Leveraging Data Science to Support Green Transitions: Evaluating Electrification, LEZs and Modal Shift in Scotland's Transport System

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Executive Summary

This consultancy project leverages real-time data science techniques to analyse the impact of three recently developed policies of bike sharing, electrification and low emission zones, and their effectiveness in supporting green transitions within Scotland. It first involves understanding the business problem, structuring an issue tree, and developing action plans with the help of the McKinsey framework.

To achieve results, the report uses Time Series, Geospatial and Comparative analysis for each different scheme. It helps identify seasonal trends, cycles of demand and comments on possible areas of improvement using CRISP–DM methodology. The evaluation includes collecting real – world datasets from Scottish councils and further visualizing them using Power BI to draw conclusive findings based on geography and demand.

The important findings conclude that the bike-sharing scheme is highly seasonal, being influenced by peak hours and the areas close to universities. The electric chargers' infrastructure shows an excellent network for AC chargers, around 75% of total chargers, but a need to install more DC rapid chargers on-street to build public trust in EVs. In the end, the comparison of substances before LEZ was reduced by 14% overall compared to after LEZ implementation in just six months, showing a positive contribution towards the environment. However, challenges remain, and to support this modal shift, there are recommendations that must be put into action, along with incentive-based strategies to achieve the aims of net-zero carbon emissions by 2045.

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List of Abbreviations Used

CO2 – Carbon Dioxide

NO2 – Nitrogen Dioxide

NOx – Nitrogen Oxide

PM2.5 – Particulate Matter (less than 2.5 microns)

PM10 – Particulate Matter (less than 10 microns)

Q1 – Jan: Mar

Q2 – Apr: Jun

Q3 – Jul: Sep

Q4 – Oct: Dec

AC – Alternating Current

DC – Direct Current

KW – Kilo Watt

EV – Electric Vehicle

E-Bikes – Electric Bikes

LEZ – Low Emission Zones

NHS – National Health Service

WHO – World Health Organization

CSS / CHAdeMO – Type of EV charging connectors

Terminologies

Net – zero: A balanced air quality without explicit substances and greenhouse gases into the environment, that affect human health.

Modal Shift: The process of shifting from private cars to more sustainable transportation like active travel and public transport.

Stakeholders: The key groups – the Scot. Government, Academia, Transport Scot., and Public – must collaborate for this green transitions.

Hypotheses: A set of assumptions that are can be tested through analysis, and if true guides to develop action plans.

Euro Standard: The set standard of engine emissions i.e. Euro VI, that tests how much a vehicle emits, crucial for LEZ implementation.

Chapter 1 – Introduction

1.1 Background

Transport is a key enabler of economic prosperity for a country. It plays an important role in facilitating business operations, promoting tourism and connecting regions. An efficient transport system not only helps citizens commuting to the daily driven places like schools, workplace and shopping centres with ease, but also provides employment opportunities. In Scotland, with over 500 million passenger journeys recorded per year, the demand for a more reliable transport system is evident. The Climate Change (Emissions Reduction Targets) (Scotland) Act 2019 committed to reducing carbon emissions around 75% by 2030 and achieving net-zero emissions by 2045. As transport is among the largest contributor of emissions of oxides of nitrogen and particulate matter in the environment, it must be accounted for to control these emissions. Therefore, to clean the air, reduce the concentration of such harmful substances, and to have positive impact on the environment, it is essential to implement sustainable solutions in Scotland's Transport System.

The UK government has initiated multiple ongoing projects to address these challenges and planned policies to support this green transition. However, the need to involve stakeholders and introduce incentive-based strategies for supporting this modal shift is evident. Improving infrastructure and allocating funds under definite checks will be best when thinking about advancing road technologies. It will not only modernise our roads but also build trust on EVs, ultimately decarbonising the cities. Nevertheless, recent initiatives like Electrification of rail, establishment of Low Emission Zones in big cities such as Glasgow and Edinburgh and promotion of Bike Sharing Scheme like Next bike in Stirling are showing significant positive outcomes in achieving the aims. Yet there must be some strategic investments in the infrastructure based on regional demands, public behaviours and seasonal trends in making the policies more reliable for future. In the same way, changing lifestyle preferences from private to public transport through social campaigns and action plans would also be very beneficial in adopting such initiatives to protect the land.

1.2 Problem Statement and Justification

Despite the government policies in achieving the targets to reduce carbon emissions, transport still accounts for more than 37% of greenhouse gas emissions, making it one of the major contributors of pollution in Scotland. In recent years, several practical approaches have been introduced in the Scottish Transportation System but factors such as car dependencies due to long travel time and lack of advanced technologies across public means of transportation appear to hinder in achieving sustainability goals. This project will analyse areas that need advanced infrastructure and where policies must expand outward, which will be helpful in decarbonisation. It will also focus on behavioural resistance in shifting towards public transport and propose actionable recommendations by examining:

- Study the role of modern infrastructure on building trust in electrification.
- Identify improvements in bike-sharing schemes to promote active modes of travel.
- Evaluating the potential of LEZs in reducing harmful substances within specified areas.

In addition, the study will analyse the business problem in detail to identify the factors that limit the potential shift towards a more sustainable and low-carbon transport system.

1.3 Aim

The aim of this project is to leverage real-time data science techniques to reduce fossil fuel exhausts and achieve net-zero carbon emission goals by 2045. Introducing sustainable transport options, promoting technological advancements and changing public preferences towards active travel are must-have policies. The study will assess how electrification and low emission zones could encourage decarbonisation and help in achieving social and economic benefits. It will address how better infrastructure and proper road spacing can help cut commuting time by public buses and thus discourage car usage. The aim also includes examining how a bike-sharing scheme would benefit active travel, forecast demand and suggest usage trends based on weather conditions. Lastly, the plan is to propose meaningful insights and key observations that would support improving transport networking.

1.3.1 Objectives

This consultancy project includes understanding the business of Scottish Transport System and identifying what potential challenges might need to focus on for achieving net-zero. It will facilitate addressing those key issues and synthesize findings. Following are some objectives that will be used to reach the overall aims for this project:

- Structure the business problem and identify possible areas of focus.
- Analyse if recent initiatives are impactful in reducing carbon emissions.
- Preparing and manipulating data after getting from trusted organisations.
- Use Power BI to clean, map and visualize the data for quick insights.
- Implement methodologies within CRISP-DM for analysing the trends within data.
- Identify the potential findings, encourage effective schemes and draw conclusions.
- Propose actionable recommendations to drive further sustainability advancements.

1.4 Research Questions

I. What impact will electrification and the implementation of LEZs have on improving air quality and decarbonising emissions?

II. How effective have the introduction of active travel, bike-sharing schemes, and improved road spacing been in encouraging a shift from private to public transport?

1.5 Expected Audience and Benefits of Project

Being one of the essential businesses for every country, transport involves its citizens, governing bodies and travelling companies to work together and improve transportation system for passengers. This can be explained with the help of Quadruple Helix Model, an excellent framework that shows how ideas arise by involving four social sectors. As this project is specifically designed to support sustainable transport system in Scotland, it will call for the public, government, academia along with forth organization like Transport Scotland, ScotRail etc. to be involved for this innovative change to electrification. Likewise, it requires the behavioural change from citizens to shift from private cars to public means of transportation, and continuous communication between research institutions and government authorities to implement incentive-based strategies. Hence this project will truly leverage data science and involve stakeholders to work for the reduction in carbon emissions and achieve net-zero gaols.

1.6 Report Structure

This report is divided into chapters to section the workflow and improve quality for the readers. Chapter 1 discussed about the background and overview of the transport system in Scotland, the challenges it is facing and how we can develop objectives to achieve specific aims. Chapter 2 focus on justifying and breaking down the problem statement into sub-sections using McKinsey 7-step. This framework will help prioritize key issues and provide business insights for developing action plans. Section 2.7 – 2.9 will analyse CRISP-DM methodology and its effectiveness for this project. It will also help me provide quick insights on what tools, methodologies and stages of CRISP-DM are being used and why. In chapter 3, a detailed view of certain methodologies will be accessed to identify patterns within data and draw potential observations. It will explain how to collect, manipulate and prepare data under legal ethics. This chapter will synthesis Time Series Analysis, Geospatial Observation, and lastly Comparative Analysis to analyse each recently introduced scheme. Chapter 4 will explore findings, present results and conclude discussions based on visualized data in Power BI and evaluate those observations for this modal shift and deploying the results. Lastly, Chapter 5 will conclude everything, propose actionable recommendations and what further improvements could be made to make the public transport a sustainable means of travel.

Chapter 2 – Problem Exploration and Analysis

2.1 Introduction

In this chapter, section 2.2 discusses about the rising emissions of harmful substances, increasing demand for more reliable transport network and what further developments must be adopted to shift towards sustainable transport solutions. Section 2.3 benefits in exploring the problem statement in detail and learn how transport plays an important role in running businesses. In section 2.4 – 2.5, there comes to structure the key issues, prioritise them and see what factors are influencing negatively to the environment. I also analysed the challenges being faced using McKinsey 7-step framework (Emmanuel Arakpogun, 2024). In section 2.6, I developed action plans and formulated hypotheses again under this McKinsey framework. (See Appendix A). Section 2.7 further discuss the need to analyse data using an advanced visualisation tool named Microsoft Power BI, and provide proper reasoning for that. To start off with the visualization, I first analysed how the implementation of Crisp-DM will prove beneficial in the selection and preparation of data and draw actionable insights later. I also mentioned the key methodologies that will be applied in chapter 3 to draw observations and evaluate the outcomes of this project.

2.2 Literature Review

Historically, around the globe, transport has been a major contributor to the emissions of oxides and other harmful substances into the air. Almost 99% of these emissions that affect human health contain CO2, the most important greenhouse gas when talking about transport, while other include NOx and particular matter PM10 & PM2.5. According to Scottish Transport around 13 million tonnes of CO2 comes from different modes of transport that accounts for around 37% of the total emissions. (Transport Scotland, 2024). NOx emissions were estimated to be 89kt in 2022, of which transport accounts for 54%. Although advanced ‘Euro Standards’ and turbocharged engines have reduced the level of emissions and other harmful substances that helped declining transport emissions by 69% from 1990 to 2020. But the need for some strategic policies is still evident to protect the land.

In Scotland, public journeys rose by 15% in 2023-2024 with 451 million journeys made by either bus, rail, ferry or air. But around 340 million of these were made solely by bus showing a 13% increase from previous year., highlighting how frequent bus services are used for public means of transportation (Transport Scotland, 2024). These statistics were profoundly affected by covid-19 resulting in the smaller number of vehicles on the road. But after 2022, these numbers have begun to rise again. Consequently, buses being an essential service of Scottish transport network, is still among the largest contributor of greenhouse gas emissions. On the other hand, rail journeys are recorded to be 81 million on ScotRail services in the year 2023-2024. In Scotland, Glasgow Central was the busiest among the rail network serving more than 25 million passengers followed by Edinburgh Waverley with 21 million passengers and Glasgow Queen Street by 15 million (Transport Scotland, 2024). Recent statistics shows more than 33% of the rail network has now become electrified, making rail a most efficient and sustainable means of transportation, contributing least towards the CO2 emissions. Even diesel trains contribute around 4% of NOx and only 1% of other pollutants. This advancement is evident to be applied to the buses as well. Whereas, ferries produce many harmful substances into the air, but these particulates can be reduced if the speed is decreased by

10%, resulting in emissions being cut by at least 19%. In the same way, when we talk about transport emissions in descending order, planes are worst in emitting, followed by private cars, public buses and then trains (Murray-Smith, 2019). As most of the plane flights in Scotland are international ones, emitting at very high altitudes so it is not a primary mode of concern for Scottish Transport. Private cars account for around 39% of exhausts, making them a significant contributor to carbon emissions. Hence reducing car usage for smaller distances is ambitious in supporting sustainable transport solutions. Also, electrifying public buses will not only help reduce these emissions but also cut travel costs and boost economic developments.

In Scotland, being outdoors in long-term can lead to significant health conditions equivalent to have an effect from 1800 – 2700 deaths a year (Public Health Scotland, 2024). The impacts can even go further because of increased number of vehicles as discussed previously, that are leading to more harmful pollutants in the air. However, to reduce emissions for improving public health, support climate targets, and make transport more accessible than ever before, the Scottish Government passed a bill, Transport Scotland Act (2019). There were included multiple aspects to commit improve accessibility and support sustainable solutions within the transport network. Some of these incentive-based strategies were smart ticketing, improved road infrastructure, and the implementation of Low Emission Zones in urban areas of Glasgow, Edinburgh and Dundee. These policies have already been implemented and are showing significant positive impacts. Studies also show that there is an initiative to reduce the car usage by 20% in Scotland, whereas Glasgow and Edinburgh aim to reduce the numbers by more than 30% by the end of 2030. It is also important to know that more than 27% of journeys made by car are one kilometre or less in distance in Glasgow, and 70% are under five kilometres (Massey-Chase et al., 2022). This highlights the importance of introducing active travel policies and raising awareness among public to change their lifestyle preferences.

2.3 Problem Definition and Business Understanding

From reducing commuting burdens to streamline daily travelling, transport falls under one of the effective services to run the countries. It helps in driving business growth, connecting supply chains and assisting citizens in their ability to reach from point A to B. Efficient and reliable transport is considered a backbone for the economic prosperity of a country. In Scotland, there are several factors making its transportation system a highly demanding business by ensuring travellers get the best experience and citizens reach destinations fast. The most important is the increasing number of tourists here because of its natural beauty, history and heritage, and vibrant culture. As the transportation system is getting more crowded each year, the number for vehicles are also growing to meet the requirements.

This increasing number of road vehicles made the transport stand among one of the major contributors of oxides of carbon, nitrogen and other substances. On top of that, factors like long travel time on public transport, lack of proper road spacing and congestion are some factors making increased use of private cars even for smaller distances. As a result, more emissions are produced, polluting the environment. To reduce private journeys, and lessen emissions, it is evident to improve the effectiveness of public buses, introduce active travel policies, and engage stakeholders for installing on-street charging stations for EVs. Transport Scotland has introduced numerous initiatives and undertaken many innovative projects to promote sustainable solutions. However, behavioural resistance remains a major factor hindering the reduction of vehicles on the road and thus limiting modal shift. Also, minimal efforts in introducing electrified buses, regional disparities, and lifestyle preferences are some known challenges that must be addressed. Hence, this framework will structure the issue tree, conduct analysis and formulate hypotheses to better understand the business of Scottish transport and hence propose actionable insights to make our earth a green planet.

2.4 Structuring the Key Issues

To understand the specific areas of focus and address the business problems in a structured manner, an issue tree has been developed under the McKinsey framework (See Appendix A). It provides a detailed overview on multiple aspects that are seen as pillars hindering the adoption of this green transitions. The problem definition is reducing carbon emissions and proposing incentive-based strategies to enhance a shift from private cars to public transport, supporting the evidence by the most impactful sub issues as given below:

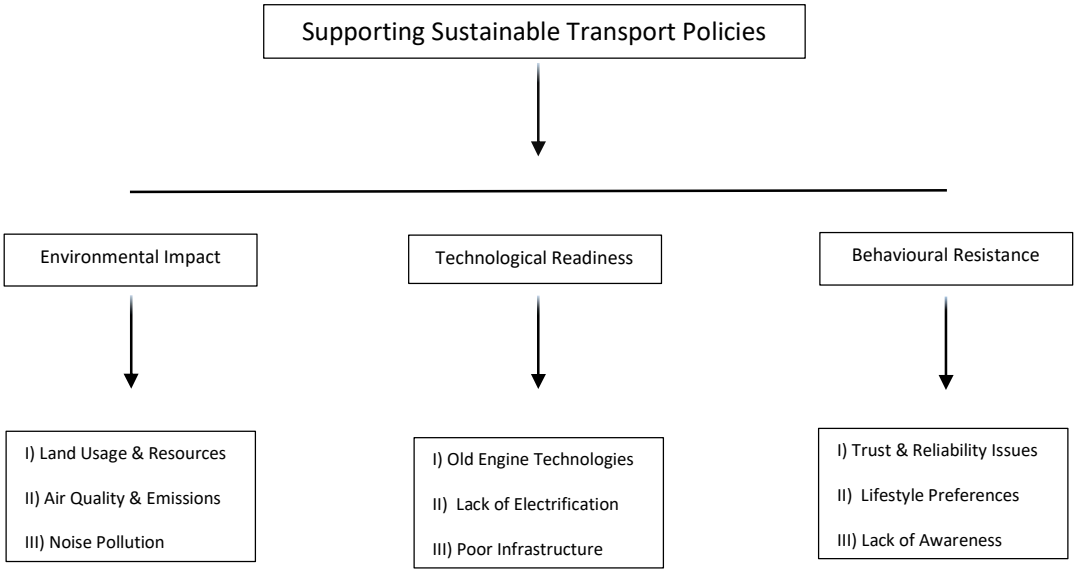


Figure 1: Issue Tree

The first main issue is the environmental impact that has significant affect in terms of carbon emissions and usage of land. Researchers estimate that only Glasgow uses 25% of its land in just the road infrastructure (Massey-Chase et al., 2022). This reduces the resources availability and thus impacting the environment in negative sense. In addition, noise produced from engine knocking, tyre and exhaust emissions affects the air quality by contributing PM substances into the air. The second major issue is still the use of old engine technologies for most of the vehicles that emit more emissions that modern turbocharged engines. Likewise, fewer efforts in electrifying the vehicles, and public buses as road transport accounts for more than 69.8% of emissions (Transport Scotland, 2024). This is because of poor road infrastructure, also a demanding sub – issue. The last and the most important one is the behavioural resistance that makes people not to give up their habits of using privately owned diesel cars. It also involves lifestyle preferences and lack of awareness. The infrastructure also doesn't cover the charging station requirements for broader community. As a result, there comes trust and reliability concerns on electric vehicles because of low range and high prices for batteries. It also highlights issues with the less use of public buses likely due to long travel times and high fares, which often leads to more reliance on cars over public transport.

2.5 Prioritise Issues

When we need to prioritize these issues based on the impact and preferences to focus first, technological readiness comes on top, as it leads to the severe environmental impacts on the habitat we live in. This involves old engine technology like EURO 3, 4 and petrol engines before catalytic converters, along with the still limited use of electrically powered vehicles. It is also because of poor charging infrastructure in addressing the needs to serve community and limited efforts in allocating better road spacing.

The second most important issue is negative environmental impacts. The first sub-issue, such as land usage for building roads and assets for manufacturing vehicles, is among the most impactful natural resources being used. Similarly, air quality is being affected because of increased carbon emissions and appears to be a demanding challenge with the rising number of road vehicles. Also, noise pollution is considered an important sub-issue in traffic-populated areas because of engine noise, braking, and horn sounds.

The third major issue that holds a significant attention and must be addressed is behavioural resistance to the use of public transport. There are certain factors that lead to this mindset, and one is lifestyle preferences, followed by trust issues over public buses in terms of delays and low awareness of the green transitions. This can be addressed by social media and public campaigns. This resistance might have been developed due to the lack of education for high school and college students on the importance of green transitions. All these three major issues are linked to each other, as one follows from the other. The starting point is from introducing technological advancements in vehicles and improving infrastructure that will lead to positive impacts on the environment.

2.6 Conduct Analysis and Formulate Hypotheses

The plan to get done with analysis first involves picking the right data, visualizing it effectively, drawing observations and proposing actionable insights to support this green transition. First thing first is to formulate hypotheses, a set of developed assumptions, and conduct analysis later using CRISP-DM. It will help propose action plans and, if successful… test whether the formulated hypotheses are beneficial to implement in future or not. Below are given some potential hypotheses that can drive the problems being faced:

- Bike-Sharing Schemes promote active travel in Scotland.
- Improved infrastructure helps build trust in electric vehicles.
- Expand Low Emission Zones to improve air quality.

The next step will be to use the cleaned data and draw actional insights through several methodological techniques. This will help identify whether the assumptions align with the policies implemented by Transport Scotland. If they do, deploy the developed action plans and present recommendations on the next progress, and which initiatives need to be promoted. Hence, this will provide guidance on how on shaping policies and investing in right directions.

2.6.1 Develop Action Plans

A structured roadmap to present your findings can prove very beneficial when proposing future policies. Under McKinsey framework step four, an action plan calls for a set of hypotheses that will guide the proper selection of data and help formulate the results. Using methodologies mentioned in next chapter, I would know the areas of focus to help me develop action plans. For instance, if recent Bike – Sharing Schemes have proven efficient in promoting active travel, recommend an action to expand the network in small towns and villages with perks and discounts for students and regular users.

Hypotheses	Action Plan (expand)	Action Plan (rethink)
Bike Sharing	If promote active plan	If do not impact much
Electrification	If infrastructure build trust	If charger types do not impact
Low Emission Zones	If concentration reduced	If substances remain high

Table 1: Action Plans

In the same way, if Low Emission Zones are showing improved air quality, the action plan should expand the zones and raise awareness. Likewise, if public show interest in EVs with efficient charging infrastructure, actions should focus on expanding the fleet of electric buses and free charging points to build trust. If the developed hypotheses work fine… there should the need to expand the policies. Otherwise, the policy must be shifted towards more sustainable solutions or reconstruct that.

2.7 Tools Being Used to Address the Issues

Being one of the most advanced tools for visualising data and excellent for building reports and sharing with colleagues, Power BI is always a first choice in every workplace environment. I would use it for cleaning the data, manipulating it once cleaned, identify patterns within the datasets and draw findings and conclusions. According to Gartner**,** it is a leading BI tool with over six million customers. More than 97% of Fortune companies, five hundred companies use Power BI for business intelligence, means mastering it will advance the career options. The reason to use Power BI is obvious because of its data analysis and report creation features including Power Query Editor. Power BI Desktop is completely free; it can connect to 100+ datasets and comes with more than 30 customized visuals. (Microsoft Learn, 2025). It is also best for allowing you to publish your work over cloud services. Likewise, you can access reports in your workplace, publish them online and even collaborate via a mobile app, showing how user-friendly is its interface. Hence, using Power BI for this project will help me transform the data, draw actionable insights and identify focus areas… like which Stirling zone benefit more from EV chargers, what factors will help in improving active travel modes and so on. Moreover, it can help assess whether student-focused regions or social sectors are the most demanding and develop policies accordingly for effective real-world collaboration.

2.8 CRISP-DM Methodology

Cross-Industry Standard Process for Data Mining (CRISP-DM) is a structured approach to prepare the data, evaluate using relevant methodologies and formulate the results. Being one of the leading frameworks for data science projects, it will prove very beneficial for integrating real methodologies i.e., Time Series Analysis and Geospatial Observations to address the formulated hypotheses (See Appendix B). Overall, I would be using CRISP-DM

from part two - five that involves data understanding and preparation to modelling and evaluation. I would be using datasets related to Bike-Sharing Schemes, Walking Statistics, Electrification and Low Emission Zones. It is also important to know that both part two and three are the most fundamental ones that deals with data, as only a clean and reliable data can lead to accurate findings. CRISP-DM stage two will be used here, which involves cleaning the data, modelling it, followed by the next part to evaluate it effectively. In evaluation, I would use methodologies to understand how the usage trends help in building real-world policies.

Time Series Analysis will be used for bike hangars and sharing policies to understand pattern over time, seasonal trends and multiple potential parameters like demand forecasting. Similarly, I would prefer mapping and clustering in Geospatial Observations to know which specific station location is serving the community well or need future investments. This methodology will also be used for evaluating the EV charger infrastructure and draw potential findings. In addition to that, I would deploy Comparative Analysis when assessing the impact of Low Emission Zones in decarbonising our cities and improving the air quality. The concentration of air pollutants before and after the LEZ implementation will be analysed to draw meaningful insights through A/B hypotheses testing, best for business analytics.

2.9 Conclusion

This chapter explored the problem statement in detail, prioritised key issues and analysed the impacts of how addressing these issues will help make transportation system more efficient. In addition, if the government focuses on formulating hypotheses and developing action plans accordingly, it can help analyse the recent policies and thus prepare for future incentives. In the next chapter, a detailed evaluation is conducted for bike-sharing, electrification and LEZs policies. It highlights the importance of these policies, their effectiveness in future developments with detailed discussion on how the project will achieve the desired outcomes.

Chapter 3 – Methodology

3.1 Introduction

In this chapter, I will outline the quantitative framework necessary to prepare the data and visualize it under CRISP – DM part two. To conclude potential hypotheses and synthesise analytical facts on electrification, and bike-sharing schemes, I would use various modelling techniques. Power BI will be used to communicate findings using a line/bar chart for time-based analysis and a map for geospatial observations. This chapter will also help me dive deeper into each methodology, why it is being used for certain datasets, and conclude meaningful observations. I would use methodologies such as Time Series Analysis, Geospatial Observations and Comparative Analysis for each different scheme. Bike – Hiring and Installation policies will be examined for Stirling and Edinburgh, whereas Electrification for both Stirling and Perth councils. Likewise, active travel data will be visualized for Stirling based on certain locations. As far Low Emission Zones are concerned, I would compare before and after LEZ implementation in Glasgow to study the air quality using comparative analysis. Lastly to access the results in detail and discuss critical points I would again consult CRISP – DM part five of Evaluation and conclude how these can be deployed for future improvements.

3.2 Data Collection and Understanding

A reliable data is a backbone for every consultancy project, as visualising it effectively helps finding key observations and draw meaningful insights about the topic. I collected the data for bike sharing schemes, electric chargers' network and active travel from Open Data Scotland: Transportation, Glasgow City Council, Edinburgh Transport Open Data and Stirling Council Transport Data. More information was collected from Transport Scotland Official Webpage and Low Emission Zones Scotland. The next step was to look for specific files of data, understand its practicality to the transport system, relevancy to problem statement and its linkage with the developed issues in achieving the aims.

3.2.1 Data Selection

Bike – Sharing data was sourced from Next Bike Cycle - Stirling Trip, available on Open Data (Cycling Scotland, 2023). The data contained information on cycle hire date, duration, and rental and return stations. Whereas the data for bike hangars' installation dates and location from 2020 – 2024, was also available on Open Data (City of Edinburgh Council, 2025).

The data for Electrification, was gathered from Electric Vehicle Charging Points in Stirling available on Open Data (Stirling Council, 2025). In the same way, there was also data for Perth and Kinross charging points showing location for each charger, its type, capacity and charging fee (Perth & Kinross Council, 2023). Both datasets will help analyse the charging infrastructure, how effectively it serves the community and development opportunities for future. Lastly, Walking Data was collected for Stirling to analyse the pedestrian count across multiple locations (Stirling Council, 2024). The data shows the location and count sum for the pedestrians, best to visualize busy corridors and develop actions consequently.

For Low Emission Zones' data, I gathered the concentrations of certain pollutants in the specific areas of Glasgow before and after LEZ implementation for the year 2022 and 2023 (DEFRA, 2025). I will visualize the concentration of each substance like No2, Nox, PM10 etc. for 2022 and compare it with the concentrations for 2023. This will help identify if restricting

certain vehicles usage after LEZ has really affected the environment in improving the air quality or not. Hence, it would prove a perfect evaluation that give future insights on whether such policies are beneficial to implement in other regions of Scotland and to what extent.

3.2.2 Ethical Considerations

The available data was collected and cited in accordance with the University of Stirling's ethical policy. All councils have provided consent for the use of publicly available data to enhance the quality of research, foster collaboration with stakeholders, and propose actionable recommendations based on analysis. No confidential, unethical, or biased information was used in any sense.

3.3 Preparation of the Data

After gathering the right data from trusted sources, there was a need to clean the data and prepare it for accurate results and better decision making. The unclean data can mislead to the results and thus lowering the accuracy of the model. Hence, I transformed the data first, removed any missing values and errors to make it usable for drawing insights. To clean the data for bike-sharing, electrification and LEZs, Power Query Editor proved a leading champion. The data cleaning starts with loading the data files, click on Transform Data, followed by a window that shows the editor. There comes removing unnecessary columns, handle null values, check data types (like number, text, date etc.) and fix if any typo mistakes. Following are some steps taken to clean data, build relations and draw visuals for better result.

3.3.1 Data Cleaning and Manipulation

The data for bike hangars installation was approximately clean, just had to change some data types. But for bike sharing schemes in Stirling was having duration in seconds with some extensively large values. I had to change the duration column into minutes and changed the large values with appropriate mean values. Likewise, as for electrification data is concerned, it was appropriate just changing some names of the locations that were misspelled. In case of active travel walking data, I had to manage count sum and drop percentage column. For Low Emission Zones, there was just to drop unnecessary columns and focus on most demanding ones like No2, Nox, PM10 etc., with rest of the cleaned data. After cleaning, I decided to manipulate the data by asking multiple questions to me like is bike usage seasonal, how does electric chargers' infrastructure serve the community, which geographic area need more investment to implement LEZs, and will active travel help in reducing traffic flow etc. After that, I used appropriate bar graphs, charts, tables, slicers, card, map and many other visuals better to draw meaningful insights.

3.4 Modelling and Methodology

Methodology usually refers to planned strategies and organized efforts for your research. It is an important part for any data science project as without a right methodology, one cannot achieve desired outcomes. I am using CRISP-DM framework, and under part four i.e. modelling, there comes to select appropriate methodology. Keeping in view the type of available data, project requirements and action plans I would use three main approaches necessary to address the problems and achieve required aims. Firstly, I would be using Time Series Analysis to analyse how variables change over time, and any seasonal cycles or trends. Geospatial Observations will not only help to read census data tied to specific geographic locations but also visualize relevant community trends. Lastly, I would go with Comparative Analysis to identify if the concentration of pollutants reduced after LEZ implementation compared to previous year or not. Each of these methodologies are explained in detail below:

3.4.1 Time Series Analysis

Time Series Analysis is an approach to visualize the sequence of data collected over a certain period and hence figure out how seasonal trends vary with time. Stock market is an excellent example of this analysis, that help see when and how an event occurred so business users can make better decisions. The most generalised visuals include line or bar chart, cycle plot verse time on x-axis. There are several types of time series analysis and choosing right one helps you detect the relations without error and false predictions (Tableau, 2025). So, I would use the following time series techniques to identify how each can address specific challenges.

I would use Intervention Analysis, a study that shows how an event can interrupt the data variables and affecting the future actions. Under this technique, I analysed the outcomes of Covid-19 on fluctuating bike installation plan in Edinburgh. The bar graph showed that there was no installation of bike hangars between 2021 – 2022. Similarly, the Next Bike data was also examined under this technique and draw conclusions that there was a smaller number of trips during lockdown likely due to the closure of university, colleges and offices in Stirling.

Both these datasets were again visualized with the help of Explanative Analysis, a study that attempts to understand relationships within data, as well as the cause and leading effects. For bike installation, it will explain why Morningside and Leith Walk have higher number of stations, whereas for Next bike it will address why bike usage duration is lower in Winters. In addition, Descriptive Analysis will also prove beneficial to identify patterns like seasonal variation and draw conclusions. In case of bike installation plan in Edinburgh, this methodology helped explain the fact that most of the development was undergone for the months of June to October likely because of favourable weather. Whereas, for bike scheme in Stirling, I would study usage cycles based on weather, geography and demand.

On the other hand, descriptive analytics will be used to explain active travel data that includes walking data by location for 2024 in Stirling. It will explain why there are more pedestrians on weekdays rather than weekends. Based on locations, I will analyse walking cycles and trends and hence predict the demand. Whereas, in case of EV charging data… for both Stirling and Perth, I will use explanative analysis to identify the types of chargers, their shared charging stations and how well they serve the community. It will help me explain the reasons to install certain chargers in different locations and conclude how this could build more trust in EVs.

3.4.2 Geospatial Observations

Geospatial Analysis is a process to classify patterns, identify hotspots and study cycles of demand for a census data tied to specific locations. Power BI uses geographic variables like latitude and longitude to analyse relationships within data. It also contains information to describe objects, features and attributes using range of maps. These maps can be used with custom boundaries by adding reference layer, best for demographic visuals. In addition, my data is linked to dynamic locations that will help analyse the spread of stations in the case of bike-sharing scheme and EV chargers for electrification analysis within the councils. Based on demands and geography, here includes several applications of this Geospatial Observations like point clouds, images, and so on. (IBM, n.d.). Below are mentioned two sub methodologies I am going to use in my spatial visuals.

I would first use Census Data, a study analysing community trends closely tied to locations. This will help me visualise how infrastructure is linked to regional developments and initiative policies. In case of bike installation, I observed the linkage between geography and demand under this technique. For instance, map showed councils such as Morningside, Leith Walk, and Southside which are close to two prestigious universities of Edinburgh, city centre and private rentals have much higher demand and so bike hangars compared to other councils. Whereas Next bike scheme was examined with the help of Geospatial analytics, a study that

add locations and timing to traditional types of data. It was drawn that areas close to student accommodations, the University of Stirling, Wallace High School and city centre are of increasingly high demand. It also made me learn that the duration of trips taken from train stations is generally smaller than those taken from academic institutions. In addition, the same geospatial analytics was applied to walking data in Stirling and found that a higher number of pedestrians are in the areas close to the city and major retail businesses.

For EV charging station data in Stirling and Perth, I examined the dynamic pattern of installations using both Census Data and vector and attribute analysis. The former has been explained above, while latter methodology involves descriptive geospatial information such as points, lines etc., highlighting comparable trends. These methodologies helped uncover community demand, spatial coverage, and the distribution provided by charging infrastructure. The analysis shows that areas close to natural tourist sites are typically equipped with fast chargers, whereas urban centres tend to provide a mix of fast, rapid, and standard chargers to meet diverse travel needs. Such insights build trust in EV adoption, encourage ownership, and ultimately support sustainability. This approach also makes it easier to identify charger types and speed by location and assess how they can benefit the maximum number of users.

3.4.3 Comparative Analysis

A comparative analysis is a side-by-side comparison of different ideas, business problems or specifically data sets. It is generally divided into two subtypes, that includes quantitative and qualitative data and then extending findings with the help of those analytics. It helps focus on specific data that directly impacts the challenges being faced for business growth. The best for analytics is quantitative comparative that will be used here to analyse air quality concentration before and after the implementation of Low Emission Zones. For this, I analysed the average concentration of NO2, NOx, PM10 and PM2.5 and compared it from 2022 – 2023. There were noticed reduction in the concentration of those substances. Also, pollutants are higher in winter compared to summer, likely because of more burning for heating. This will help the authorities plan and extend their regions outward for more such initiatives.

3.5 Detailed Evaluation using CRISP-DM

The evaluation section involves discussing if reliable techniques was used, understanding if the right methodologies are picked and present results accordingly. In this section, hypotheses formulated before will be analysed and identify whether the modelling covers the required aims. As per the detailed evaluation of previous methodological techniques, it can be concluded that the initiatives like bike sharing schemes, electrification and low emission zones can prove very beneficial in decarbonisation and improving air quality. The methodologies picked to analyse each of this scheme meet the requirements and are rational for examining the data. For visualising the prepared data in Power BI, discussing results and evaluating deployment, the CRISP-DM perfectly meet the requirements, and address the challenges.

But this framework does not have any section to build issue tree and understand the problem in broader sense. To understand business problem, prioritise key issues and formulate hypotheses, I involved McKinsey framework that fits better to understand the problem and conduct analysis. Lastly, again CRISP-DM helped me to prepare data, model the right approaches and thus conclude the results later in the next chapter. It will help government and authorities analyse to what extent the scheme worked, and if it’s incumbent to expand the horizons for more such initiatives. In addition, I would like to deploy the plan in the discussion part of chapter 4. It will help discuss what further improvements can be made in terms of investment, infrastructure, demand, and geography. This explanative discussion will prove evident in supporting further development of the policies and thus present the findings.

3.6 Conclusion

In conclusion, this chapter discusses in detail the data selection, cleaning and manipulating process, necessary when considering the ethical approval of content. This also evaluates the different methodologies, how each can address the specific policy and draw actionable insights after analysing the trends. Time Series Analysis is perfect to access data based on seasonal trends, Geospatial Observations to evaluate the data linked to specific geographic locations and comparative analysis to analyse before and after LEZ data. Also, it concludes how each methodology is perfectly fine to cover the broad aspect of defined policies, their effectiveness and synthesize findings later. In the next chapter, I would draw results and discuss the key findings, focus areas and future improvements using developed visuals.

Chapter 4 – Results and Discussions

4.1 Introduction

This chapter will focus on the key findings, results and discuss the potential impacts of policies evident in supporting sustainable transport solutions. I would present the visuals, analyse demand over geography, comment on the possible areas of improvement, identify usage trends, and any seasonal cycles best to draw conclusive insights. This chapter will address each specific issue, introduce areas need urgent attention, and what policies can be extended further to develop action plans. The achievements of previously implemented policies, their impacts in reducing carbon emissions and efforts in boosting social and economic growth will be discussed. It will also test the developed hypothesis, conduct analysis based on that and propose action plans that must be implemented to achieve the specified goals. In the end of each section, I would like to discuss what impacts does these policies had on current transportation system and what can be introduced further to support this transition.

4.2 Bike-Sharing Scheme and Active Travel

A bike-sharing scheme is an initiative to provide service for daily commuters and travellers, shared use by individuals who want to rent a bicycle for shorter duration of time and return it after to designated station. It is an excellent system that helps students and other commuters easily pick a bike instead of owning it and thus promote active travel. In recent years, several policies have been implemented in Scotland's major towns and cities to install bike hangars across multiple locations and provide easy access via mobile app. Below are discussed some important results drawn after visualizing bike sharing scheme in Stirling and Edinburgh:

4.2.1 Results

4.2.1.1 Bike Hangars Installation (Edinburgh)

Time Series Analysis

Intervention analysis made it clear that the need to install bike hangars in Edinburgh was evident at the beginning of 2020. This was because of an unexpected outbreak of Covid – 19 that the world has witnessed and locked down cities to save humanity. Public journeys were discouraged and a demand for active travel policies raised significantly. This led to the need for shared bike hangars in some big councils so that locals could travel with more sustainable options independently. Hence based on geographical location, housing types and demand of commuters, several bike hangars were installed in 2020. But this also can be seen that no such initiatives were in progress after this intervention, from the year 2021 – 2022. This was likely because of the focus divergence, no action plans or to cover after pandemic gaps.

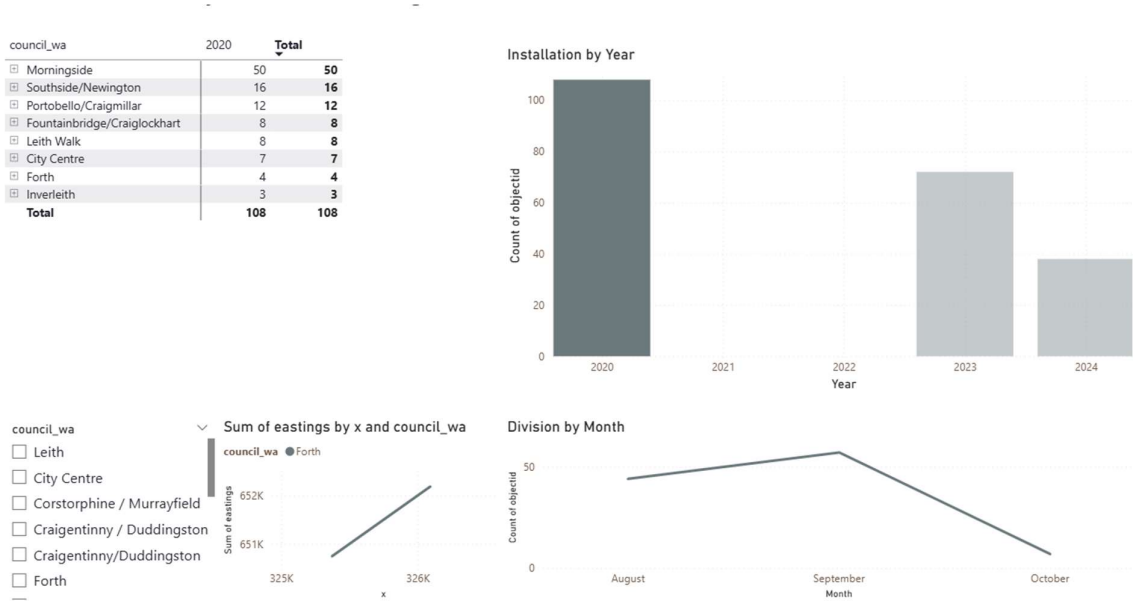


Figure 2: Bike Hangars Installation – Intervention Analysis

In here, descriptive analysis explains the seasonal variations in installation that help identify patterns. This shows that maximum number of bike hangars were installed during summer, when Scottish weather was feasible with this development. Tourists come to explore the natural beauty of Scotland from May – Sep, including residents with leisure trips, hence there is a need for more bikes in these moths. The below figure tells us that the policy was again driven in 2023 by installing around seventy-two more stations in highly busy councils. It can also be drawn that focus is purely demand-based rather than diverse community services.

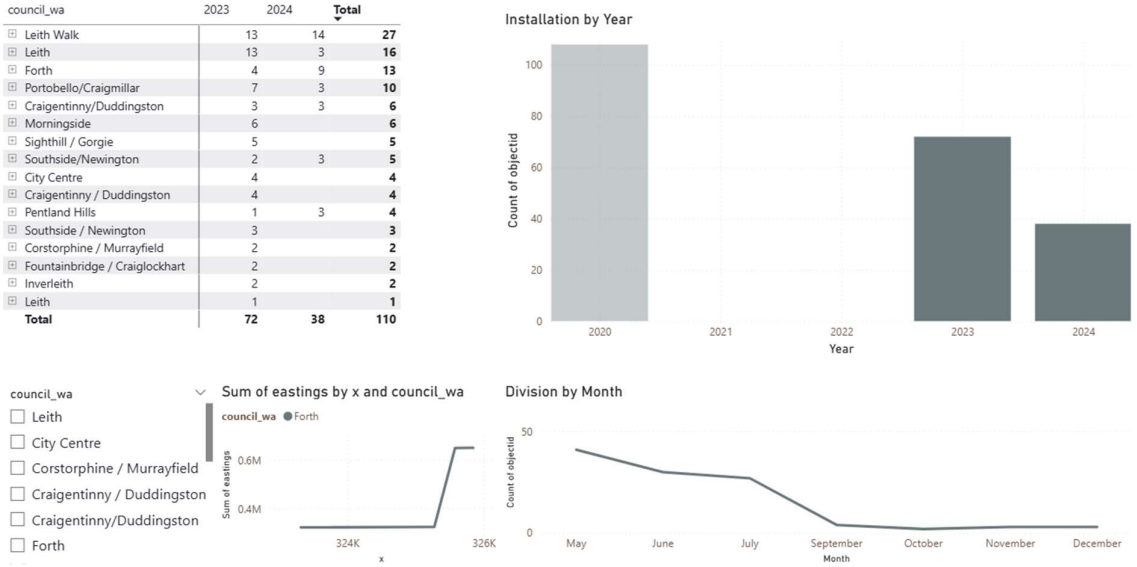


Figure 3: Bike Hangars Installation – Descriptive Analysis

Lastly the overall picture tells that two councils named Morningside (56) and Leith Walk (35) having highest number of installations because of their proximity to universities and city centre. Both these areas are crowded with students and private rentals, showing a good strategic policy. It also highlights areas accessible to student have more stations, as it will not only a cheap travel option for them but also a best plan to promote sustainable transport solutions. In parallel, council Forth shows that the trend to install bike stations is higher eastwards, which suggests installations are not evenly distributed within areas.

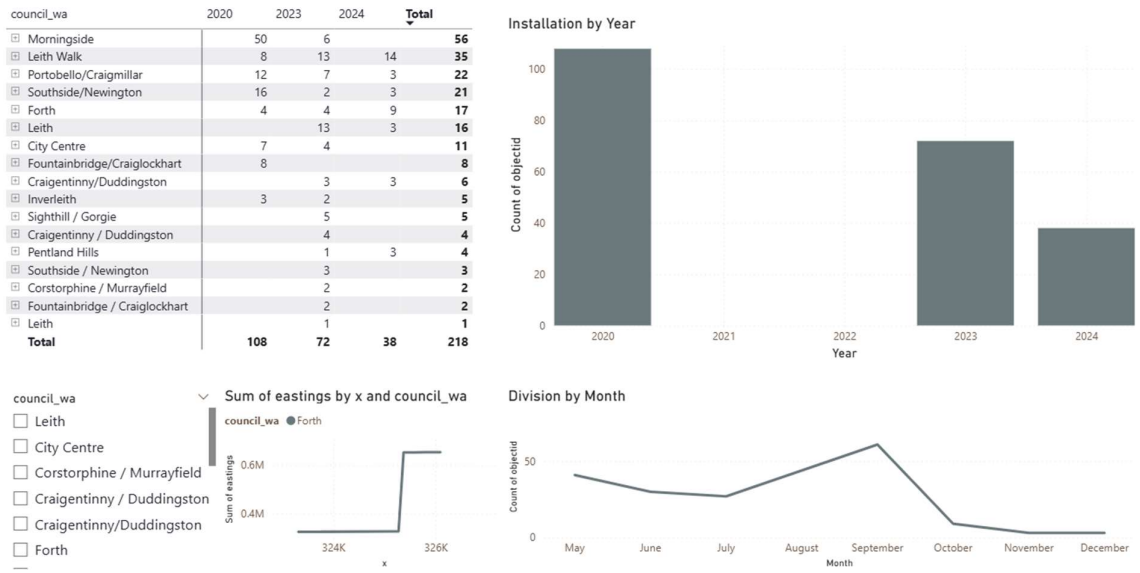


Figure 4: Bike Hangars Installation – Time Series Analysis

Geospatial Observations

On the other hand, geospatial observations were visualised under Census Data based on location, active users, residential density and proximity to amenities. It shows bike hangars installation is uneven, few councils have significantly higher number of stations because demand follows housing type not just geography. When examining Morningside, Leith Walk, Southside, and City Centre, they are in high demand and thus need more bike hangars because these are close to Edinburgh Napier University (0.6 km away) and University of Edinburgh (2.1 km away) respectively. Also, these areas have no garage or private sheds and have compact type of houses showing an excellent need for bike sharing schemes. Research show that Southside being a highly demanding council is also very close to city centre and University of Edinburgh. This council including City Centre should have more bike installation plan. In addition, it should be initiated that government must expand to areas even because of low demand to promote active travel and hence ensure fair distribution among the councils.

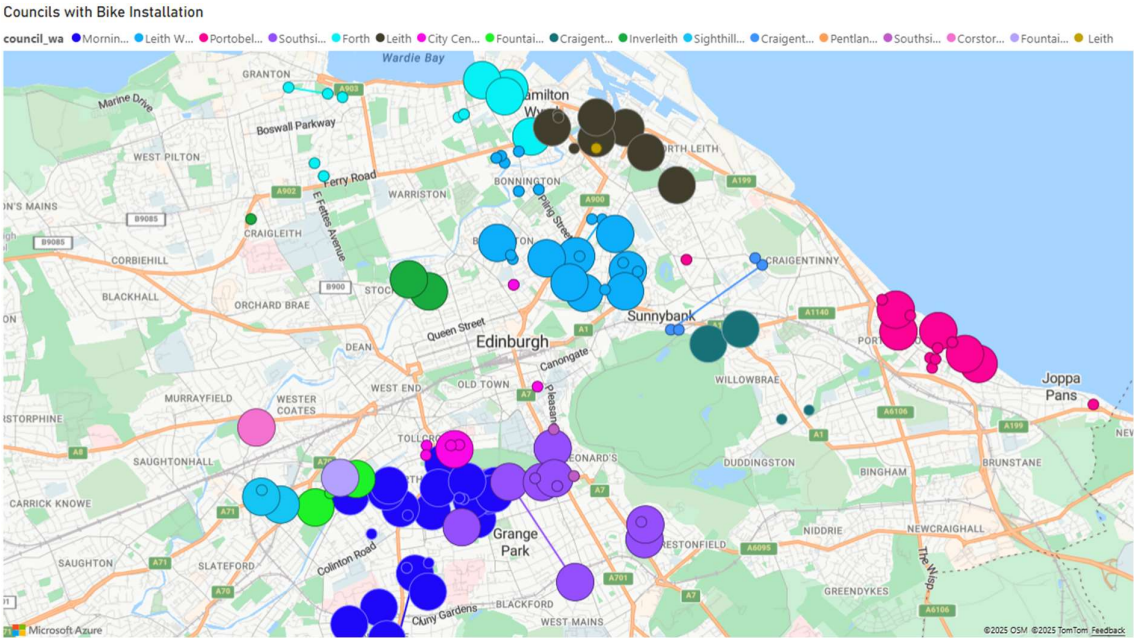


Figure 5: Bike Hangars Installation – Mapping

4.2.1.2 Next Bike Cycle Hire (Stirling)

Time Series Analysis

This dataset covers the bike usage across Stirling from 2018 – 2023. The trend doesn't show as many fluctuations as the previous bike installation policy but highlight that cycle usage was limited during Covid – 19. Again, intervention analysis helps identify this cycle and recommends that most of the bikes are used by students, to go to their institutions and from these academic locations back to their accommodation or train station. But when the University of Stirling was closed during the pandemic, usage came down. In addition, descriptive analysis highlights that cycling is highly seasonal, and hire duration is shorter in winter, from Mid-November till February. This is because more tourists visit in summer, along with leisure trips but winter restricts it may be due to icy weather, closure of academic institutes, Christmas months and less daylight, lowering duration graphs.

On the other hand, explanative analysis synthesis that cycling trend started to rise again in 2023 because the resumption of office trends, raising awareness and improving infrastructure. Even if the number of bike users are in hundreds of thousands just in Stirling council showing an excellent contribution of Next Bike scheme, and how it helped improve active travel. The initiative offering a thirty-minute free ride for students is very attractive but more perks and discounts for regular users will further help in adopting this change. In addition, more positive changes can be introduced i.e., electric bikes etc. by engaging stakeholders. Promoting winter usage and providing e-bikes will not only help support these green transitions but also appealing to users who don't want to hire a manual bicycle for their journey.

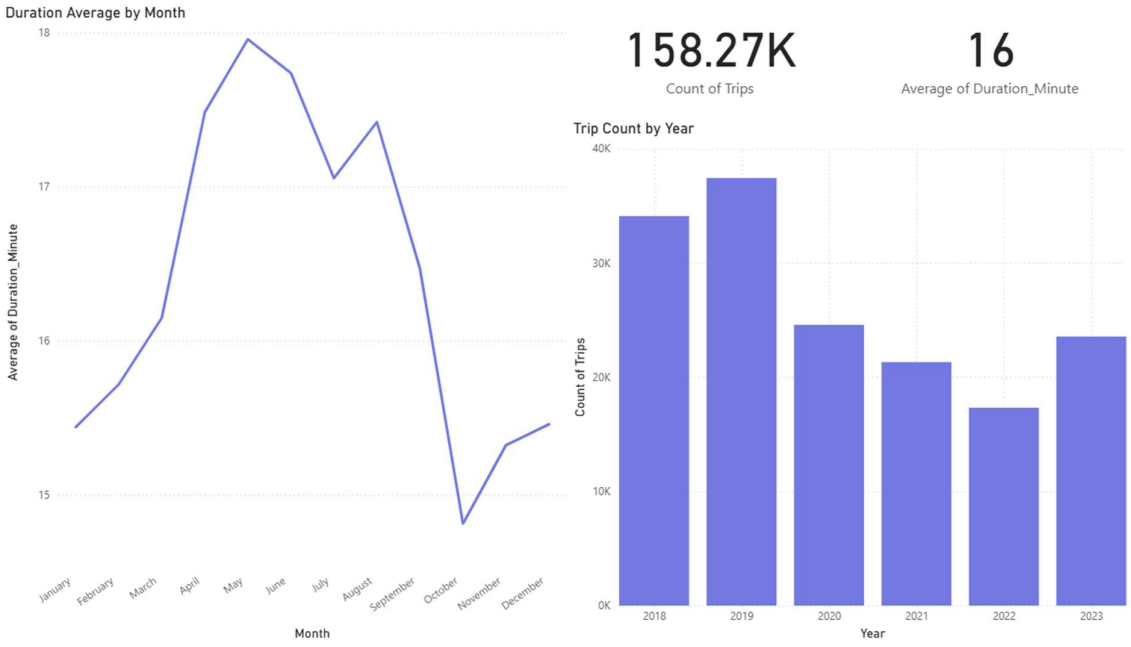


Figure 6: Next Bike Hire – Time Series Analysis

Geospatial Observations

Below visuals show that stations like Old Stirling Bridge that is located in between city centre, and the University of Stirling, Train Station, Cottrell Building and Bridge of Allan are the busiest ones with overlapping circles. Regions used by college and university students, private rentals and close to city centre are increasingly of high demand in Stirling. So, Vector and Attributes, a study based on geospatial statistics, explains that location matters when planning schemes. It can also be seen that bike usage is higher in peak hours compared to off-peak and least during night times, must consider when making business decisions.

Although the whole Stirling council is well-distributed with the bike stations, explaining good strategic investment, yet there is a need to focus on transparent model. It will promote bike usage in the local or residential areas and thus is a perfect initiative for this modal shift from private to public transport. Nevertheless, supporting last-mile solutions near bus stops is important for those who want to hire a bike for just some end durations of their journeys. It will help encourage multi-modal journeys and thus promote active travel.

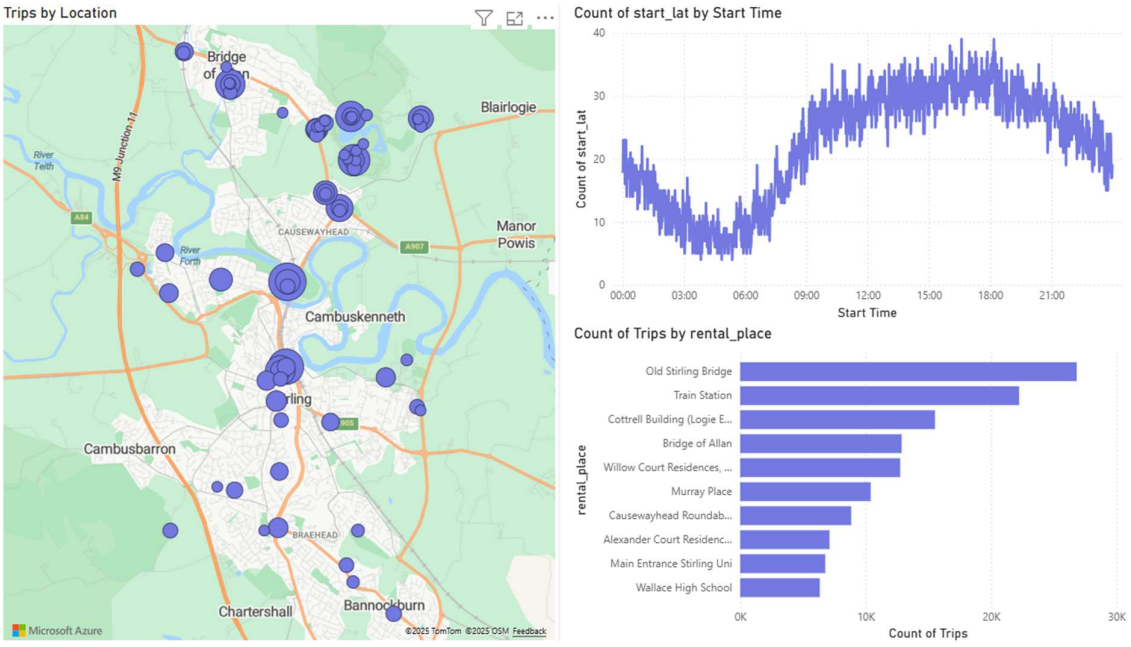


Figure 7: Next Bike Hire – Mapping

4.2.1.3 Walking Data by Location & Day (Stirling)

Descriptive Analytics

For active travel data, I would implement descriptive analytics to understand the pattern over weekends, identify location hotspots and locals' coordination with major pedestrian corridors. The image shows Kerse Road East and Craigs Roundabout (South) are the busiest of all with more than 40,000 pedestrians counts, because they both are close to the city centre, easy access to amenities like the Thistles Shopping Centre, TK Maxx, and more. Kerse Road is highly centralized around bridges, roundabouts, and major businesses, whereas Craigs Roundabout because of its closeness to the Train Station, Bus Stops, major walking corridors for locals and tourists. Weekend trends for walking are the lowest likely because of more reliance on cars for leisure trips.

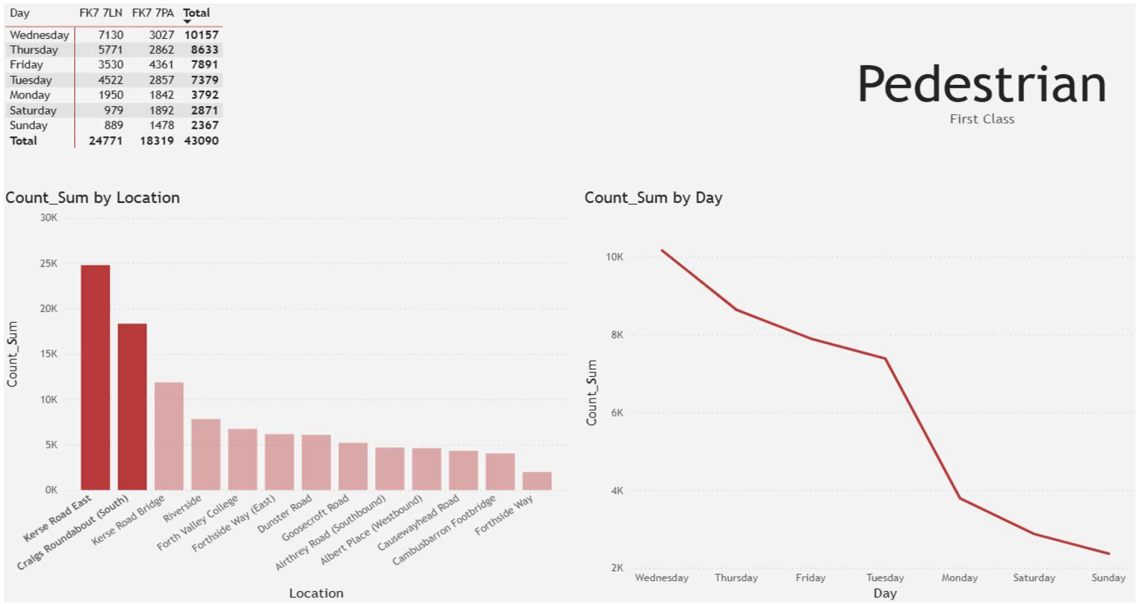


Figure 8: Walking by Location – Part I

Whereas the Forth Valley College Road is used mostly during weekdays by the students rather than weekends. The reason is obvious that the walking students going to or coming back from college. This road is also close to Sainsbury's, falling it among the busiest roads used by locals. In the same way, road named Airthrey Road also have large number of pedestrians walks mainly because of the University of Stirling and Wallace High School. Again, the walking trend is same over the weekdays… but both these roads can be encouraged by improving the safer crossing and road spacing infrastructure.

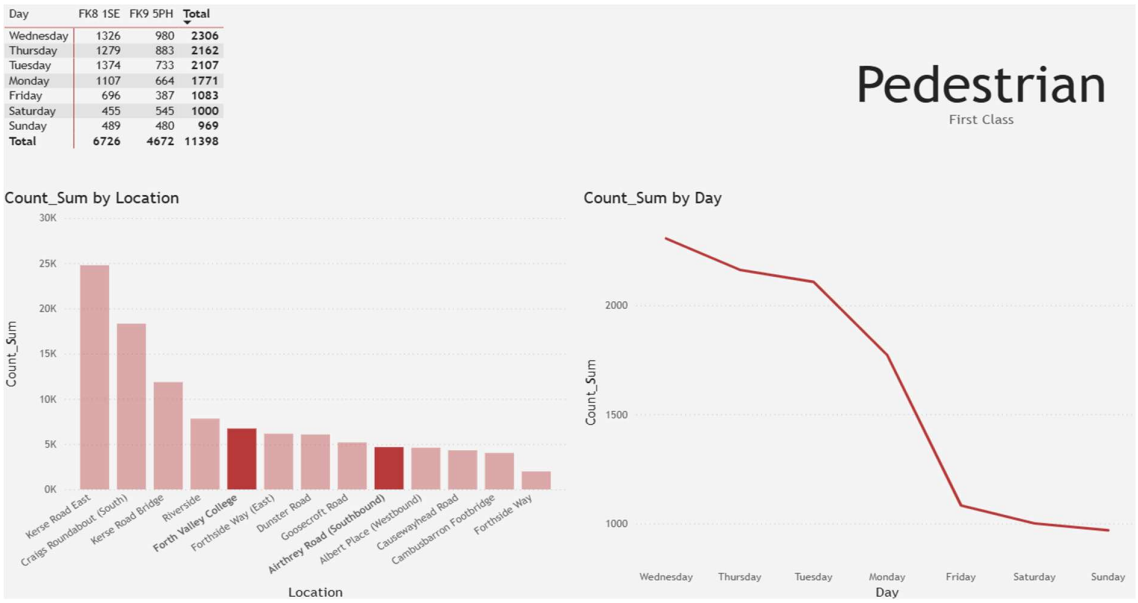


Figure 9: Walking by Location – Part II

The overall image shows that postcodes in FK7, which are close to business hubs, have a significantly higher number of pedestrians because there are more facilities, safer walking corridors, and better lighting. Whereas corridors with codes in FK9 have the lowest pedestrian activity because they lack road-spacing and are local residential areas. This shows a gap in infrastructure that must be addressed to ensure all citizens get an equal share of facilities. To encourage walking, there is a need to introduce measures in lower-activity areas like Causewayhead Road, which can be promoted due to its proximity to the University of Stirling and Wallace High School. This would help reduce traffic pressure. On the other hand, Frothside Way could be encouraged for active travel by introducing smart corridors and better wayfinding, as it has the potential to become a strong tourist site with more amenities.

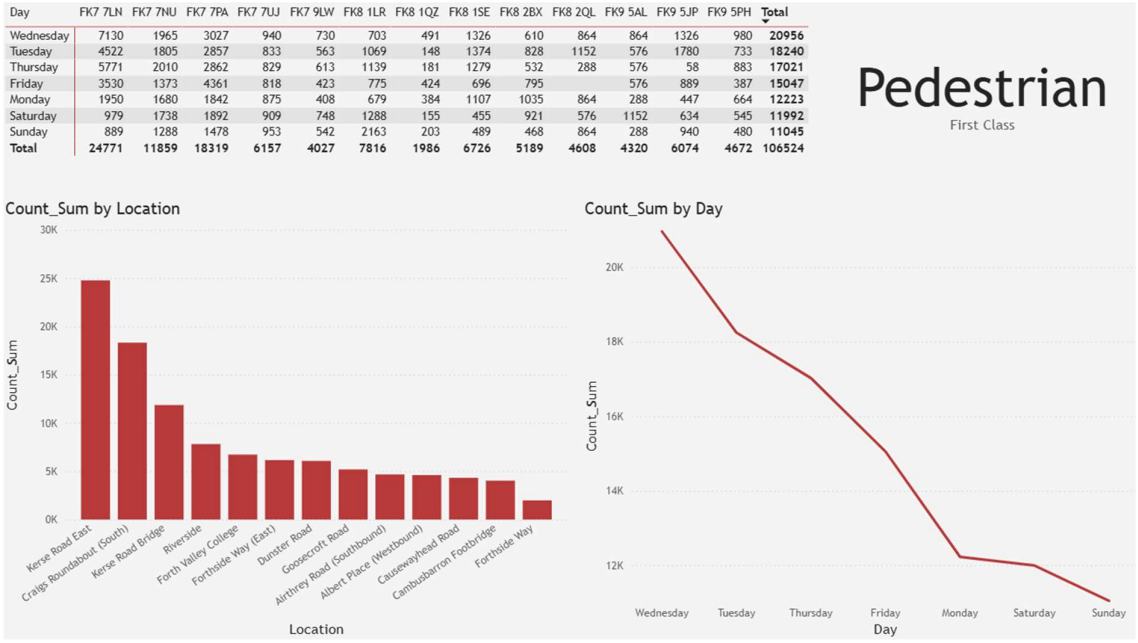


Figure 10: Walking by Location – Descriptive Analytics

Geospatial Observations

The geospatial image shows that areas close to the city centre covers the businesses and retail hubs, Springkerse, industrial estate, and more. This area is within walking distance to Bannockburn, St. Ninians and well connected to main roads (A91, A905). Hence, this shows the largest red bubbles in Stirling Centre and Kerse Road. Whereas the FK9 area is less commercially dense but still mainly connected to the university, Bridge of Allan, and residents. Most of the students hire bikes for their journeys, reducing walking activities in FK9, but FK7 has higher count because of daily retail commuters and better transport connectivity. It is also important to note that pedestrians' walk can be promoted at a very large scale in FK9 regions because of some best touring points. The Wallace Monument, Stirling Castle, University of Stirling, Loch View, and Dumyat Hill are best places and must need some active strategies. It can prove very beneficial to build smart corridors, way finders for tourists, street lighting, and some easy access to bus stops. This policy will not only help stakeholders to encourage active travel among tourists but also to meet sustainable goals and reduce carbon emissions.

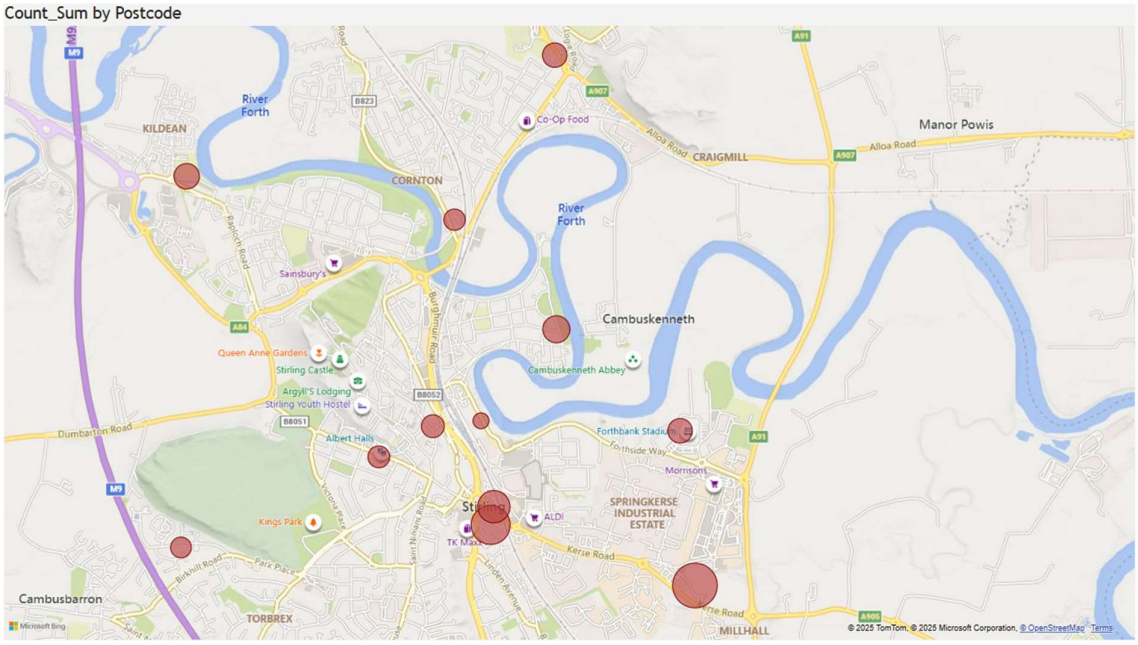


Figure 11: Walking by Location – Mapping

4.2.2 Discussion

The above results highlight the importance of active travel policies in achieving good air quality and better use of land and resources. It directs to address the first sub-issue related to Environmental Impact… by reducing pollution and advancing efficient land allocation. Such active travel policies will also have impact on the third key issue by raising awareness among the public to use bicycles or e-bikes over private cars. It will thus change lifestyle preferences and address behavioural resistance. Hence, active travel policies are beneficial in supporting green transitions, reducing road congestion, and promoting active travel for those who don't own bicycles; by testing the formulated hypotheses and confirming the assumptions were true.

More than 78% of people say combining exercise and transport at the same time is quite beneficial for health, but only 18% of people from minority ethnic groups have access to a bike. With these policies, 4251 serious long-term health conditions saved, by reducing around 90,000 tonnes of greenhouse gas emissions. Also, with recent active initiatives, £11 million has been saved by cycling, and £42.6 million has been saved by walking and wheeling. (Sustrans, 2024). The other surprising fact is that £1.1 billion in economic benefits is for individuals and index cities, with almost 440,000 cars taken off the road every day. This shows how important it is to expand active travel schemes, as it saves up to £53.6 million a year for NHS Scotland.

4.3 Electrification and Modern Infrastructure

Electrification is a process to convert an energy consuming product or service from non-electric means of power to electric ones for reducing carbon emissions. The vision of Scotland having the best air quality in Europe, is backed by multiple recent initiatives including the policies to develop highly electrified infrastructure. This will help build trust over EVs, drive efficiency and improve product quality. Keeping in view the defined goals, Transport Scotland implemented multiple projects to install electric chargers in the big towns and cities. Below are some important results from the analysis of EV charging points in Stirling and Perth.

4.3.1 Results

4.3.1.1 EV Charging Points (Stirling)

Descriptive Analytics

The image below primarily covers the charging stations in Central Scotland, Stirling Council. It serves tourists as well as inter-city travellers. Dual 7KW AC and 22KW AC chargers are close to the areas in towns for residents to travel day-to-day and make around 75% of the total. The main installation points are Fallin, Bridge of Allan, Cowie, Dunblane, Stirling and more, perfectly cover the needs. Their aim on slow charging for long stays in workplace, or home etc. The top charging locations are focused with this AC charging.

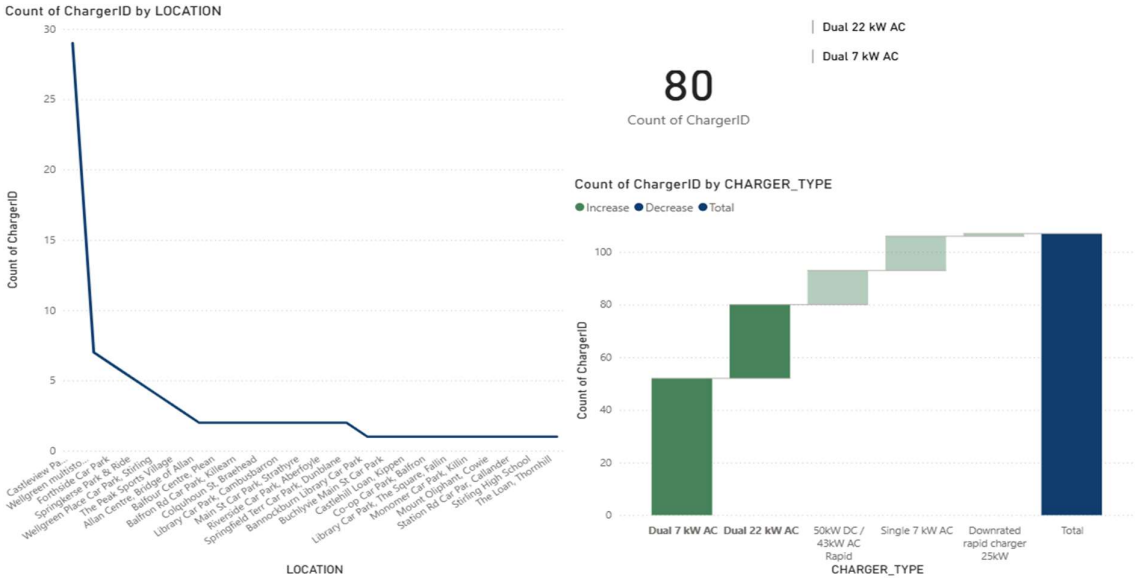


Figure 12: EV Charging Points Stirling – Part I

In the same way, 50KW DC rapid chargers are installed for a quick top up when need some hundred miles during travel. These are in Stirling, Dunblane and Callender. Its best locations must be main travel route, large towns, key junctions and tourists' points. It allows to quickly add enough milage in just 20-40 minutes, perfect for people on long journeys.

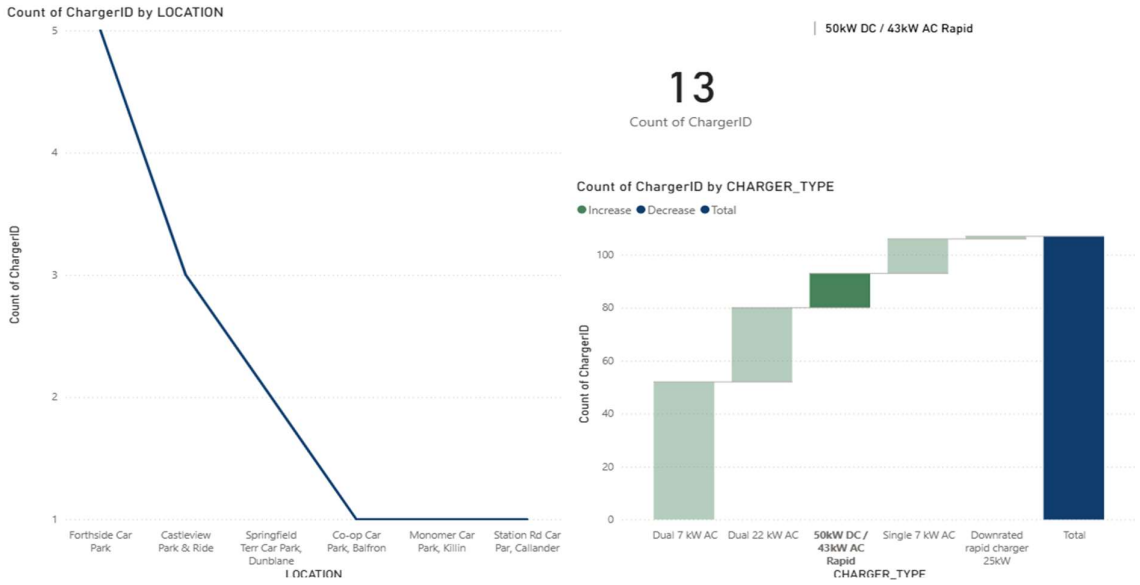


Figure 13: EV Charging Points in Stirling – Part II

The overall image shows that most chargers are installed in Catsleview Park & Ride (32), Forthside Car Park (11), and Wellgreen Multistorey Car Park (10) and accounts for around fifty percent of the total. This means charging distribution is uneven and covers the major towns and cities, but not small villages well. Also, most of the chargers are just AC ones with a focus on slow charging but there is a need to install rapid charging stations as well to serve the broader community to build trust on EVs.

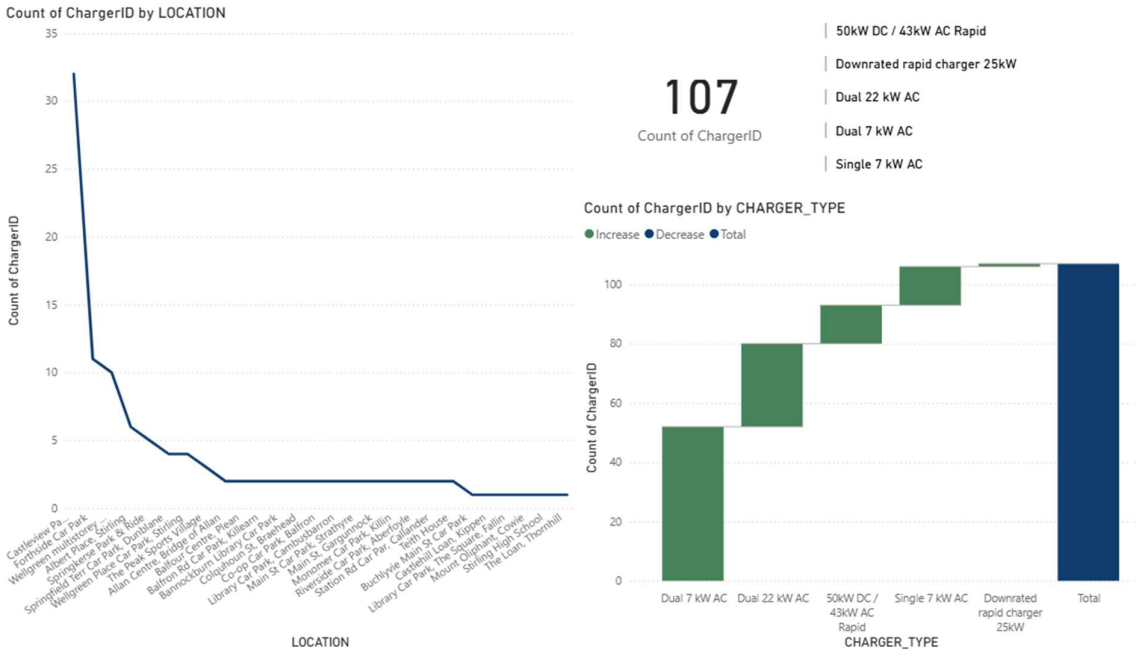
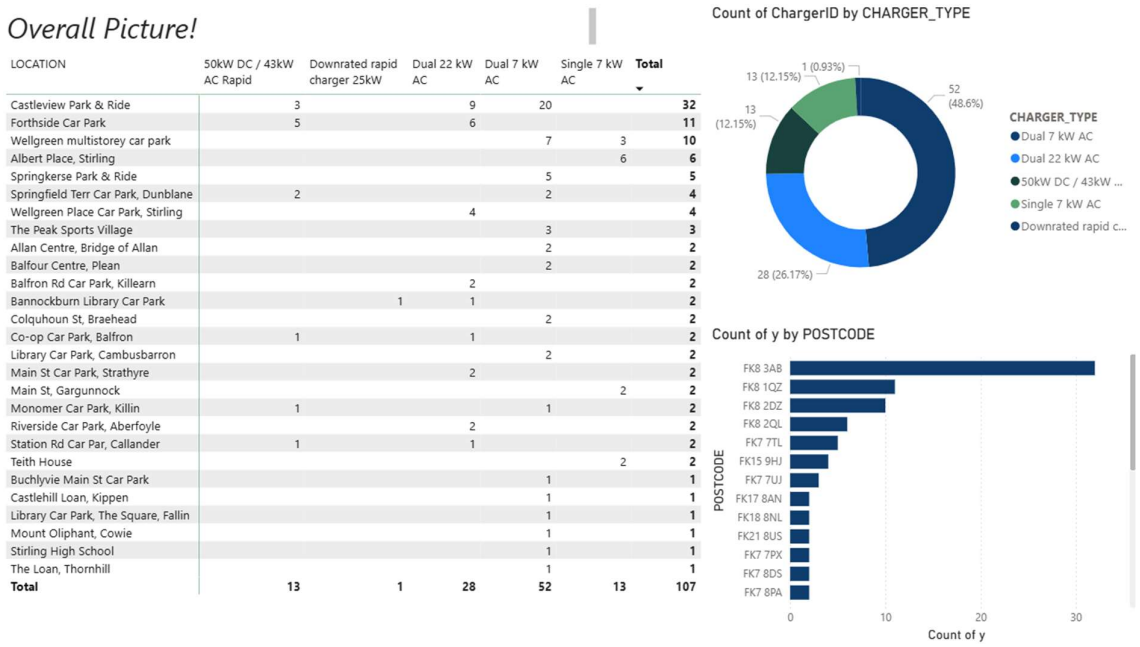


Figure 14: EV Charging Points Stirling – Descriptive Analytics

Geospatial Observations

The geospatial census data highlights the main points regarding charging infrastructure and how well it meets travel needs. We can see that there are three to five locations with most of the chargers, while others fall behind with just one or two. This discourages tourists from hiring EVs for long or intercity travel. In addition, Stirling's urban hub for AC slow and DC rapid charging is mainly located in paid parking areas. This causes hesitation among locals, because they must pay both fee for car parking and charging. A more effective initiative would be to install charging stations on-streets instead of car parks, to better serve the community. Also, certain postcodes, such as FK8, have a higher number of electric chargers, which should be accounted for in terms of inclusion and diversity.



LOCATION	50kW DC / 43kW AC Rapid	Downrated rapid charger 25kW	Dual 22 kW AC	Dual 7 kW AC	Single 7 kW AC	Total
Castleview Park & Ride	3		9	20		32
Forthside Car Park	5		6			11
Wellgreen multistorey car park				7	3	10
Albert Place, Stirling					6	6
Springkerse Park & Ride				5		5
Springfield Terr Car Park, Dunblane	2			2		4
Wellgreen Place Car Park, Stirling			4			4
The Peak Sports Village				3		3
Allan Centre, Bridge of Allan				2		2
Balfour Centre, Plean				2		2
Balfron Rd Car Park, Killearn			2			2
Bannockburn Library Car Park		1	1			2
Colquhoun St, Braehead				2		2
Co-op Car Park, Balfron	1		1			2
Library Car Park, Cambusbarron				2		2
Main St Car Park, Strathyre			2			2
Main St, Gargunnock					2	2
Monomer Car Park, Killin	1			1		2
Riverside Car Park, Aberfoyle			2			2
Station Rd Car Par, Callander	1		1			2
Teith House					2	2
Buchlyvie Main St Car Park				1		1
Castlehill Loan, Kippen				1		1
Library Car Park, The Square, Fallin				1		1
Mount Oliphant, Cowie				1		1
Stirling High School				1		1
The Loan, Thornhill				1		1
Total	**13**	**1**	**28**	**52**	**13**	**107**

Figure 15: EV Charging Points Stirling – Clustering

Most of the AC and DC chargers are in Stirling car parks, an ideal location for those travelling to long durations to Edinburgh, Glasgow, or Dundee. There is also a mix of slow, rapid and dual chargers near M9/A811 junction, is a very well-placed and perfect for on-route travellers. There is also 7KW AC charging station in Springkerse Industrial Estate, showing an excellent planning for workers to own EV vehicles to come to their offices and retails. In the same way, the image highlights how well-served is the charging network by 7KW AC chargers installed in Central Stirling, Fallin, Cowie, Plean, Bridge of Allan, and more.

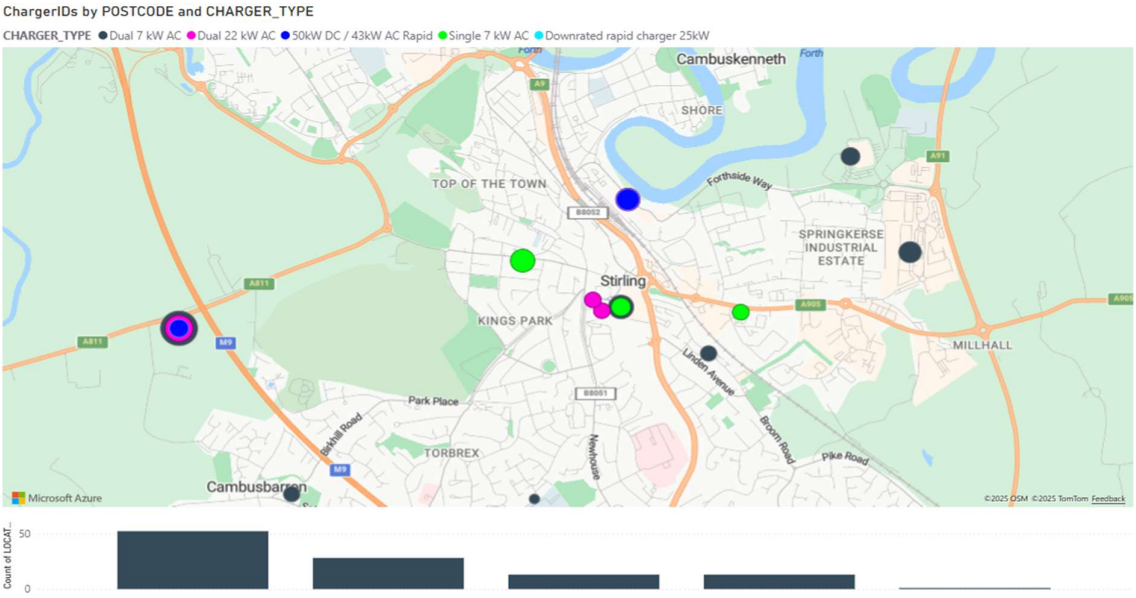


Figure 16: EV Charging Points Stirling – Mapping I

It also shows most 50KW rapid chargers are installed in M80 (a hub for Edin. and Glasgow), M9 (connect Dunblane to Cambusbarren), and A9 road (connect Stirling to Perth). The other locations are in Killin (a central highland of Scot) and Balfron (a gateway to Loch Lomond and The National Park), to promote tourism and counter the demands. But there are certain factors to focus on like at least to install ultra-rapid chargers in Central Stirling Hubs, with real-time availability, pricing and payment methods. Also, there is a need to expand the network outwards than just Stirling and put more DC chargers on Motorways rather than AC ones.

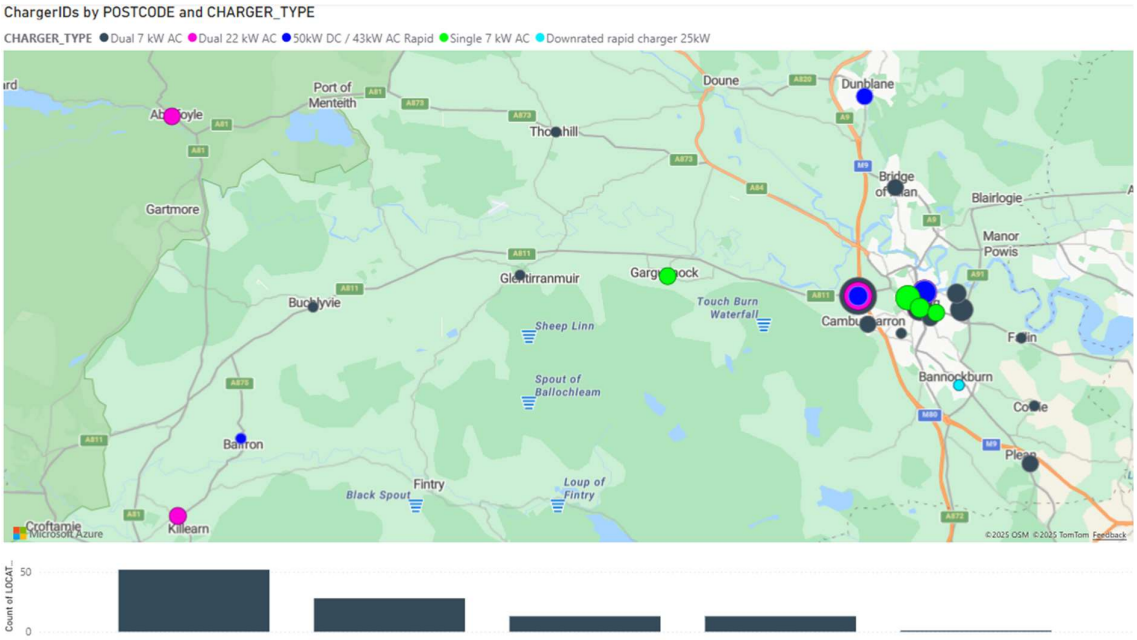


Figure 17: EV Charging Points Stirling – Mapping II

4.3.1.2 EV Charging Points (Perth)

Descriptive Analytics

The image below highlights the fast-charging infrastructure across different locations in Perth and Kinross. There are 18 fast chargers making 45% of the total, and most of them are just in Perth. The output for this AC charger is 22KW, with 2 – 4 hours of charging times during long stays. It is a type2; type2 charging system that equipped with both single and three phase AC charging and all new European EVs are compatible with it, as well as Tesla using an adapter.

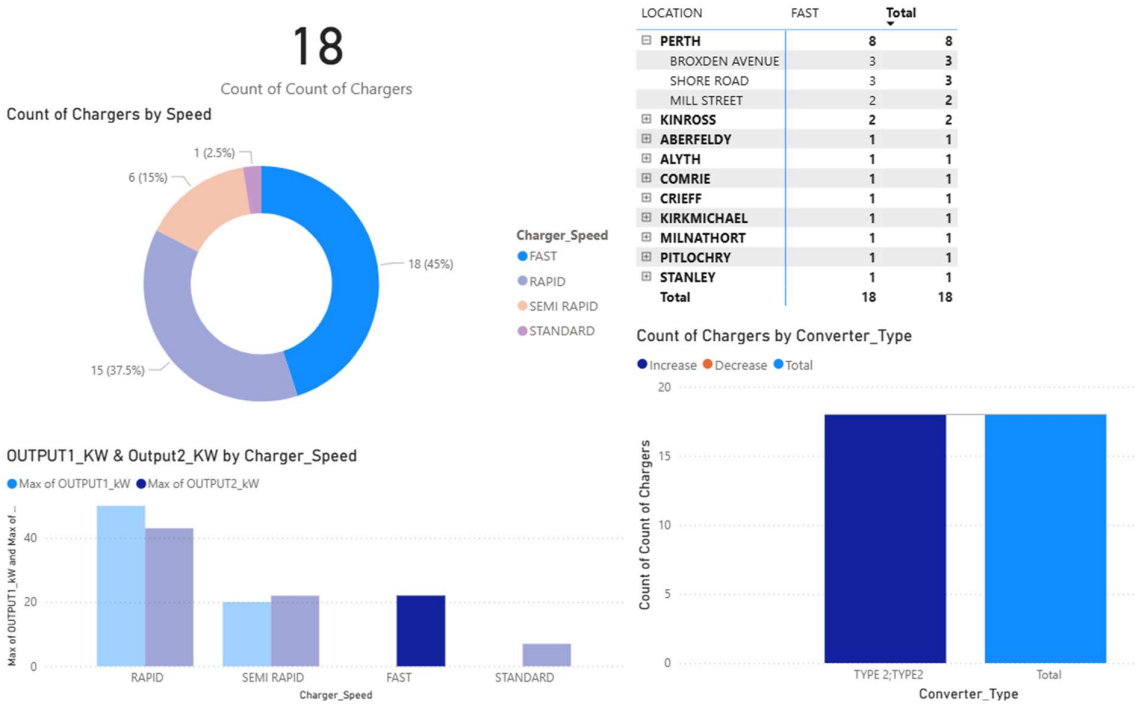


Figure 18: EV Charging Points Perth – Part I

Now come rapid chargers with most ideal locations in Perth, Crieff, and Kinross. It has 15 chargers with output power of 50KW DC supply, having an average duration of 20 – 60 minutes for full charging capacity. It is a type2; CHAdeMO; CCS charging system that makes it perfect for all types of vehicles for either DC charging or AC to DC. It is well equipped with all the modern electrification system to power AC to DC and hence best for ultra-fast charging.

Converter Type	Charging Speed	Usage	Notes
Type2: Type2	Fast / Semi Rapid	Mostly European EVs with AC charging	Common AC charger with 22KW output
Type2: CHAdeMO: CSS	Ultra – Fast	All EVs with modern DC or AC charging	Rapid DC charger with 50KW output

Table 2: Charger Types and Speed

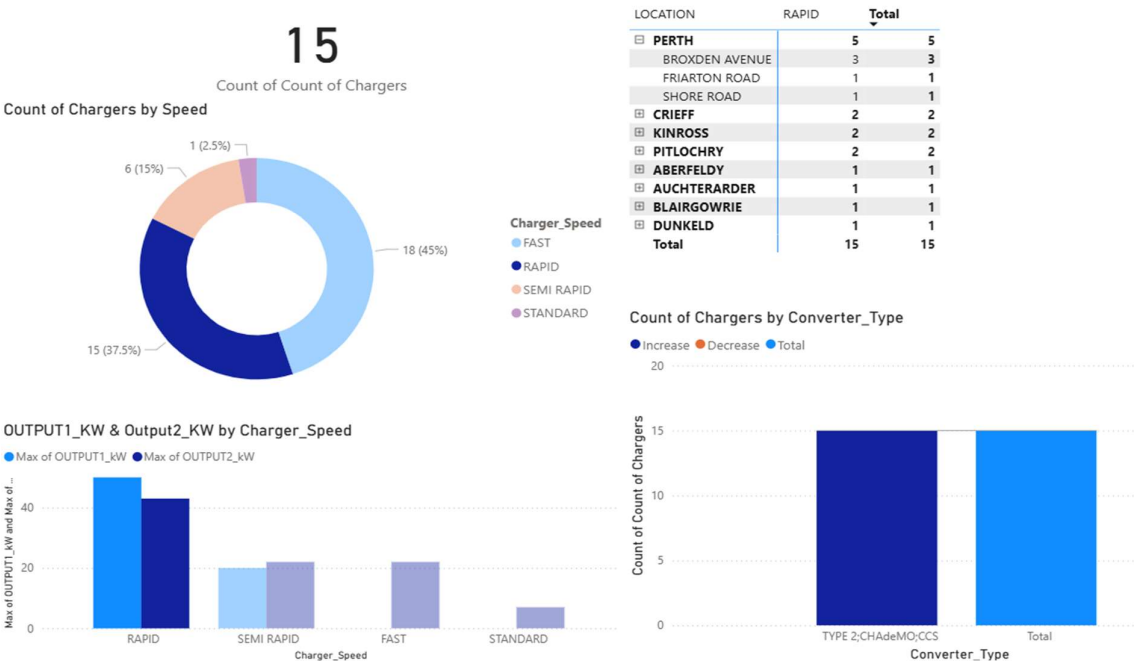


Figure 19: EV Charging Points Perth – Part II

The best location given below shows that a major serve for the community is Perth, Kinross, and Crieff… but other key locations with only one or two chargers. It highlights the charging infrastructure have some underserved towns and must be focused on like Comrie. It is well-known touring point and connects Alloa to Dunfermline, hence must have one rapid charger. Census shows that more than half of the charging locations charge fee… and that fee increases by 2.80x when the location is likely to be Perth.

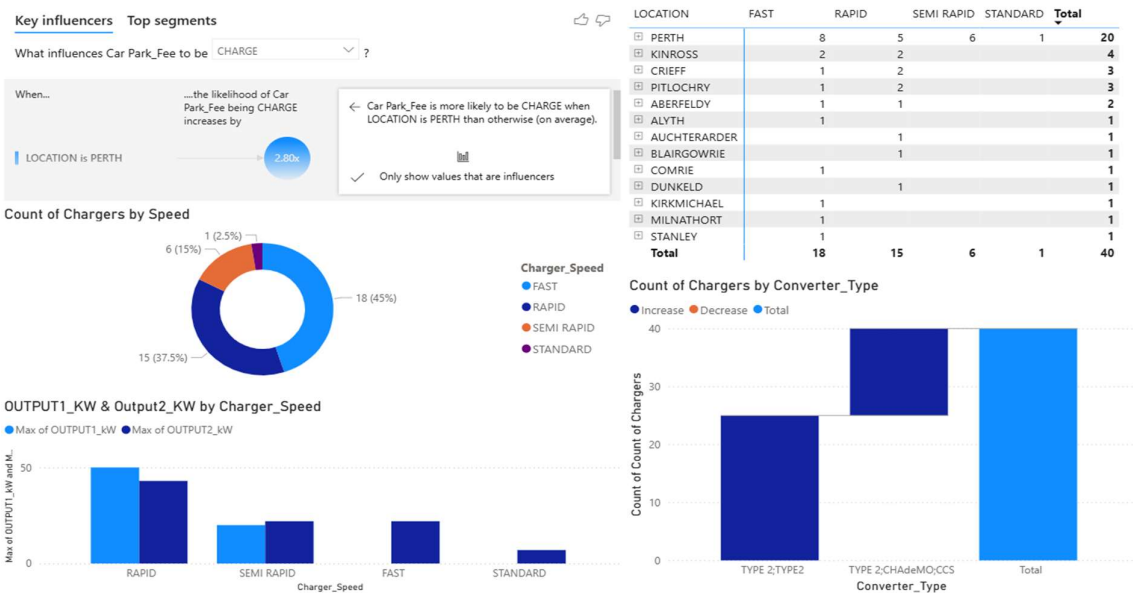


Figure 20: EV Charging Points Perth – Descriptive Analytics

Geospatial Observations

Most of the locations have solely one charger expect Perth, Crieff, and Kinross that shows a big concern of non-availability during peak hours or maintenance. Also, there must be some renewable energy sources like wind and solar to power up the charging grid stations. It will not only build initiative to lower charging costs but also help introducing discounts for low-income households. In the same way, electrifying private vehicles is not enough for this modal shift but plan to install charging stations in public transport hubs and introduce electrical buses.

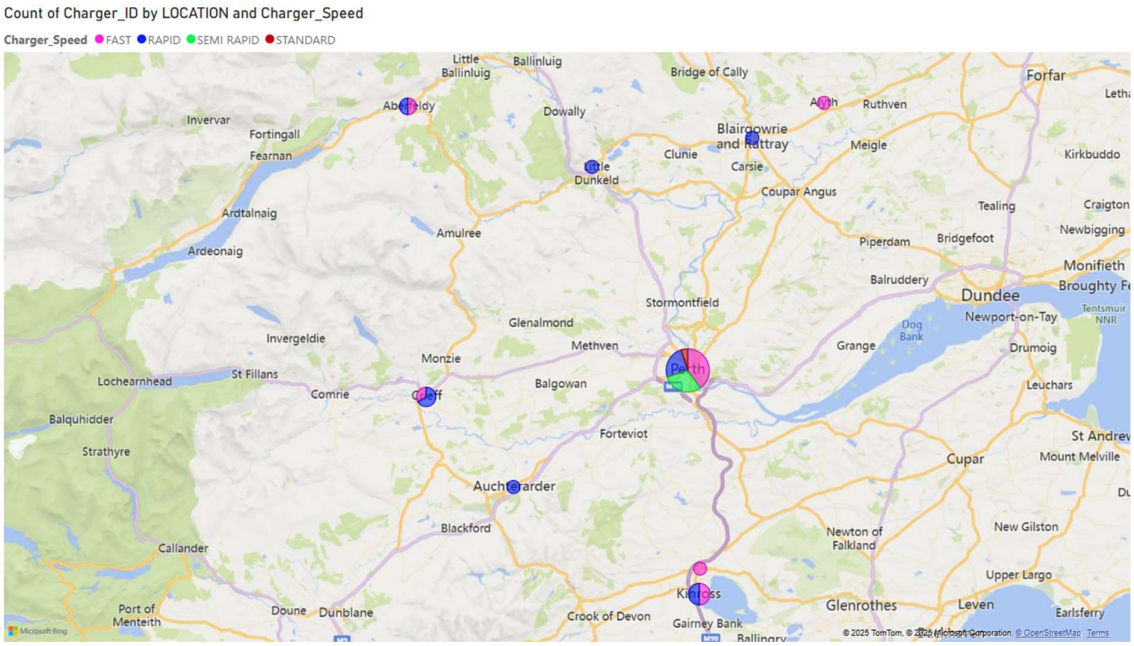


Figure 21: EV Charging Points – Mapping

4.3.2 Discussion

Implementation of electrification in both public and private vehicles is essential to shift towards sustainable solutions and address technological advancements. It will pitch on the environmental impact by reducing carbon emissions and noise pollution. It will also prepare for technological readiness with advancing electrification and removing old engine technologies. Implementing electrification can also be promoted by changing lifestyle preferences and building trust and reliability in EVs by addressing behavioural resistance. So, this initiative is highly evident to support green transitions and meet the net-zero emission goals. It also makes the formulated hypothesis true that improving charging infrastructure helps build trust in EVs and is thus good to expand action plans.

Scotland has a more comprehensive EV charging infrastructure compared to rest of the UK, with over 7,100 electric chargers, two years ahead of plan. Since 2011, Scotland has invested £65 million in electrifying the network. These developments helped save 230,000 tonnes of carbon emissions, with plans to install 24,000 additional public chargers by 2030. The initiative to provide interest-free loans worth £23 million encouraged locals to buy EVs, and it registered 8,700 ultra-low emission zone vehicles, with a vision to provide £20 million loans in 2025 – 26. (Transport Scotland, 2025). The Scottish Government has plans to invest a £40 million to boost zero-emission buses. Hence, it is evident to back these ambitions and make Scotland a green place to live in, achieving net-zero aims.

4.4 The Impact of Low Emission Zones (LEZs)

Low Emission Zones are a moving traffic contravention, allowing certain restrictions within an area to improve the overall air quality. Vehicles must meet the LEZ minimum emission standards, EURO VI for diesel and EURO IV for petrol vehicles, when being driven in such zones. The LEZ operates all year round, twenty-four hours a day, seven days a week. (Transport Scotland, 2024).

Automated cameras are fitted that read the vehicle's number plate and are linked to local and national vehicle licensing databases. It not only helps monitor vehicles within specified areas but also automatically issues penalty charges. Hence, this system ensures the smooth working of LEZs ultimately improves air quality and reduces harmful substances that impact human health. Below is the quantitative data with the concentrations of each substance into the air… to analyse if there is a reduction in the percentage of their emissions after implementation of LEZ within Glasgow.

4.4.1 Results

4.4.1.1 Townhead Pollutants Data (Glasgow)

Comparative Analysis

The image shows the average concentration of nitrogen oxides for the years 2022 and 2023. Here, Q1 refers to the first quarter of the year, Q2 the second, and so on. The concentration of NO2 before the implementation of LEZ in Q1 and Q2 for both 2022 and 2023 was approximately the same. But after June 2023, LEZ was officially implemented in Glasgow, allowing to compare the data for Q3 and Q4 from 2022 – 2023. It noticed the reduction in the concentrations of nitrogen oxides from $12.26\frac{ug}{m^3}$ to $10.21\frac{ug}{m^3}$ (~16% decrease) for Q3 and from $22.77\frac{ug}{m^3}$ to $19.55\frac{ug}{m^3}$ (~15% decrease) for Q4. On the other hand, NOx before LEZ implementation, i.e., for Q1 and Q2 in both 2022 and 2023, was approximately the same but shows a decreasing trend in Q3 to Q4. Again, the concentration of NOx was reduced from $2.11\frac{ug}{m^3}$ to $1.67\frac{ug}{m^3}$ (~20% decrease) in Q3. The same was reduced from $10.27\frac{ug}{m^3}$ to $5.99\frac{ug}{m^3}$ (~42% decrease) in the last quarter from October to December. This shows a decrease in the concentration of both of nitrogen oxides in last two quarters for 2023 because of active LEZs.

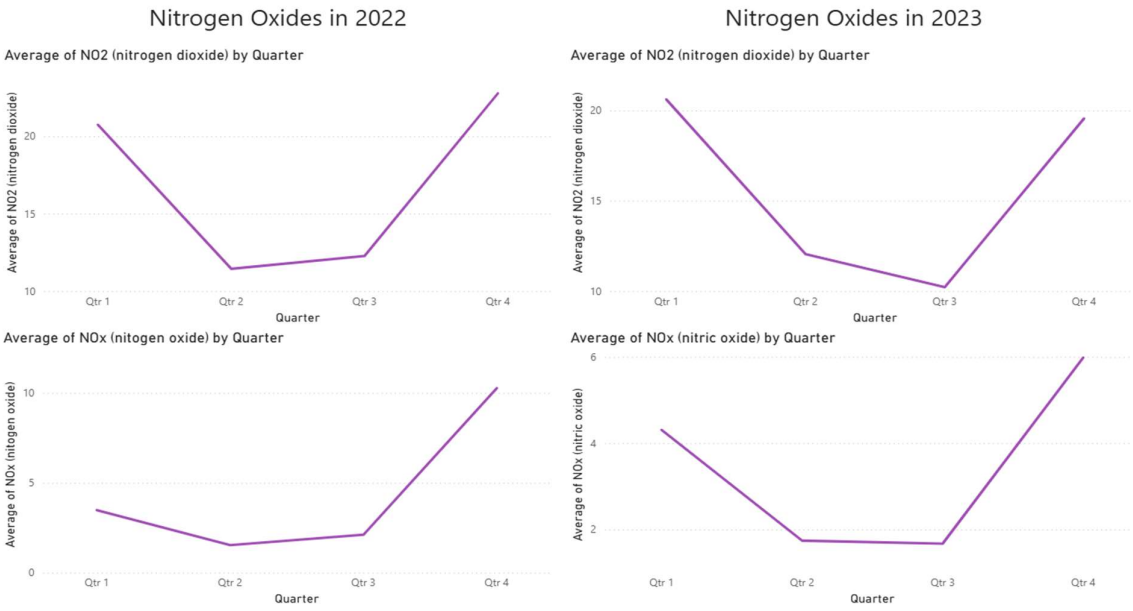


Figure 22: LEZ before and After – Part I

In addition to that, the concentration of particulate matter, tiny solid particles in the air, also noticeably decreased after the implementation of the Low Emission Zone. The first two quarters showed a very unlike trend, maybe because of weather conditions, a drier spring, or some other industrial activities. But when we compare post-LEZ data, the concentration of PM10 and PM2.5 is noticed to have decreased. The concentration of PM10 from Q3 to Q4 decreased from $8.26\frac{ug}{m^3}$ to $7.43\frac{ug}{m^3}$ (~10% drop), and from $9.86\frac{ug}{m^3}$ to $7.39\frac{ug}{m^3}$ (~25% drop) respectively. Whereas, the concentration of PM2.5 for Q3 was noticed to decrease from $4.26\frac{ug}{m^3}$ to $3.95\frac{ug}{m^3}$ (~8% drop) and from $5.57\frac{ug}{m^3}$ to $4.15\frac{ug}{m^3}$ (~25% drop) for Q4 in early winter.

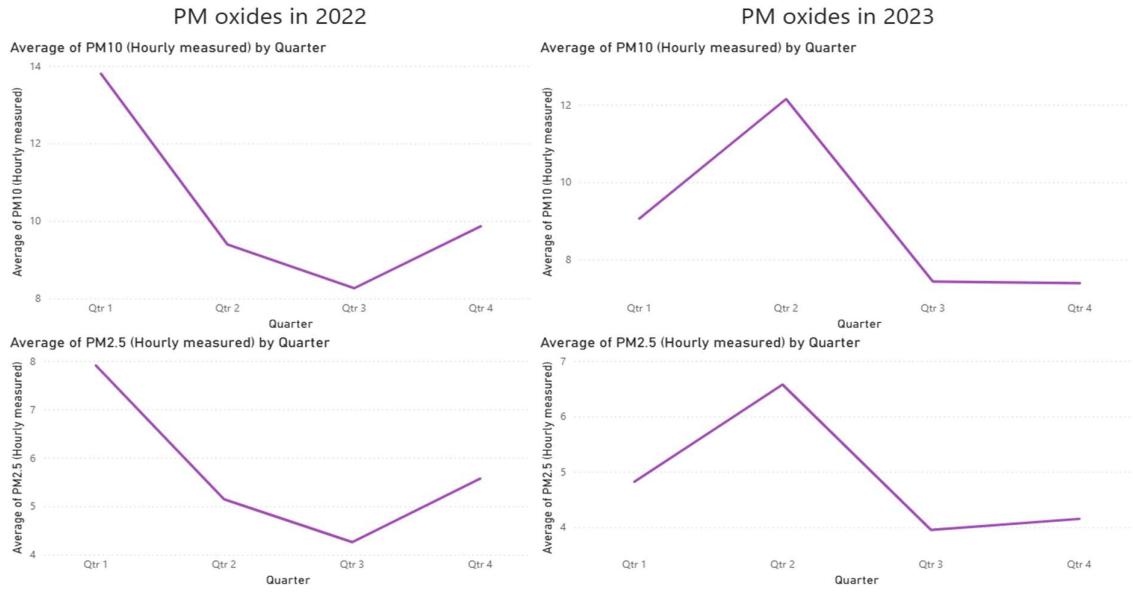


Figure 23: LEZ before and after – Part II

All pollutants showed year-to-year reduction in the percentage concentration into the air. It highlights LEZ worked and must be expanded to achieve overall positive effects. The average of NO2 decreased from $16.80\frac{ug}{m^3}$ to $15.59\frac{ug}{m^3}$ (~7% drop), and Nox from $4.36\frac{ug}{m^3}$ to $3.43\frac{ug}{m^3}$ (~21% drop). Also, the average concentration of PM10 and PM2.5 noticed to decreased from $10.31\frac{ug}{m^3}$ to $9.00\frac{ug}{m^3}$ (~13% drop) and $5.71\frac{ug}{m^3}$ to $4.87\frac{ug}{m^3}$ (~15% drop) respectively. The data presets that there is clearly a sign of improvement in the air quality roughly around 14% reduction after the implementation of LEZ and must be expanded outwards to limit emissions.

The results show that LEZ policies worked, but still the air quality is not sufficient considering WHO guidance. It is also drawn that winter has a large impact on the exhausts because of vehicles as well as domestic exhausts for heating. Hence, there must be some strategic guides to implement the LEZ hypotheses and analyse expanding its boundaries over time. It will help in modal shift through investing in infrastructure, tightening the EURO standards for vehicles and getting control over non-road machines for achieving better results.

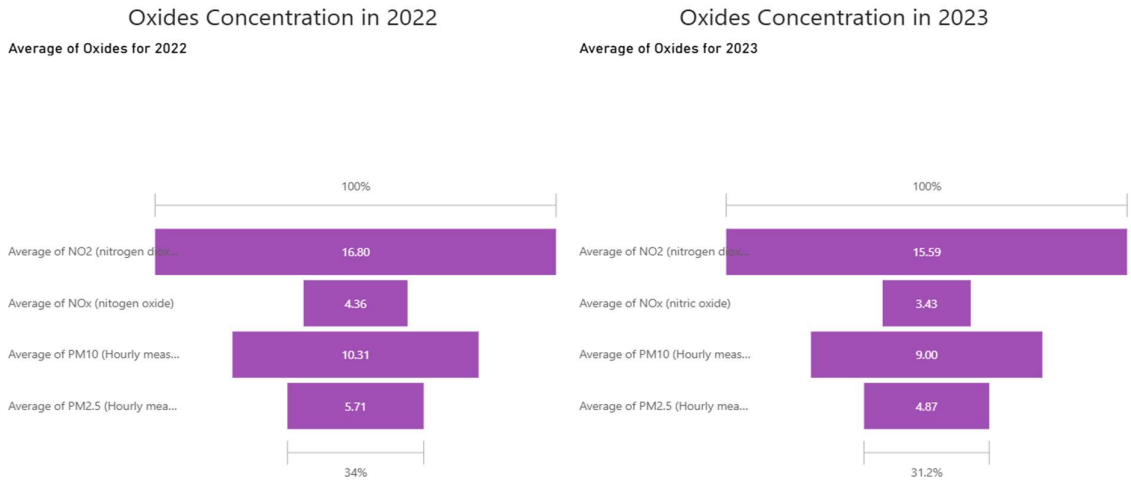


Figure 24: Overall Concentrations before and after LEZ

4.4.2 Discussion

Implementing LEZ policies is evident in supporting sustainable solutions as it will address each sub-issue developed in the issue tree. This initiative will clearly impact the environment by improving air quality, reducing noise pollution, and rightly allocating the available resources. Secondly, it will help address the issues related to technological advancements. In addition, Euro Standards for vehicles will limit old engine technology and build infrastructure, ultimately powering electrification. Implementing LEZ will also address the third key issue related to behavioural resistance in a positive way. By this, it will change lifestyle preferences and raise awareness in shifting from private cars to public transport. Hence, Low Emission Zones are important in achieving the aims, confirm that results align truly to the formulated hypotheses.

The statistics for both Q3 and Q4 are lower in 2023 compared to the previous year's trend, for all four pollutants. Significant improvements are seen for NOx (-21.3%) and PM2.5 (-14.7%), both are linked with vehicle emissions, showing an improved air quality. Although LEZ is impactful additional measures should also be taken for more sustainable Scotland.

4.5 Evaluating Findings Towards the Potential Modal Shift

Bike – Sharing schemes proved essential in promoting active travel schemes, best even if you don't own a bicycle. Charging infrastructure with multiple charger types, in addressing the demands of a range of travellers, has helped the community build trust in buying modern electric vehicles. Low Emission Zones proved very beneficial in reducing certain pollutants in the designated regions. All the evaluated schemes address each issue developed before in section 2.4, interconnectedly. But there is a need to deploy action plans for the expansion and improved practicality of these policies. For bike – sharing, the action plans must be introducing electric bikes, real – time availability, and even more discounts for all groups. In case of electrification, powering up charging grids with renewable energy sources and expanding more rapid/fast chargers beyond town centres to on-street charging points. Also, for LEZs… expand the zones to multiple areas of high demand within different cities and build modern infrastructure. These actions will not only help towards the potential modal shift for green transportation but also create many social and economic benefits to regulate businesses.

4.6 Conclusion

This chapter concludes the analysis and observations of certain developed policies, highlight their effectiveness in reducing carbon emissions, and the future to expand their practicality. It discusses the usage trends based on geography, travel behaviour and seasonal cycles, best for testing formulated hypotheses. Then highlights certain key findings, areas of improvement, demand forecast and gave actionable insights to expand its horizons in achieving the aims.

Chapter 5 – Conclusions, Limitations and Recommendation

5.1 Conclusions

In Scotland, transport is influenced largely by geography, weather, and peak-hour times. Covid-19 was considered to have had a significant impact on transport development, reduced people's travel generally that raised again after the pandemic. In the same way, public buses are noticed to be the most used service among students and employers referring to car as the second leisure mean of travel. These recent impacts of road transportation on the environment demand efficient sustainable solutions to shift towards the green transition. But this modal shift is not dependent only on introducing efficient travel policies but also on changing lifestyle preferences. This will happen with excellent infrastructure, a diverse EV charging network, and better road spacing. Public transport is not enough to be an option but must be a desirable mode of travel and can only occur when there is less commuting time, more accessibility, and affordable travel tickets. Also, there must be inclusion and diversity across all regions irrespective of demand. Install EV chargers near public bus stops and bike stations even in less demanding areas to promote own electric vehicles and adopt active travel options. It is also evident to replace current old engine public buses with electric ones as the most impactful is the carbon emissions by these buses. There is also needed to introduce some extra efforts like stakeholders and large companies can promote active travel by encouraging their employees, and government can play its role in making policies in terms of infrastructure and future requirements. Likewise, public awareness institutes should collaborate with schools and colleges to launch training programs for those who need the right knowledge, confidence, and skills. It will build their trust in how to charge EVs, cycle bikes and thus keep sustainable travel an efficient mode of commuting. Here is given hierarchy on how impactful the implementation of recent policies is in decarbonization.

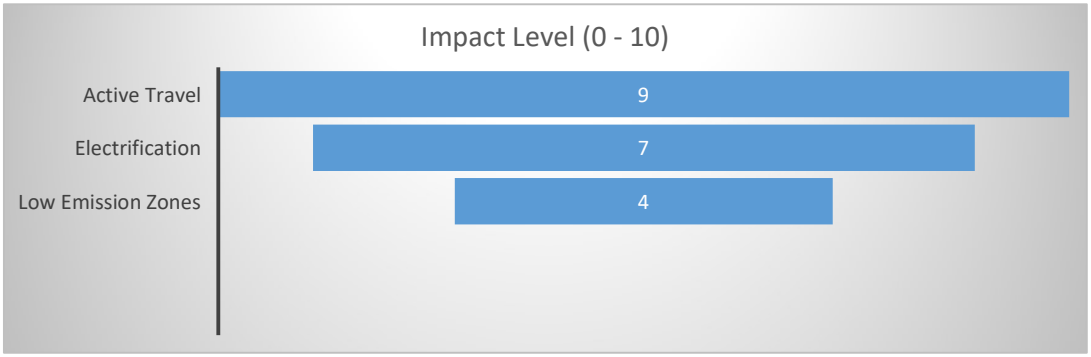


Table 3: Hierarchy: Impact Level

From the survey, more than 78% of respondents said that combining exercise with transport is highly motivating. This indicates that taking the right actions at the right time can significantly benefit the community. In addition, installing more rapid and ultra-fast DC chargers, compared to AC ones, is crucial because many people prefer a quick top-up instead of spending 5–6 hours charging. Currently, almost 75% of the installed charging infrastructure in Stirling is focused on AC options, as shown in the visuals, which has been a significant barrier to the wider adoption of EVs. Furthermore, the implementation of Low Emission Zones (LEZs) has proven to be effective, as it helps build infrastructure, supports the transition away from old engine technologies, and raises public awareness. Expanding LEZs to other major cities in Scotland would further improve air quality and accelerate progress toward achieving net-zero carbon emissions by the end of 2045.

5.2 Limitations

This project does not deal with the real-time availability of electric chargers on the spots, and methods to build renewable batteries for EVs. Of course, these must be addressed but the aims of the project do not cover the horizons. The carbon emissions related to air travel are not addressed in this project. Again, air travel is not a big concern, as most of the flights in Scotland are international and emit at high altitudes. This project covers some big councils of Edinburgh, Glasgow, Striling, Perth and Kinross but does not include Dundee, Aberdeen and other cities because of the limited word counts.

5.3 Recommendations

There are given set of actionable recommendations necessary to implement for improving accessibility and support these green transitions in shifting from private to public transport. These includes:

- Introduce e-bikes and cargo cycles within the available bike hangars to encourage more people towards active travel for all ethnic groups.
- Collaborate with Cycling Scotland to launch cycling training sessions for both children in all schools and for adults in workplaces.
- Install more bike hangars in Southside and City Centre councils in Edinburgh as these are close to academic institutes and amenities.
- Ensure bikes inclusion and accessibility across all councils in each city, probably because people are more likely to use them when they have access to bike – sharing stations.
- Offer extra bikes between May and Aug, as trip counts are higher in summer likely due to high tourism demand across Scotland.
- Power up EV charging stations by renewable energy sources like wind and solar etc.
- Integrate defined policies to electrify around 30% of public buses by the end of 2030.
- Set more duties over diesel and petrol vehicles compared to electric ones.
- Initiate discounts to use EV chargers for those with low-income households.
- Give more interest-free loans to people for encouraging them to buy EVs.
- Set targets to limit car manufacturers in making petrol or conventional diesel engines.
- Implement extra DC rapid chargers compared to AC ones, as people do not want to spend two to three hours charging except at night.
- Talk to EV manufacturers on launching joint ventures with Transport Scotland to provide subsidies for trusted customers.
- Build on-street EV charging stations in Stirling, located outside car parks so that citizens can avoid paying parking fees in addition to charging fees.
- Install at least two chargers at every location having both AC and DC options to serve the broader community.

- Reallocate active travel spaces for big roads in every town and city within Scotland.
- Ensure efficient and working USB charging facilities in almost every public bus.
- Reducing bus fares by 20% will encourage public transport usage among all groups.
- Introduce separate bus lane in busy corridors to ensure fast travel within less time.
- Expand LEZs in areas outer to city centres, to some extended regions.
- Introduce free travel for those under 25, as most of the students are with this age group in Scotland.
- Supporting AI-driven solutions for managing administrative tasks will save roughly £6.70 million of the budget and invest those costs in active travel and electrification.

By collaborating between multiple stakeholders, continuous communication with public and transparency of policies, we can make the public transport a preferable option to travel. (Scottish Government, 2024). Below is listed the plan for proper budget allocation:

Focus Area	Budget 2024 – 25	Budget 2025 – 26	Rationale Notes
Active Travel (Walking & Cycling)	£185.4 million	£164.4 million	It must be more than £300 million, as active travel is the most sustainable travel option
Administration Costs (i.e., Data Analysts)	£29.20 million	£26.70 million	It should be less than £20 million and can be by introducing AI to let do the administrative tasks
Sustainable Travel (low carbon policies)	£270.3 million	£313.6 million	It is evident to raise it more than £500 million, because such schemes really benefit in achieving sustainable solutions
Fiscal Resources (spending pots)	£84.40 million	£57.50 million	Fiscal resources are declining but should remain at least more than £100 million.

Table 4: Budget Plans for Transport

If Transport Scotland try their best in implementing the proposed budget plans, it will encourage active travel policies, reduce administrative costs and increase fiscal resources best to build plans. These incentive – based plans can then be implemented with proper checks and balance to encourage positive impacts on the environment.

5.4 The Future

The future of Scottish transport lies in adopting AI-based transport solutions that focus on all groups of society. One of the main futuristic developments would be to introduce electric – powered vehicles in all modes of transportation from public to private. These vehicles must be equipped with all the electronic facilities and plug – in hybrid engine technologies. In parallel, investing in autonomous driving systems for trains and buses will not only support zero carbon emissions but also cut administrative and salary costs. Ultimately, these innovations will create a smarter and more reliable transportation network.

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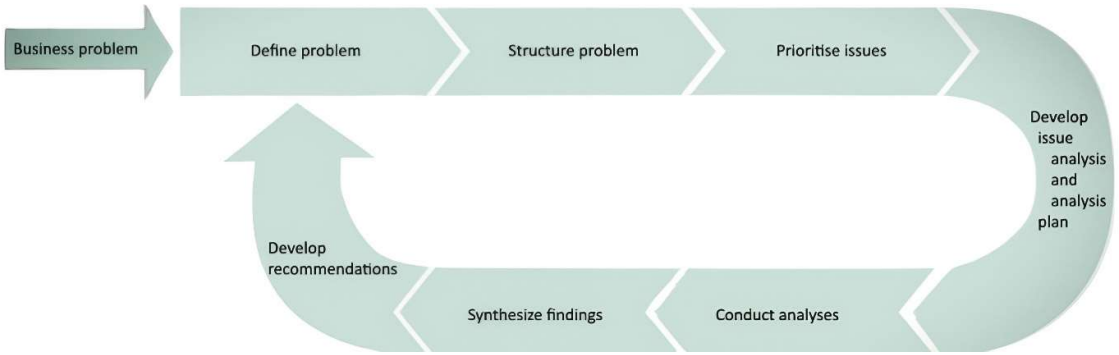
APPENDICES

Appendix A. McKinsey Framework Step by Step



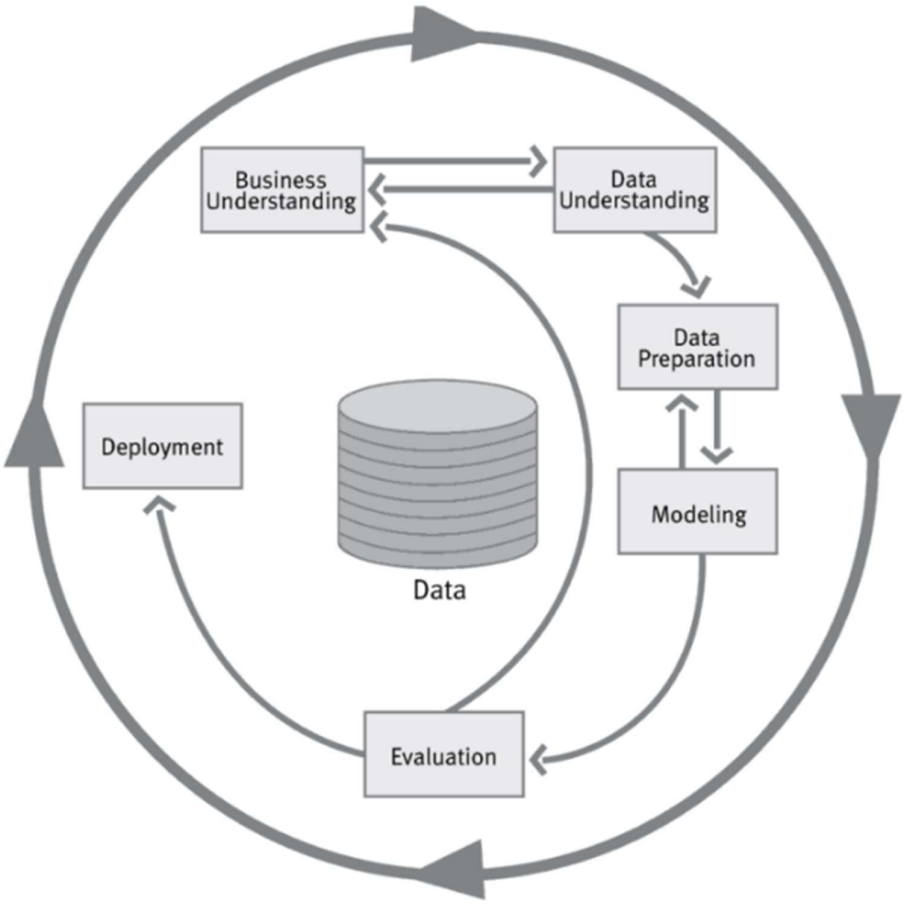
(Emmanuel Arakpogun, 2024)

This framework defines the business problem, structure it for better understanding the type of business and then contrast an issue tree as we did in Section 2.3. Transport Scotland is not a single business but multiple sectors working beneath it like ScotRail, Government, Public, Academia etc. There comes developing issue tree, one can understand deeply which area to focus on more and prioritize them based on that.

Again, there comes analysis of each issue, by dividing it into sub-issues… and prioritise them based on their impacts. As given in section 2.6, formulate hypotheses, and conduct analyses to identify if the developed hypotheses are true… introduce action plans otherwise plan policies again as described in Table 1.

Appendix B. CRISP – DM Framework Guide

In this project, I used crisp-dm from part II to part IV… that includes data understanding to evaluation. Data Understanding involves collecting and describing the data under part two. When done with the selecting of verified data, there comes preparation of the data. In here, I clean and manipulate the data like removing null and missing values and structing it in a right format (Data Science PM, 2024).



(Wuttke, 2023)

Lastly, there was to select right methodologies in part IV i.e., modelling. It includes techniques like Time Series Analysis or Geospatial Data and accessing if it aligns best to the requirements. The more detail for the methodological approaches is given in Section 2.8.