as Transport Share in the integrated dataset where it is defined as the transport emissions divided by the total emissions in a year. This serves the purpose of analyzing the emission levels with respect to time and assessing Scotland net CO_2 emissions as the transport contribution to it. The integrated dataset is considered cleaned and standardised to serves as a basis for the analysis of emission trends towards the transport policy priorities of modal shift, modal shift electrification, and sustainable mobility.

Cleaning & preparation (Tool: Power Query)

a. Scope: Filtered to Transport and transport sub modes where available.
b. Unit normalisation: Converted to ktCOe consistently.
c. Reshaped to tidy form: Year, Sector/Mode, Emissions_ktCO e.
d. Combine years: Appended (13.2/13.3/13.4 tables) into a single long-series table for time series analysis.
e. Derived measures: Transport Share % = Transport Emissions / Total Emissions.

4. Findings, Analysis and Discussion

This chapter is on the findings of the dissertation, organized by the five problem areas of the rationale and objectives: accessibility of bus stops, satisfaction with services, integration with active travel, trends in demand, and emissions. Each section integrates a descriptive analysis of the Power BI visualizations with interpretation, connecting the material to the policy framework of Scotland and the literature. The conclusion also reflects on the urban–rural inequity issues in transport and the implications of these findings on Scotland's Net Zero 2045 target

4.1 Accessibility Of Bus Stops

Findings: Upon cleaning and finalizing the dataset on the Edinburgh bus stops, it was discovered that there were 2479 stops, while for Stirling, this count was only 970. Stirling's count, on the other hand, does on the surface appear to be significant for an area of such small size, but upon visualizing, the stop density and distribution, the gaps in the findings are very significant. In the case of Edinburgh, the bus network is of an impressive density and uniformly distributed all over the city. Nearly all neighborhoods have several bus stops within walking distance of service overlap and coverage. In comparison, however, Stirling's bus service is as described, very uneven. While the city center and areas such as Bannockburn and Bridge of Allan do have their fair share of bus stops, outlying areas such as, Argaty, Ashfield, Kilmahog and Balmaha were woefully lacking, as there wfere hardly one or two bus stops provided.

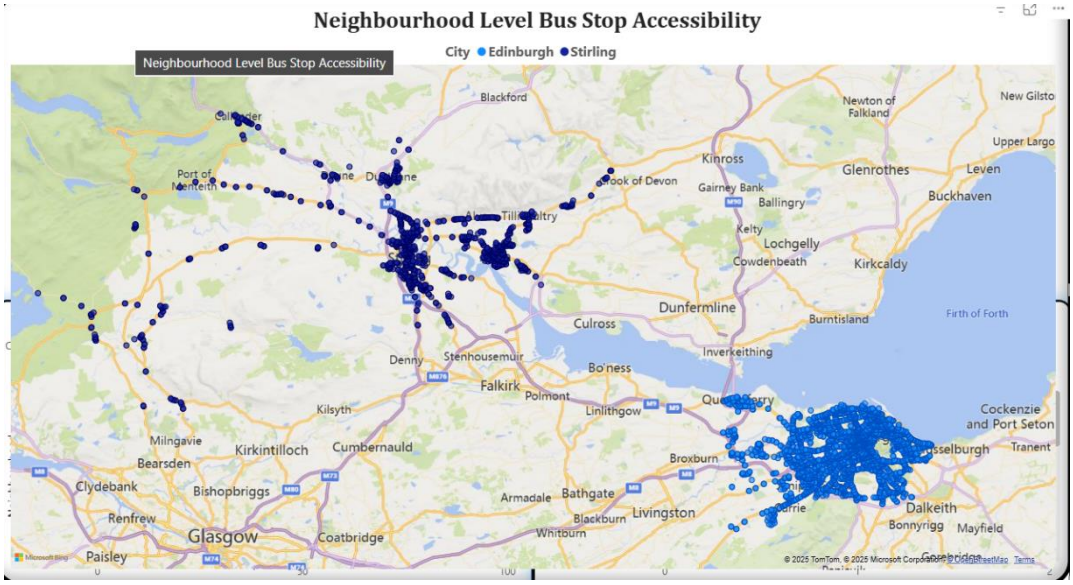

Figure 4.1.1 Neighbourhood Level Bus Stop Accessibility

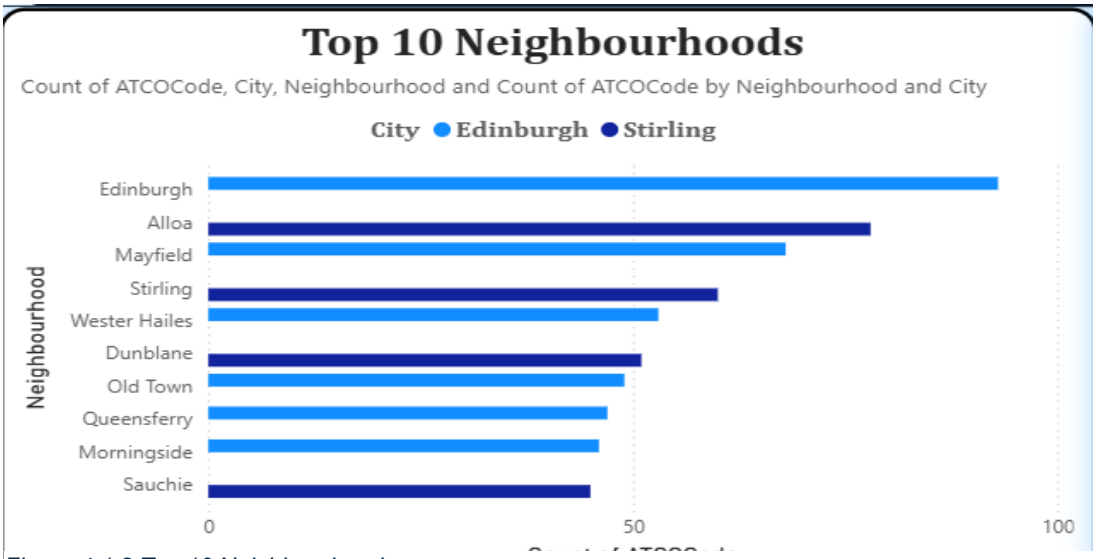

Figure 4.1.2 Top 10 Neighbourhood

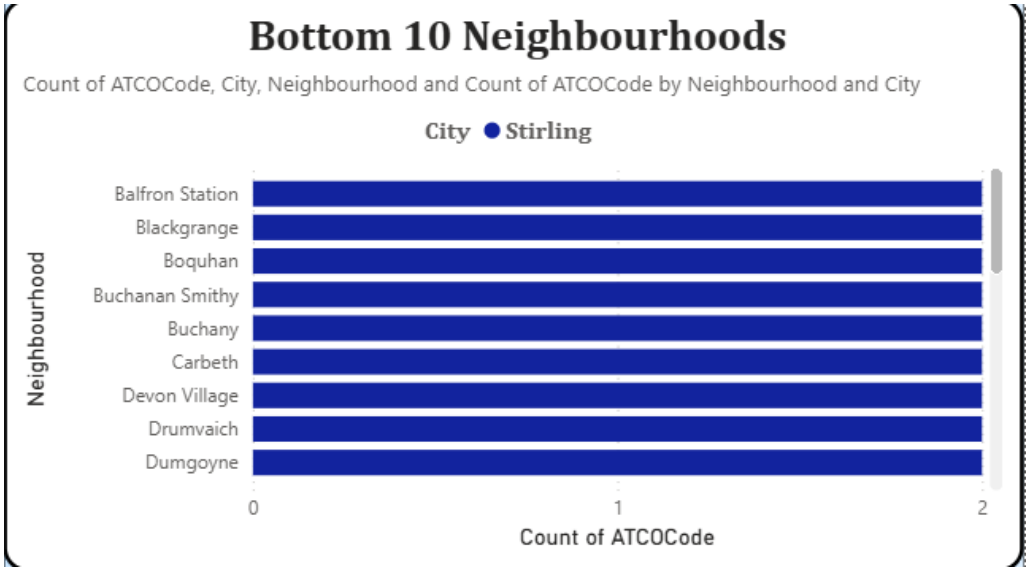

Figure 4.1.3 Bottom 10 Neighborhoods

Analysis

The developed visualizations in Power BI — along with the steep disparity between the two cities — are indeed telling. In Edinburgh, the bus stop map shows that there is a dense, connected network of 2,479 bus stops which many residents can easily walk to. In stark contrast, the bus stop map of Stirling is littered with gaps, with a number of rural settlements being poorly connected to the bus network. This inequality is further accentuated in the bar chart depicting neighbourhood stop counts, where certain regions like Argaty, Ashfield, Kilmahog, and Balmaha are starkly underprivileged, garnering access to only 1 or 2 stops.

This is in keeping with the Transport and Travel in Scotland 2022 report that states that satisfaction levels with public transport were the lowest in rural regions (40–42%) in comparison to large urban areas (68%) (Transport and Travel in Scotland 2022)

Transport Connectivity for Remote Communities in Scotland,2020 which highlighted that 30% of rural households do not have access to a bus stop within a 15-minute walk. This study's Stirling patterns assist in illustrating aspects of these national issues (Laird and International Transport Forum, 2020c)

This also aligns with the Sustainable Mobility Strategy 2025, whereby respondents living in peripheral regions felt “disconnected” from the bus network on account of the

inadequate service during the evenings and weekends (Sustainable Mobility Strategy 2025)

Discussion

The gap in accessibility is a factor of social exclusion which increases the likelihood of residents without bus access being forced to rely on private cars. This underpins NTS2's worries about inequality in access to opportunities. For policymakers, this suggests that rural councils need to develop more focused strategies for the placement of bus stops to minimize the risk of rural communities being bypassed. (National Transport Strategy (NTS2) Transport Scotland, 2022h).

4.2 Satisfaction with Bus Services

Findings: According to the Scottish Household Survey dataset, a major paradox surfaced with regards to satisfaction over a period 2005 - 2025, when in Edinburgh, satisfaction remained above 80% during the whole period while in Stirling, satisfaction decreased to 49% in 2020 and has not recovered to pre pandemic levels.

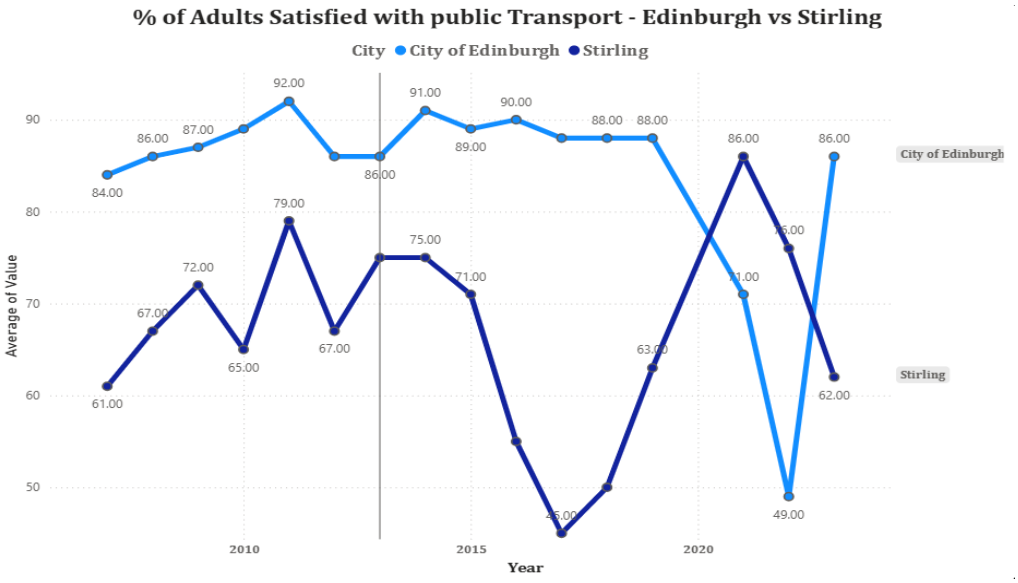

Figure 4.2.1% of Adults Satisfied with public transport

Analysis

The dissatisfaction surrounding access gaps only supports the previously outlined findings on access gaps alongside the service gaps. The negative perception surrounding bus services in Stirling is due to the poor bus coverage and service reliability in the region. Frequency dissatisfaction and affordability dissatisfaction and the dissatisfaction with the

weekend/evening provisions expressed by residents mirror the findings the Stirling Council revealed in their 2025 Sustainable Mobility Strategy consultation (Stirling Council)

Discussion

The findings reinforce the idea that not only the absence of bus stops is an issue, but the perception, frequency, and reliability of the services on offer. Even if stops are provided, an absence of services is certain to drive people away from the bus. The findings in the "vicious cycle of decline" in rural bus services argues that stagnation in service use, service decline and the dissatisfaction that follows suffering have become part of the rural bus service model. It is the case that bus service dissatisfaction in Stirling does not stem from the mere presence of bus stops, but the perception gaps in service reliability and affordability that accompany the coverage and high service frequency.

4.3 Integration with Active Travel

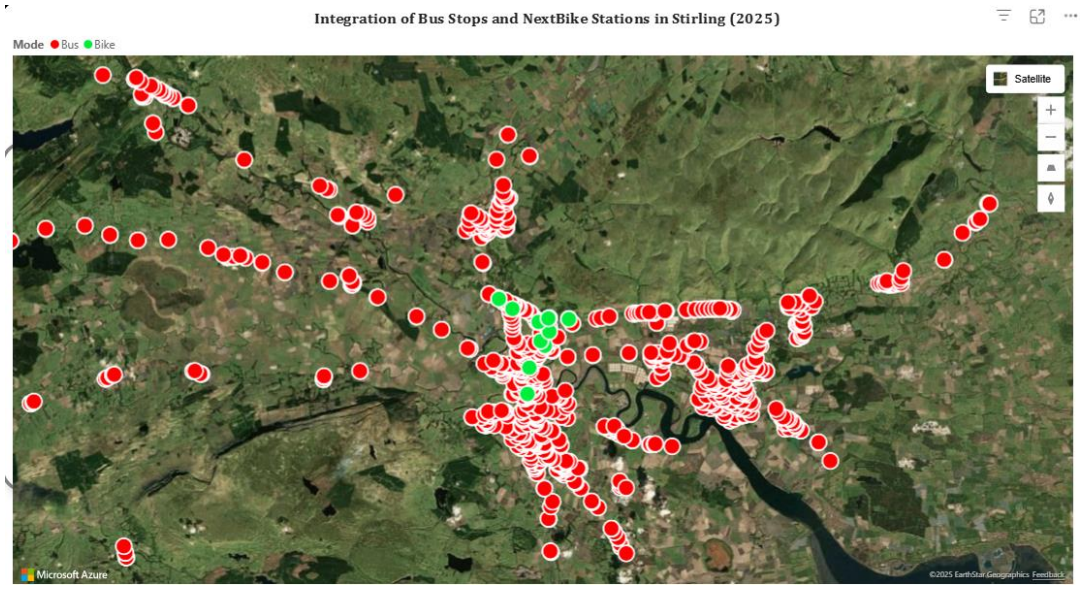

Figure 4.3.1Integration of Bus Stops and NextBike Station in Stirling (2025)

Findings: The overlay of bus stops with NextBike docking stations showed integration to be almost non-existent. The docking stations were focused in the city centre and around the University, while the rest of Stirling's over 970 bus stops were still unserved by cycle hire facilities. The trip data verified this gap, with NextBike's total usage dropping from 0.38 million trips in 2022, to 0.09 million trips in 2024, and with only a partial rebound in 2025.

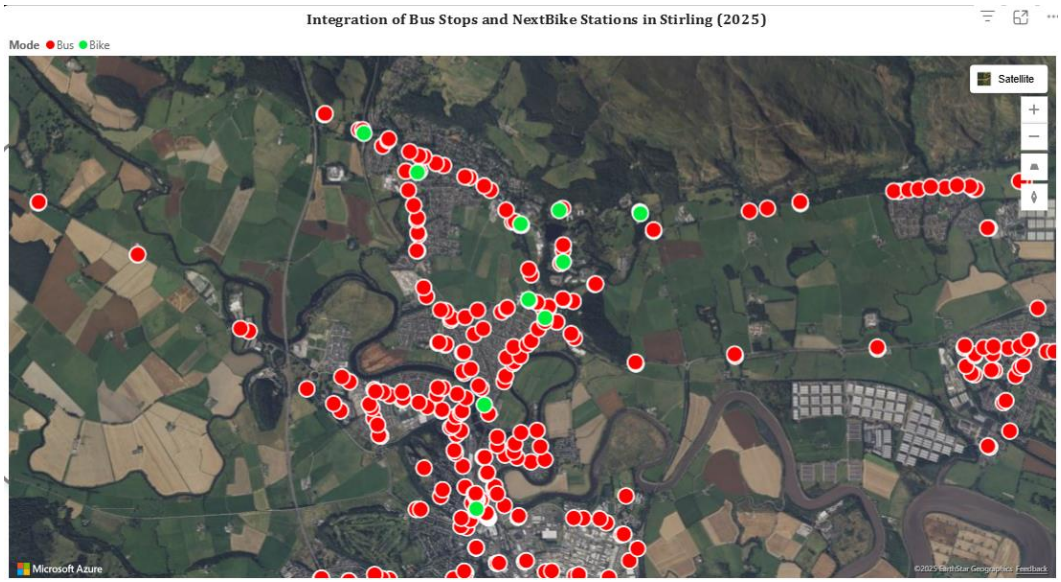

Figure 4.3.2 Integration of Bus Stops and NextBike Stations in Stirling (2025)

Analysis

The absence of last mile connectivity undermines Stirling's attempts to promote modal shift. Intercity cycle hire services ought to be complimentary to buses by covering the gaps between bus stops and residential and commercial areas, but the service is only available in areas with dense bus coverage

Discussion

This particular result appears to be the opposite of the outcome desired in the Cycling Framework for Active Travel 2030, which prioritises the integration of active travel with public transport. This would imply that there is a disconnection between the cycle hire scheme and bus access in Stirling. From the perspective of sustainable transport policy, this highlights the need for improved cycle docking station planning, ensuring that bus dominated, low accessibility areas are served to genuinely promote last mile connectivity. (Cycling Framework for Active Travel, p.g:6, 2023)

4.4 Transport Demand Trends

Findings: The assessment of demand from the combined NextBike datasets for the years 2022 and 2024 indicates a drastic reduction in the activity of cycle hiring in Stirling. In October 2022, the volume of trips was around 383,000, which then sharply declined to below 100,000 trips by January 2024. This indicates an overall cycle hire demand reduction of about 75% within the span of two years, which points to a significant reduction in the activities and services utilisation in the region.

This phenomenon is further understood through the NextBike station spatial distribution in Stirling as well. In the city, the stations are primarily located in the region of the University of Stirling campus, Causewayhead and Bridge of Allan, while the distribution in the city centre is rather sparse. This model however creates a significant gap, and same could be taken for the distribution of large residential quarters and the peripheral neighbourhoods, which limits cycle hiring accessibility for the potential consumers.

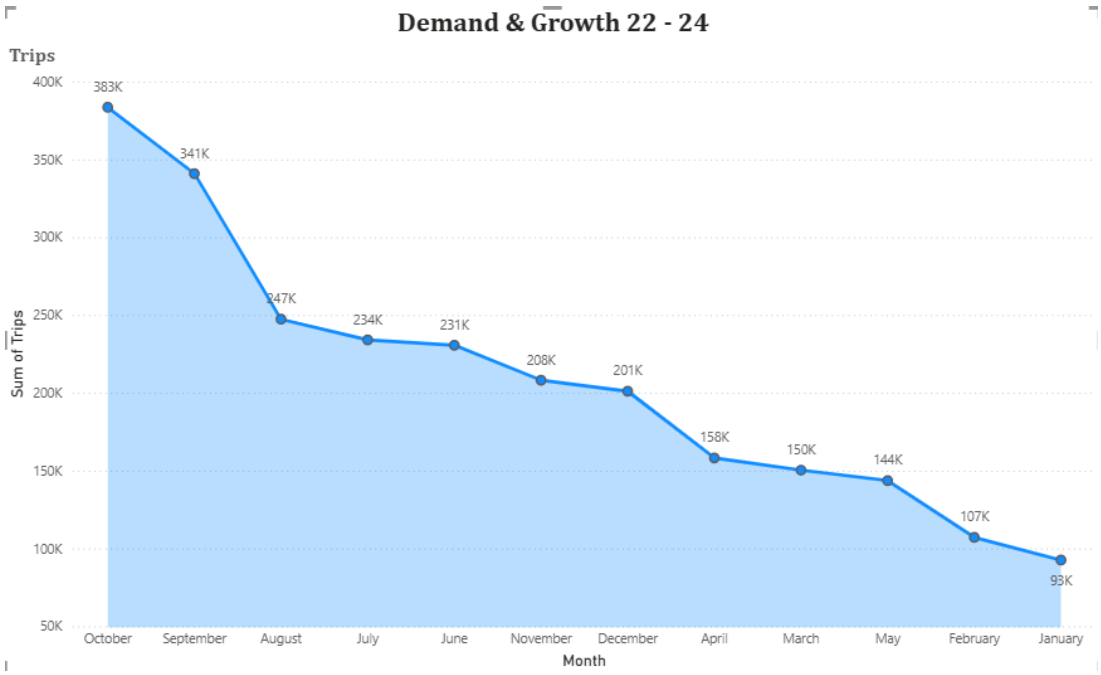

Figure 4.4.1Demand & Growth 22-24

Analysis

The drop in demand is attributed to poor coverage and insufficient integration with bus stops. Docking stations are mostly situated within the academic and city central zones, leading to demand from university students and city center users. Such narrow dependence on a demographic base puts usage at risk with any behavioral shifts and disruptions like COVID-19 recovery patterns.

The steep decline indicates that cycle hire systems are not yet adopted as part of daily travel routines by the general population. Instead of facilitating a modal shift, the system serves as a poorly integrated bus system that fails to provide last mile connectivity.

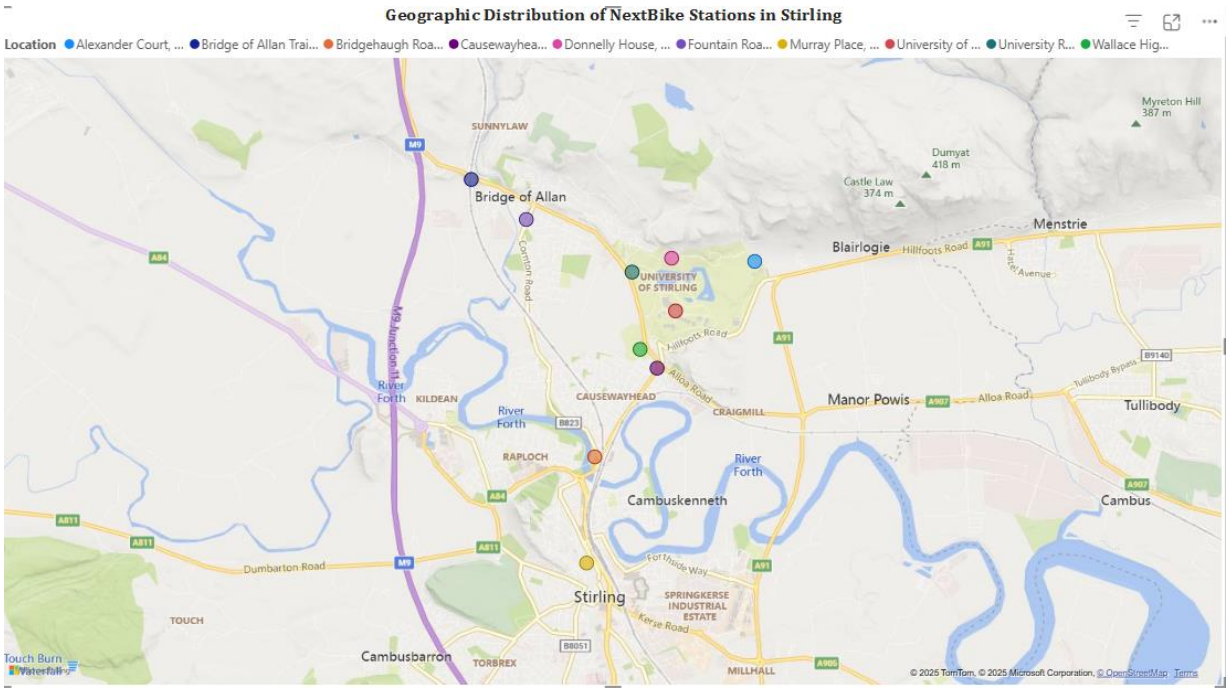

Figure 4.4.2 Geographic Distribution of NextBike Station in Stirling

Discussion

These outcomes corroborate with the 2022 Sustainable Travel Review published by the Scottish Government which illustrated that the recovery of the pandemic has not affected all transport modes equally. Even as buses slowly regain passenger numbers, smaller towns, such as Stirling, are experiencing a decline in cycle hire demand.

This also contradicts the Cycling Framework for Active Travel which states, “cycling should be integrated with public transport” as well as its expansion to the over rural area (Transport Scotland, 2023g).NextBike stations in Stirling are, for the most part, located near bus routes, with the peripheries lacking such services. (Cycling Framework for Active Travel, p.g:6, 2023)

This implies for the Stirling Council that demand will continue to grow if stations are placed in strategically underserved neighborhoods with increased promotion of cycling as a supplementary mode of transport to buses. Otherwise, the cycle hire will continue to be an underutilized service that will not adequately address the reduction of car use or Scotland’s Net Zero targets for 2045.

4.5 Emission Analysis

Findings: The datasets on emissions confirmed that in Scotland, transport is still the largest emitting sector, accounting for approximately 36% of greenhouse gases in 2019. Though the overall emissions have dropped since 1990, the rate of decline for transport emissions is much slower than for other sectors. Per capita emissions in Stirling are about 40% more than the Scottish average, indicating the higher reliance on cars.

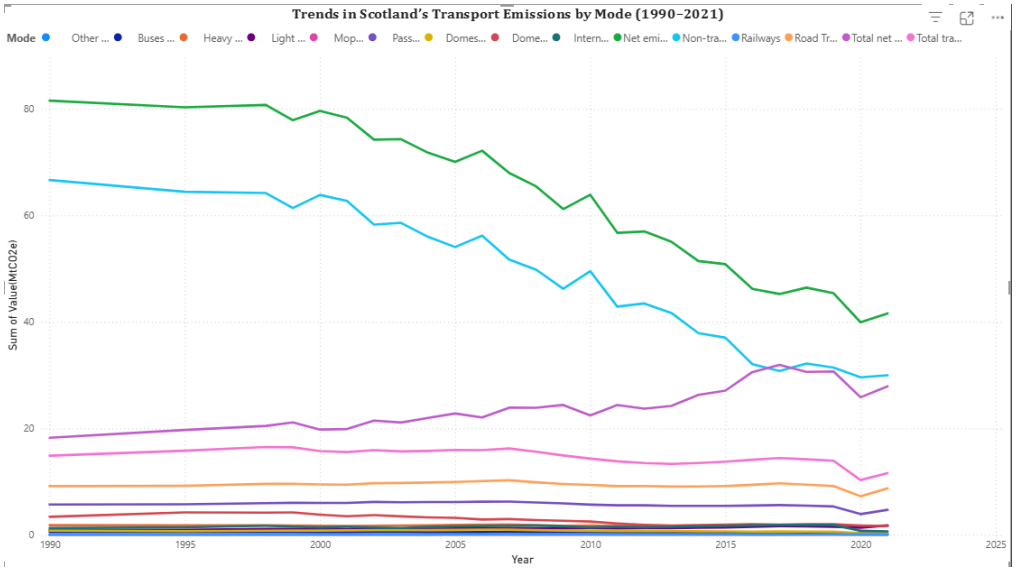

Figure 4.5.1 Trends in Scotland's Transport Emission by Mode

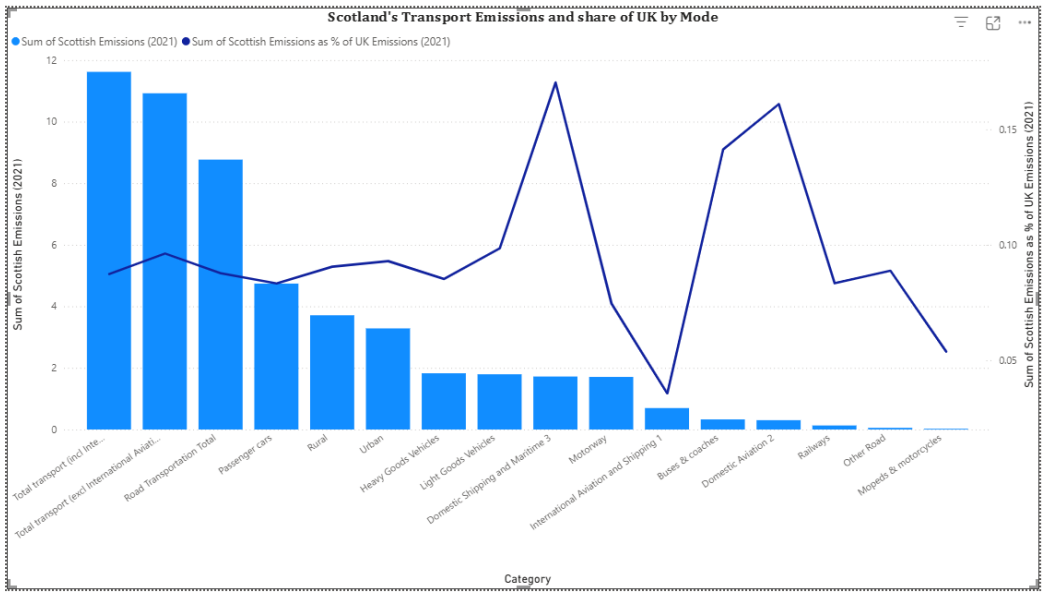

Figure 4.5.2 Scotland's Transport Emissions and share of UK by Mode

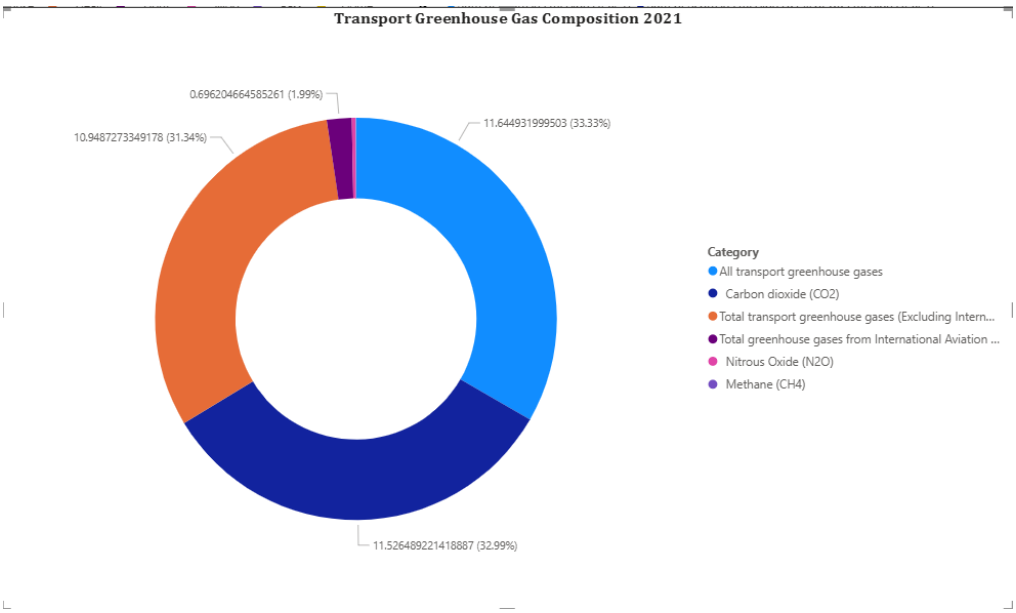

Figure 4.5.3 Transport Greenhouse Gas Composition 2021

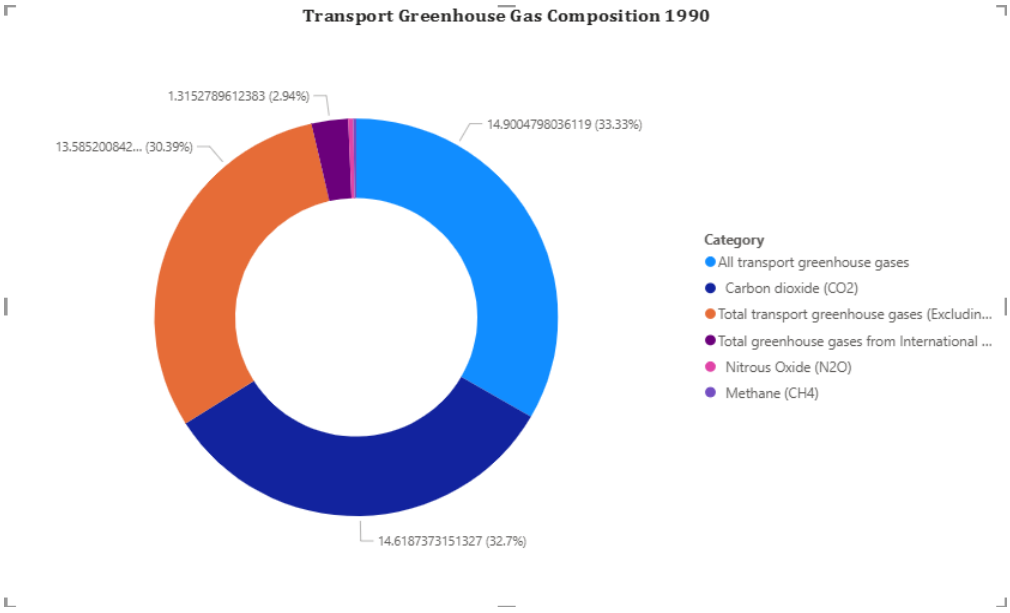

Figure 4.5.4 Transport Greenhouse Gas Composition 1990

Analysis

The relationship between accessibility, demand, and emissions speaks for itself. The deficiencies in bus and cycling infrastructure in Stirling means residents have no other choice but to drive, which in turn, worsens Stirling's higher per capita emissions problem. Edinburgh, in spite of the issues of congestion, has a more balanced modal system which lessens the dependance on cars.

Discussion

The evidence presented reminds us of the crucial role of transport in meeting the Net Zero target for Scotland by 2045. Stirling, alongside the national targets, will still be in a lagging position without improvement on rural access, and active travel integration which are the current barriers. The findings lend further support to the need for expansion of rural integrated low emission bus networks.

4.6 Synthesis of Findings

Bringing these strands together, the findings demonstrate that:

i. Edinburgh possesses dense region coverage with high multi-modality satisfaction integration, while Stirling suffers from unequal stop distribution, low satisfaction, and poor integration.
ii. Buses are slowly recovering while cycling is declining sharply, according to demand trends.
iii. Scotland's climate targets are proved to be undermined by these issues based on emission assessments.
iv. This, alongside the national statistics, demonstrates the micro-level evidence provided by the dissertation, ensuring the need for focused and actions in the rural areas of Stirling.

5. Conclusions and Recommendations

The last chapter of the dissertation serves to highlight findings, articulate the achieved research goals, and form new practice and policy suggestions. Disparities in bus transport in Edinburgh and the rural areas of Stirling were analyzed through five themes: accessibility of bus stops, service satisfaction, active travel integration, demand, and emissions. The research mission was accomplished through the analysis of open datasets in Power BI. The results provided evidence of transport micro level inequities and challenges in sustainability. The conclusions are drawn with respect to National Transport Strategy (NTS 2), 2022, the Cycling Framework for Active Travel, 2023, and the 2045 Net Zero target. (National Transport Strategy (NTS2) Transport Scotland, 2022h) (Transport Scotland, 2023g)

5.1 Summary Of Findings

i. Inequalities in accessibility, demand, and sustainability stem from Edinburgh’s high rider satisfaction and Stirling’s low satisfaction paired with the city’s uneven structural challenges.

ii. With 2,479 bus stops, the provision of public bus transport in Edinburgh is easily accessible. Stirling, in contrast, is only serviced by 970 stops, of which only some are

accessible in the neighborhoods of Argaty and Ashfield, leaving the region with little to no provision, which is often described as bus deserts.

iii. According to the 2020 Scottish Household Survey, rider satisfaction in Stirling dropped the lowest at 49% and Edinburgh never dropped below 80% satisfaction. Edinburgh's satisfaction levels were consistently high, which goes to show Edinburgh's poor service reliability, high bus fares, and limited services on weekends and evenings.

iv. Low usage in 2024 compared to 2022, 383,000 trips is likely due to poor integration of public transport with active travel, evidenced by the distribution of NextBike stations which are only around the University and city center and the bus stops which are isolated from the bike stations.

v. Demand for bus services is recovering slowly whereas demand for rented cycles dropped by 75% in the same period. This disparity demonstrates the current state of active transportation in Stirling, which is low and poorly integrated within the city.

5.2 For Stirling Council

The research confirms that Stirling is starkly deficient in the number of bus stops as compared to Edinburgh, and the distribution of bus stops is also inequitable as some areas serviced bus stops are underserved and therefore poorly catered to. To mitigate this, Stirling Council needs to add bus stops in Argaty, Ashfield and Kilmahog peripheral areas, which currently have only one or two bus stops. The placement of bus stops in outlying areas is likely to minimize the 'bus deserts' and provide fairer public transport access.

A separate issue is the frequency of services. Satisfaction scores from the Transport and Travel in Scotland, 2022 indicated that people from Stirling were far less satisfied compared to people from Edinburgh and the rest of the Scotland (*Public Transport | Transport Scotland*, no date e). The primary reason was found to be unreliable and infrequent services. Hence, Stirling Council needs to improve evening and weekend services, which are the most deficient, to go to the services. This will improve access to the public transport system for shift workers, young people, and carless residents, while also addressing the issue of social exclusion(Transport and Travel in Scotland, 2022).

The integration of active travel also require attention. Currently, NextBike docking stations are spatially concentrated around the University and the city centre, leaving most bus stops disconnected. Stirling Council should extend the NextBike docking stations into the hinterland and around key bus stops in order to strengthen last mile connectivity. This would enable users to undertake intermodal bus and cycle trips.

Lastly, the analysis indicates a rapid drop in cycle hire usage between the years 2022 and 2024. To reverse this trend, Stirling Council should implement targeted public relation campaigns aimed at increasing bus and cycle hire usage, particularly among the drivers who use cars most

of the time. Incentives like free trial days, partnerships with employers, and promotions targeted at students are likely to increase usage.

5.3 For Transport Scotland

i. Rural targeted funding: Allocate specific funding to rural councils like Stirling to address accessibility shortcomings. Focus on "public transport deserts" as described in the analysis, where entire communities have only one or two access points to transit. Expanding investment in additional, more frequent service would address economic inequalities and unnecessary dependence on private automobiles.

ii. Satisfaction monitoring improvement: Enhance the Scottish Household Survey by separating analysis and reporting on rural and local satisfaction instead of bundling them into a regional or national average. This would address the specific rural service issues too infrequent and priced too high, allowing clearer and more targeted policy intervention.

iii. Active travel integration: Ensure compliance for local cycle hire schemes to the Cycling Framework for Active Travel 2030 which includes us as a mandatory for bus bike integration. In Stirling, analysis showed cycle hire stations clustered only in the center, leaving rural residents without last-mile options. Including integration at the design stage would enhance the urban public transport offer, improving the overall system.

5.4 For Net Zero 2045 Goals

Cleaner rural buses - Emission sources in Scotland are primarily attributed to transportation, of which personal vehicles are the leading contributor. In Stirling, the emissions in the rural parts are higher than average because the population relies on personal vehicles. In response to this issue, the introduction of electric and low-emission buses on rural buses routes is proposed. As a result, emissions would be reduced, and residents would have a preferable alternative to personal vehicles, resolving the accessibility issues seen in the bus stop maps.

Integrated bus and bike tickets: Your analysis highlighted the fact that, in Stirling, NextBike stations are primarily concentrated in the downtown and university areas, which is not the case with bus stops. For people to use both for the last mile, a single payment for the bus and cycle hire would facilitate better integration. This would increase the use of public transport and help achieve the Cycling Framework for Scotland 2030.

Expansion of bus networks and subsidies for public transport: Bus networks still have considerable gaps in numerous rural parts of Stirling which represent" bus deserts". Access to bus services and cycle hire facilities should be improved in these areas. At the same time, lower bus fares, free transfers, and travel subsidies from employers would encourage greater bus usage. Each of these actions would lower the price, improve the reliability, and

increase customer satisfaction of buses, all of which assist in decreasing car utilization and overall emissions.

6. Contribution of Research

This dissertation significantly strides the academic literature on the role of public transport in mitigating urban-rural disparities.

i. It presents accessibility gaps within a locality. The study confirmed, by mapping bus stops in Stirling, the existence of "bus deserts," which are neighborhoods with virtually no buses in the vicinity. Such rural villages, with one or two stops, are especially problematic. Micro-analysis like this is useful to councils and policymakers because it identifies the areas most in need of intervention.

ii. The dissertation studies trends in public transport satisfaction over time and offers the analysis of data collected through the Scottish Household Survey. Over the past 20 years, the data has consistently demonstrated a widening gap between urban and rural domains. While urban areas like Edinburgh are content, rural areas like Stirling are still dissatisfied. The argument is made more persuasive by the demonstrated persistence of rural discontent. It substantiates the argument that the problem is not a trivial one, but rather, deeply rooted.

iii. Lastly, this study contributes to the discourse on transport inequity and sustainability by integrating various datasets within the single analytical framework. The dissertation systematically demonstrates clean and construct data techniques applicable to bus stops, satisfaction surveys, cycle hire units, and emissions datasets using Power BI, thus presenting a practical and reproducible approach to analysis. The analysis sheds light on Stirling and Edinburgh and corroborates wider policy discussions, such as the National Transport Strategy of Scotland (NTS2) and the Net Zero 2045 ambition.

iv. Collectively, these contributions illustrate the ways in which data-driven evidence can uncover service gaps, illuminate service disparity, and analyze gaps and provide actionable recommendations for the increased accessibility, integration, and sustainability of transport systems in Scotland.

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