Measuring Micromobility

Final Report

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Transport For London (TFL)
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Executive summary

Micromobility has been used to describe the rise of urban mobility in the areas of bike and e-scooter arrangements. The interest in micromobility has come from the agglomeration of huge urban centres and pressing increase in subsequent transport needs. Urban transport demand across all modes transport is set to double between 2015 and 2050 (Deloitte, 2019). Micromobility offers tangible solutions to deliver on this demand in a way that is sustainability and delivers much needed pollution reduction. In London specifically, two thirds of car trips could currently be made using micromobility in 20 minutes or less (Centre for London, 2021).

Transport for London (TfL) considers micromobility a critical component of its policy development. While micromobility has the potential to improve the public transportation system, the lack of sufficient regulation, such as addressing parking issues and fare control, poses significant challenges. These challenges hinder the goal of facilitating the "last mile" of users' journeys through micromobility.

The aim of the Capstone report was to provide Transport for London (TfL) with an evidence-based analysis and comprehensive understanding of the E-bike market framework and size. Our research question was mainly focused on proposing an accurate forecasting model of E-bike demand in London.

The report employed a detailed methodology that focused on the four areas that drive E-bike demand: temporal effects, climate and weather, spatial factors (such as topography and cycling infrastructure) and socio-demographic factors. We then used these categories to quantitatively model demand across and within London boroughs. The project also provided analysis from a consumer sentiment survey collected at corresponding tube stations to give an indication of how robust E-bike demand is, particularly as it relates to price.

Our approach helped identify significant factors influencing E-bike demand, such as population density, public transport accessibility, and socio-economic indicators. The analysis compiled data from multiple sources, including Transport for London, the UK census, and survey data, to construct a robust demand forecast model.

Key Findings

London's E-bike demand is significantly influenced by spatial characteristics such as proximity to central London and public transport hubs, demographic factors including age and income levels, and perceived benefits of E-bikes over traditional mobility options. With this considered, our model indicates that there is significant demand in all of the boroughs of zone two, and a majority of boroughs in zone three to sustain an efficient market. The profits from the highly demanded boroughs (such as city of London) could also be used to subsidize low demand zones. Furthermore there is significant evidence that further demand can be unlocked through better cycling infrastructure or availability of bikes.

E-bike demand is significantly robust and inelastic. Price was not the driving factor behind many cyclists' reasons for choosing third party providers. There may be some evidence to suggest that the E-bike rental market is considered a luxury good.

E-bike users in London also tend to be more routine commuters, rather than tourists and occasional users. This may indicate demand is equally robust to weather and seasonal affects, as routine cyclists tend to endure these conditions worsening better than irregular users (Morton, 2020).

Moreover, the study revealed substantial potential for E-bike usage expansion in strategic areas, contingent upon currently stated infrastructural improvements and targeted policy interventions. This in line with several academic arguments regarding cycling infrastructure inducing its own demand (Schneider, 2018).

Recommendations

The report strongly recommends TfL improve and formalise its market framework with third party providers. The report offers three ways to move forward:

- to maintain an **open market** for any participating firms (status quo);
- to move towards a staggered set of **procurement** programmes with a select number of firms;
- or to move towards a more **controlled contract** where TfL mandates supply and pricing.

The report advocates to firstly move towards a procurement process with the understanding that a controlled contract may also be explored in future years where TfL has established better knowledge of the current and future E-bike market. The benefit of a staggered procurement programme also allows TfL to influence strategic priorities around performance – namely regarding parking bays and bike safety.

We provide further analysis on how TfL could implement efficient pricing and revenue strategies to do this. These measures aim to optimize the benefits of micromobility in enhancing urban transport efficiency, reducing congestion, and contributing to environmental sustainability.

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Introduction

The term micromobility has been used to describe the rise of urban mobility in the areas of bike and e-scooter arrangements. The “micro” element refers to both the size of vehicles (set at any vehicle under 500 kilograms) and the size of the relatively short distances that people travel on those vehicles – introducing the principle of micromobility delivering “the last mile” of travel for users (Horace Dediu, 2019).

Transport for London (TfL) specifically uses the phrase “micromobility” to cover E-bike and E-scooter arrangements. This is an active area of policy development for TfL and contains a range of policy problems. New technologies can be disruptive to existing arrangements, and the arrival of global providers of micromobility services presents opportunities and threats to London and other cities around the world.

In an ideal world, micromobility can be an attractive complement to the existing public transport system, help manage the “last mile” and provide individual flexibility and deliver on London’s sustainability goals. On the other hand, if the micromobility market remains unregulated and disjointed, it may lead to worsening parking problems and pressure for inefficient fare control and provision.

A challenge to TfL in moving forward in the E-bike space is the difficulty in understanding market levels of demand for E-bikes, and the geographical coverage of that market. There is a dearth of available information and standardised methods for measuring both current demand at current prices, and how robust that demand is if prices fluctuate, or infrastructure improves.

Understanding demand is a critical first step for TfL to move towards better operational or market regulation in the micromobility space. The purpose of this Capstone project is to review standardised methods for measuring micromobility demand and provide a suitable model to measure demand given available data and London’s characteristics.

The paper will take the following structure. Chapter one will review the E-bike market framework and TfL's institutional and operational context as a devolved state body and role as both a provider and potential regulator of micromobility services. This chapter also outlines the current understanding of the size of the micromobility market paper's main policy problem. This includes the current well-established understanding of production costs (supply), and the current knowledge and gaps of understanding in demand, from which we derive our research question.

Turning to methodology, Chapter two includes an extensive review of best practices for micromobility demand modelling. This will consider quantitative methods based on spatial and sociodemographic analysis, climate, weather and temporal factors as well as qualitative survey methods for understanding user characteristics. Summarising these techniques, we provide a model best suited to London and TfL's needs.

Chapter three will provide a borough-by-borough review of London's climate, spatial and socio-demographic characteristics outlining an estimation of the areas where micromobility demand will be adequate to meet supply.

Chapter four provides the quantitative model's analysis to measure static demand in these areas, with results from select areas of the Boroughs of interest. We also seek to answer specific questions TfL asked us in our final presentation meeting in this section.

Chapter five examines consumer sentiment through a user survey collected at the Boroughs of interest. The purpose of which is to examine how robust demand is in the E-bike market, giving an indication of the demand's price elasticity as well as other factors which might influence future demand, such as infrastructure investment.

Chapter six provides policy recommendations for TfL. Namely, the research indicates that there is sufficient current and future demand in the areas where private companies currently operate for TfL to consider market regulation. We provide three possible options for TfL going forward before recommending a staggered procurement process similar to that of their e-scooter trial (TfL, 2023). We also state that our research does not yet indicate whether demand is sufficient to consider direct public provision, however this may be explored when future data is available following the procurement process. In this chapter we also propose revenue strategies for if/when TfL would consider moving forward with a controlled contract.

We conclude with areas of future study – specifically that a borough-by-borough review of revenue may be of significant value especially to examine cross internal subsidy between profitable and loss leading boroughs.

1. Contextual background

1.1 Governance framework

Regarding the institutional governance framework of TfL, legislation for micromobility services is set out by the Department for Transport (DfT). London's Greater London Authority (led by the mayor and including TfL) holds the local transport budget, expects to control regulation as well as the existing micromobility scheme. Finally, the 33 Council boroughs control parking bays and pavements (Greater London Authority Act 1999).

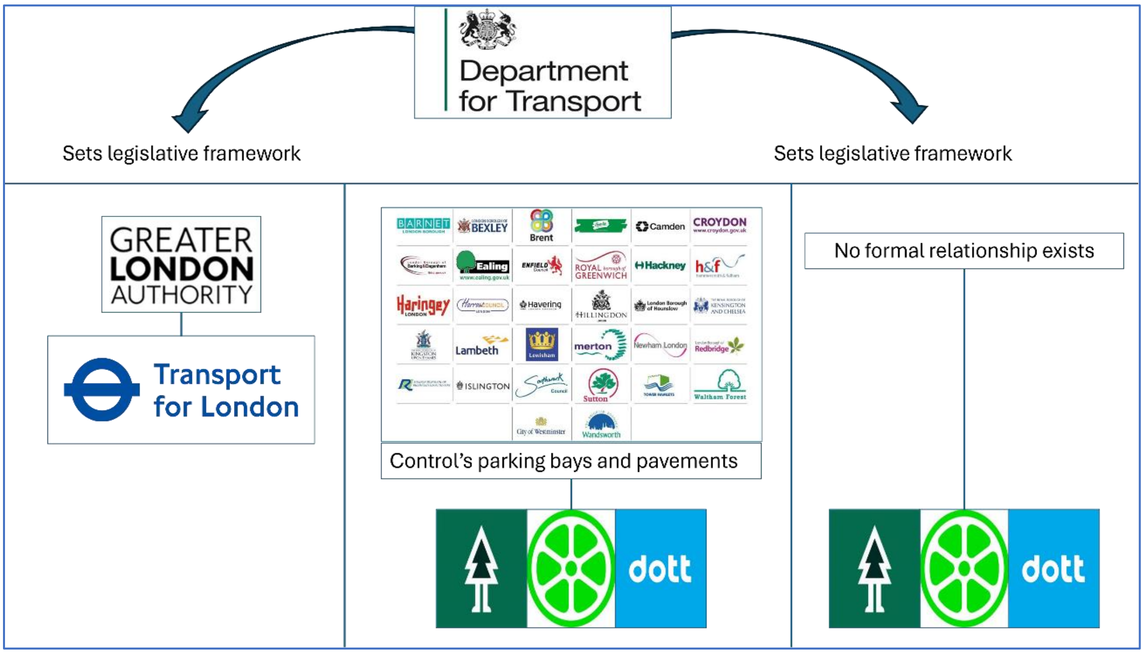
As noted, the definition for micromobility rental services is quite broad and refers to a range of vehicles from docked bikes to dockless E-bikes to e-scooters. TfL is currently a provider of a docked bike scheme in inner London known as the Santander Cycles (TfL, 2017). TfL has also already conducted an ongoing rental e-scooter trial across a range of selected boroughs since 2023 (TfL, 2023). This trial is co-hosted and organised amongst chosen London boroughs as agreed with the DfT's legislation, and then procured competitively to select operators. Given this study's focus on forward-looking market research, the paper's analysis therefore restricts itself to London's dockless E-bike rental market, currently only provided by third-party global companies, in a generally unregulated market.

In contrast to the rental e-scooters which operate on a contract basis, TfL currently doesn't have any formal relationship with E-bike providers. This means that there are currently no controls around E-bike rental (either in London or elsewhere in the UK). As such, TfL has no direct control over the dockless bike market and has no say over which companies provide rental bikes, in which parts of London, or to what standards – even though in most cases the rental bikes are provided by the same companies as TfL's e-scooter fleets (TfL, 2023).

As a result, local arrangements for dockless bike rental tend to be made between individual London borough councils and operating companies - though this isn't a legal requirement and some Boroughs don't have any legal contract. Given the varied approaches of different boroughs, these local arrangements have led to a patchwork of different bike rental options across London.

This causes various problems, for example mismanagement of supply with some boroughs with no E-bike service whereas in others there are up to four different companies. There is also no coherent set of operational standards – some boroughs allow carriageway parking, others allow footpath parking, others have specific marked bays, and some have a hybrid system (TfL, 2023).

Figure 1: Market Framework



For consistent service supply and operational standards, a centralised approach to scheme design is needed. The government expects to bring forward targeted legislation on this matter (Appendices 3) and this report hopes to inform TfL's policy options if and when that power is devolved.

1.2 Current market understanding

TfL has a relatively robust understanding of the costs for E-bike hire schemes. These costs are made up of four factors: the fixed costs of E-bikes, variables upkeep costs (e.g. batteries, fee costs, overheads insurance and electricity etc), Borough charges (fixed throughout the year) and finally redistribution costs (moving bikes from one area to the next). The intuition of the redistribution costs is that as the geographical market of E-bikes increases and as the population density of that market decreases, the production costs of supply increases at scale. TfL is aware that these costs become increasingly inefficient compared to alternative transport methods beyond zone 4.

In comparison, revenue from E-bike rental is much less predictable and is impacted by several factors both within and outside of service provider's control. These include the revenue per minute of bike usage, availability of the bike, length of trips, cycling infrastructure, the weather and climate and more. Seeking to streamline, a baseline E-bike demand models generally incorporates the following factors. The number of trips taken per day, the time length of those trips, and vehicle availability (Chardon et al, 2015). Multiply this by the cost of E-bike services per minute gives us the revenue function.

This model suffers from several forms of uncertainty. First, the number of trips taken per day and length of those trips is currently unknown as the market increases geographically and both population and vehicle density reduce. Second this model tells nothing of how robust and elastic demand is. The model is currently set as a static model and measures current demand, rather than the dynamic demand if prices increase.

From this market analysis based on supply data there is enough evidence to suggest demand in the areas of inner London is sufficient to meet the costs of supply, and additionally demand for the areas of outer London, broadly viewed as beyond zone 4, are not sufficient to meet the increasing costs of supply. However, there are still questions whether there is currently sufficient demand in zone 2 and some of zone 3 to meet supply (static demand), and whether this demand will be maintained into the future if inflationary pressures increase (dynamic demand).

The research question for this paper is to provide a more robust demand measurement model for E-bike trips in the zones 2 and 3 and to provide policy recommendations to TfL on how to move forward based on the preliminary results of that model.

2. Review of demand forecasting techniques

2.1 Optimal model

As mentioned, the optimal demand model is dependent on the following variables: number of journeys taken per day, time length of those trips, and the vehicle density. This can be summarised with the following function:

$$Demand = \frac{J}{d}TV$$

With:

$J \ = \ number\ of\ journeys\ per\ day$
$T \ = \ time\ length\ per\ trip$
$V \ = \ Available\ vehicles\ (measured\ by\ vehicle\ density)$

As stated, the issue with the optimal model is the lack of available data for the number of journeys per day and the length of those journeys. As such, our research will examine "second-best" proxies for the measurements of $\frac{J}{d}T$. We have done this through a methodological review of international and academic best practices in the next page (Changxi 2024, Ming 2022, Mi et al 2020, Bednarwoska-Michail 2021, Melia et al 2020, Morton et al 2020, McCreevy Philips et al 2023, Reck et al 2021, Sze et al 2019, Yu et al 2022, Zhang et al 2023).

2.2 Extending to a "second-best" model

For our research, we have found broadly four sets of established proxies for measuring E-bike demand. These are: temporal variables (Changxi 2024, Ming 2022, Mi et al 2020, Sze 2019, Zhang 2023), weather (Sze et al 2019, Morton 2020) spatial/geographical variables (Zhang et al, 2023, Changxi, 2024, Ming, 2022, Mi et al,2020, Bednarwoska-Michail, 2021, Yu et al, 2022, Melia et al, 2020) and socio-demographic variables (McCreevy Philips et al 2023, Reck et al 2021). While a good model will ideally incorporate all of these proxies, we are also cautious in the econometric risks of overfitting and multiple variate analysis, as well as the data constraints available to the London market. This section therefore evaluates the qualities and drawbacks of each category, provides a bibliography of methodological papers that relate to each, before proposing our preferred proxy based on data availability, that being a mix of spatial and socio-demographic analysis.

Variable Categories	Intuition	Requires	Useful for	Variable	Description	Paper
Temporal	Urban travel peaks and pits	Long period time series data	Isolating **demand average and range**	Time	Time of day on a 24-hour scale, indicating peak and off-peak usage periods.	Changxi (2024), Ming (2022), Mi et al (2020), Sze et al (2019)
				Day	Day of the week, affecting demand fluctuations.	Changxi (2024), Ming (2022), Sze et al (2019)
				Weekend/holiday	Binary indicator denoting whether the day is a holiday or weekend, influencing demand patterns.	Changxi (2024), Sze et al (2019)
				Seasons	Coded representation of the season, which can significantly influence demand due to weather and sociocultural factors.	Zhang et al (2023), Changxi (2024), Sze et al (2019)
Weather/climate conditions	Affects user comfort	Long period time series data	Isolating **demand average and range.** Also useful for isolating whether London demand is mostly regular (e.g. commuters) or	Temperature	Actual and felt temperature, affecting user comfort and willingness to use the service.	Sze et al (2019), Morton (2020)
				Humidity	Air moisture level, which can influence the comfort and likelihood of bike-sharing usage.	Morton (2020)
				Wind Speed	Impacting riding comfort, speed and safety.	Sze et al (2019), Morton (2020)
				Visibility	Indicates the distance visible ahead, potentially affecting riding decisions.	Morton (2020)

Variable Categories	Intuition	Requires	Useful for	Variable	Description	Paper
			irregular users (e.g. tourists)	Dew Point Temperature	Temperature at which dew forms, providing an indication of atmospheric moisture.	Morton (2020)
				Rainfall	Indicating precipitation levels that could deter bike usage.	Morton (2020)
				Snowfall	Representing snow conditions that can affect service demand.	Morton (2020)
				Solar Radiation	Affecting weather conditions and possibly the comfort level of riders.	Morton (2020)
Spatial Factors / Geographic layout	Affects user comfort and efficiency of cycling	Cross-country data	Isolating variation **across city cases**	Topography and geographic spread	Affecting user effort in using the vehicle	Zhang et al (2023), Changxi (2024), Ming (2022), Mi et al (2020)
				Transport infrastructure	Affecting the user comfort	Bednarwoska-Michail (2021), Yu et al (2022), Melia et al (2020
Sociodemographic	Highly correlates for certain measurable attributes.	Granular census and council data	Isolating variation **within cities**	Population density	Demand positively correlates	Reck et al (2021), McCreery-Phillips et al

Variable Categories	Intuition	Requires	Useful for	Variable	Description	Paper
						(2023), Sze et al (2019)
				Age distribution	Demand negatively correlates	Haustein et al (2016), Reck et al (2021)
				Average income levels	Demand positively correlates	McCreery-Phillips et al (2023)

2.2.1 Weather, Climate, Environmental and Temporal proxies

Weather and climate conditions are a large driver of whether people cycle or prefer other transportation methods. The variables included in this category relates to typical weather conditions – such as temperature, humidity, wind speed, visibility, rain, and snowfall – as well as climate conditions – such as air pollutants and solar radiation.

The general intuition behind weather and climate effects is that poor weather influences preference for cycling. In this way, weather conditions can be used to predict the average demand and demand range.

London specific research in this area by the London Bike Sharing Scheme (LBSS) study found that demand of casual cyclists is likely to be inclined to delay trips to avoid poor weather, while regular cyclists were much more likely to continue to use their bikes regardless of the weather (Morton, 2020[19]). This means that weather data could be used to isolate whether demand in London is robust and made up of commuters, or more utilised by "fair weather" cyclists and tourists.

London's environmental conditions, air pollution and its impact on cycling demand is inconclusive. High concentrations of ozone are linked with lower levels of demand from cycles; however, the demand is positively related when there is a high concentration of particulate matter 10[20]. This shows an unlikely causally significant relationship.

Where London specific research is lacking, international comparisons are also useful to gauge the affect of weather on E-bike demand. Generally, E-bike share demand showed more tolerance to the weather variables than bike-shared demand, however a muted effect still exists (Campbell et al., 2016). In contrast to conventional bicycles, E-bikes reduce the required cycling effort and travel time, offer easier access to hilly terrain, ultimately providing the potential to reach more distant destinations and better tolerance of bad weather. Despite this, multiple international studies still indicated that precipitation and temperature are significantly affecting factors on the demand for the shared E-bikes (Guidon et al., 2019; Julio et al., 2022). Based on the analysis of the transaction data in Zürich, there was 17% less demand on days with precipitation

(Guidon et al., 2019). Also, high temperatures or summer months contributed to an increase in ridership of E-bikes (He et al., 2019; Guidon et al., 2019). Other weather variables such as visibility, and solar radiation do not play a significant role in E-bike share demand (Guidon et al., 2019; He et al., 2019).

Temporal variables are another set of logical forecasting metrics for measuring E-bike demand. These can range from the time of day, the day of the week, to seasons. The general intuition behind these factors is that there are clear peaks and pits behind *when* people travel and therefore taking a temporal approach can be useful to isolate average demand as well as demand range.

While we did not find a specific London study that examined temporal effects, Guidon et al (2019) found that weekend exhibit significant fall in E-bike demand of 37% compared to weekdays. In addition, during weekdays, the highest demand was shown during peak hours in the morning (7 and 8 am) and evening (6 and 8pm). These usage patterns according to day type and time are also consistent with the study of Jianhong Ye et al. (2020), which analysed Shanghai's usage patterns.

Temporal usage pattern also varies across locations and depending on the main purpose of using E-bikes. It was stated that the main users of E-bikes in Shanghai were commuters, which is reflected in the data. However, in the case of Utah for example, where the proportion of tourists using shared E-bikes is high, the use of E-bikes on weekends showed a significant increase compared to weekdays (Yi He et al., 2019). Finally, more demand for shared E-bikes is observed in the summer season (Yi He et al., 2019; Guidon et al., 2019). For this reason, temporal analysis may be particularly useful for analysis the determinants of usage, beyond just static forecasting.

Regarding methodology for weather, climate and temporal analysis, most papers followed a similar pattern. For weather and climate, meteorological data over significant time periods (longer than one year) was used with the assumption that worsening weather conditions would reduce cyclists' comfort levels. For temporal factors, demand data was simply regularly taken across time. This was then regressed on daily cycling level data based on either vehicle density or docking return data, a more accurate, but less openly available metric.

Particularly for variables related to temporal dynamics or weather conditions, the project's confined timeframe and capability presents a notable obstacle. Our methodology cannot feasibly cover the full spectrum of weather conditions, seasons, and days throughout the year or indeed years. This limitation precludes us from empirically forecasting these variables on demand. The transient nature of weather and the logistical impracticality of year-long data collection severely limit our ability to gauge how changes in weather or temporal factors correlate with shifts in E-bike demand. However, we believe that TfL could build on our review of these categories going forward and develop a long term and more coherent understanding of E-bike demand.

2.2.2 Spatial proxies

Spatial analysis is another typical forecasting proxy (Zhang et al, 2023, Changxi, 2024, Ming, 2022, Mi et al,2020, Bednarwoska-Michail, 2021, Yu et al, 2022, Melia et al, 2020). Specifically, typical metrics include geographical distance from city centre, cycling and other public transport infrastructure, and altitude, with the intuition that these two factors affect both cyclists' comfort, safety and efficiency.

Unlike the temporal and weather categories, this proxy would be expected to remain relatively consistent across time periods. Instead, the benefit of this proxy is its ability to indicate variation across similar cases and whether improved infrastructure has the potential to increase demand. For example, cities with similar geographical features could compare their relative levels of cycling infrastructure to isolate this metrics' impact on demand. This proxy can also be used to examine variation within a particular case – for example in comparing different boroughs.

Spatial analysis can also be used to broadly estimate where demand is likely to be highest, before coming in on a more quantitatively detailed analysis. We have used this technique to map out the demand intensive boroughs based on cycling infrastructure and central proximity before analysing their demand levels in greater detail.

2.2.3 Socio-demographic proxies

Finally, socio-demographic proxies, such as population density, age distribution, ethnicity and income levels also correlate highly with E-bike demand and can be used to forecast potential demand levels (McCreevy Philips et al 2023, Reck et al 2021). These proxies do not always have a theoretical link, but many have well-grounded correlational evidence to link to cycling habits. Moreover, what makes these proxies attractive is the available detailed data that is granular at the borough level. These proxies are therefore particularly useful for examining variation *within* cases (for example across London Boroughs). A review of London specific empirics that we used in our model is laid out in the analysis section.

2.3 Measuring vehicle density

While the four categories seek to interrogate potential proxies for user trips and trip length, vehicle density from third party providers is not publicly available and equally provides a challenge in finalising the model.

Despite the absence of direct data, it's possible to estimate real demand for shared E-bikes by observing the operational behaviours of current service providers (LSE Cities, 2024). A particularly insightful proxy for estimating demand involves analysing the logistics and distribution patterns of these services. Given that these providers are profit-driven entities, their primary goal is to maximize the utility of each vehicle. This is achieved by strategically arranging their fleet across various locations to meet demand comprehensively, ensuring that no demand goes unanswered, and no vehicle remains idle.

By utilising how these companies arrange their E-bikes, we can deduce their expected real demand across different zones. Specifically, understanding the prearranged pattern of vehicles each morning offers a glimpse into the anticipated demand for those locations throughout the day.

Our approach utilised the available image data from third party service applications to monitor provider behaviour at the beginning of the day in each location.

From this the number of E-bikes we counted by an Artificial Intelligence tool, which gave a consistent methodology across locations of vehicle density.

The integration of sociodemographic data with the measured availability of Lime vehicles near these tube stations facilitates a comprehensive analysis. This correlation aims to uncover insights into how various factors inherent to each location influence the propensity of commuters to utilize Lime's services for their last-mile connectivity.

For instance, we hypothesize that areas with higher population densities or significant commercial activity may exhibit greater demand for Lime vehicles, reflecting the critical role of shared E-bikes in enhancing urban mobility. Similarly, examining the availability of Lime vehicles about the demographic profile of each area could reveal patterns in usage preferences among different commuter segments.

2.4 Towards a demand forecast model.

The study employs Pearson's coefficient and multiple linear regression analyses to establish the linear correlations between these determinants and the demand (ridership), focusing on the hypothesis that these variables significantly impact E-bike sharing service usage.

Understanding how demand responds to changes in various sociodemographic variables is crucial for optimizing service delivery and enhancing user satisfaction. We utilised an Ordinary Least Squares (OLS) regression approach, enabling us to estimate the sensitivity of demand to shifts in key sociodemographic factors. This approach offers a clear and quantifiable insight into the relationships between our dependent variable—estimated demand derived from app images—and an array of independent sociodemographic variables.

At its core, OLS regression aims to model the relationship between a dependent variable and one or more independent variables by minimizing the sum of the squares of the differences between the observed and predicted values. This method provides an efficient means to assess how changes in independent variables, such as population density, income levels, and age distribution, impact the demand for shared E-bikes. With the model expressed as:

$$Y = Bo + B1X1 + B2X2 + \cdots + BnXn + e$$

Where
$Y = estimated\ demand$
$X = Sociodemograpic\ factors: population\ density, average\ borough\ income, job\ density$
$Bo = Intercept$
$B1, \ldots Bn$
$= coefficient\ reflecting\ change\ in\ Y\ for\ one\ unit\ change\ in\ independent\ variable$
$e = error\ term$

By applying OLS regression to our dataset, we can quantify the extent to which various sociodemographic characteristics influence E-bike demand. For instance, a positive coefficient (β) for an independent variable suggests that an increase in this variable correlates with an increase in demand. Conversely, a negative coefficient indicates an inverse relationship. This analysis highlights the significance of each variable and provides a basis for forecasting demand under different sociodemographic scenarios.

Complementing our OLS regression analysis, Pearson's correlation coefficient offers a preliminary measure of the linear relationship between two continuous variables. Calculated as the covariance of the two variables divided by the product of their standard deviations, Pearson's coefficient ranges from -1 to 1, where values closer to 1 or -1 indicate a strong linear relationship and values near 0 suggest a weak or no linear relationship.

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This focused examination of Lime vehicle availability near selected central London tube stations lays the groundwork for a nuanced understanding of shared e-bicycle demand. By correlating this empirical data with sociodemographic characteristics, our study examines the underlying dynamics that drive the utilization of shared mobility services. The insights derived from this analysis are anticipated to contribute significantly to the optimization of shared e-bicycle systems, ultimately facilitating more efficient, responsive, and user-centric urban transportation solutions.

2. 5 Consumer sentiment

Our proposed model is intended to forecast current levels of demand at current equilibrium prices. There is however a myriad of factors that can influence both current and potential cyclists' incentives to utilise micromobility (Melia 2021). It is important to develop an understanding of these factors and examine whether the risk they pose to current demand is realistic. There are three main factors that can influence E-bike demand which TfL can potentially anticipate and control.

First, the fare price for e-bike services is likely to inform future demand levels (Reck, 2021). While under our model it is possible to model equilibrium demand at current prices, it doesn't give us demand's elasticity. This poses a problem as since 2020 inflation has become particularly unstable, and the potential for e-bike price fluctuations outright or relative to other transport alternative may greatly affect cyclists' structural routines, either positively or negatively.

Second, there is significant empirical evidence that improved bicycle infrastructure will induce greater cycling uptake (Morton, 2021). This follows the spatial induced travel demand hypothesis (Schneider, 2018) that the development of transport infrastructure, particularly roads, often can induce its own demand. While the original theory applies to motor roads, similar arguments have been made for other forms of transport infrastructure.

One potential solution would be to examine variation across cities with similar geographical, climate and socio-economic factors to try and isolate the effect of cycling infrastructure, however this would equally be beyond the scope of this project.

Finally, there is some academic work that indicates that social networks and norms may affect cycling demand (Morton 2020). The theory presents as a typical collective action game where the benefits of cycling increase as the number of cyclists increase. This leads to a network agglomeration affect, particularly in urban centres. Empirically, this has been seen in the form of "micromobility tourism" a phenomenon where E-bike renters may be made up of highly seasonal tourist in certain cities.

While these factors will not be incorporated into our predictive model, we have tried to capture and examine how much of a risk they may be going forward through the use of a qualitative survey in the Boroughs analysed. The short survey is broken into four parts, interrogating each three dynamic affects as well as the respondents' demographic factors. The survey is also only asked of current cyclists – rather than the population at large. We believe this to be suitable as the main purpose of the survey is to examine whether there is a major risk to demand dropping sharply due to price increases.

The survey was conducted with E-bike users on the street and near the tube stations which we also used as our samples for the demand modelling. This gives us a general representative sample of a population who already use E-bikes and indication of whether they will continue to use e-bikes in the future or if circumstances change (i.e. if E-bikes become more expensive, if London's cycling infrastructure improves or if more of their social network cycles). In this way it is more about maintaining the current demand levels measured in section above.

The survey was conducted at five tube stations (Temple, Southwark, Highbury and Islington, Westminster, Whitechapel) and collected 68 responses. The survey was conducted in each station over a number of days during peak hours in the mornings and afternoons, as well as on weekend days for three hours each.

3. London Spatial and Socio-demographic Analysis

3.1 Qualitative review of spatial and socio-demographic factors

To understand the user's demand for E-bike, it is necessary to clarify the spatial and socio-demographic factors which impact the demand of an E-bike or dockless bike as a mode of travel. While the E-bike and dockless E-bike research field is newly emerging field, research concentrating on E-bike travel behaviour is scarcely developed (Kazemzadeh & Ronchi, 2021, and Melia & Bartle 2021). In the UK, the demographics and characteristics of E-bike users remain uncertain. However, from existing research and surveys, this report can roughly summarise the factors that relatively affect the demand for an E-bike sharing scheme in London: spatial, socio-demographic, attitude.

3.1.1 Demographic

Evidence on demographic factors, such as gender, ethnic, and age, is mixed. A case study of E-bike in Exeter found that with higher age in different age group, the demand for E-bikes is decreasing (Thomas, 2019). However, the differential use of E-bike between different age group requires more information to establish the relationship between these two factors, as one study mentioned that the use of E-bike in each different age group are rarely noticeable (Haustein and Møller, 2016). The demographic factor, such as age, can be more describe in attitudes between generations towards E-bikes due to generational differences in acceptance of technology.

International research can also give an indication of London's trends. E-bike share was preferred by young to middle age in Beijing, with a peak effect at 36 years (Campbell et al., 2016). Based on the E-bike usage pattern of the Summit Bike Share system in Utah, most of the trips were taken by non-regular users and younger users (age 15 – 35) account for the largest portion of the non-regular users (Yi He et al., 2019). Similarly, in New York city, the percentage of people aged 25 to 34 has the largest positive impact on E-bike usage and the older group has less influence on the usage of E-bikes (Zhang et al., 2023). Although there is electrical assistance, it seems that this did not help retired or older people in the adoption of shared E-bikes (Bieli'nski et al., 2020).

Turning to gender factors, several studies indicate a different result in gender distribution, such as in the case of USA and Austria, which found that most of E-bike users are males. On the other hand, studies in Netherland, Denmark, and Belgium found that female users are larger than males. In the case of UK, the result of the large survey conducted with 2,092 participants showed that men strongly outnumber of women among E-bike users in the UK (Melia & Bartle, 2021).

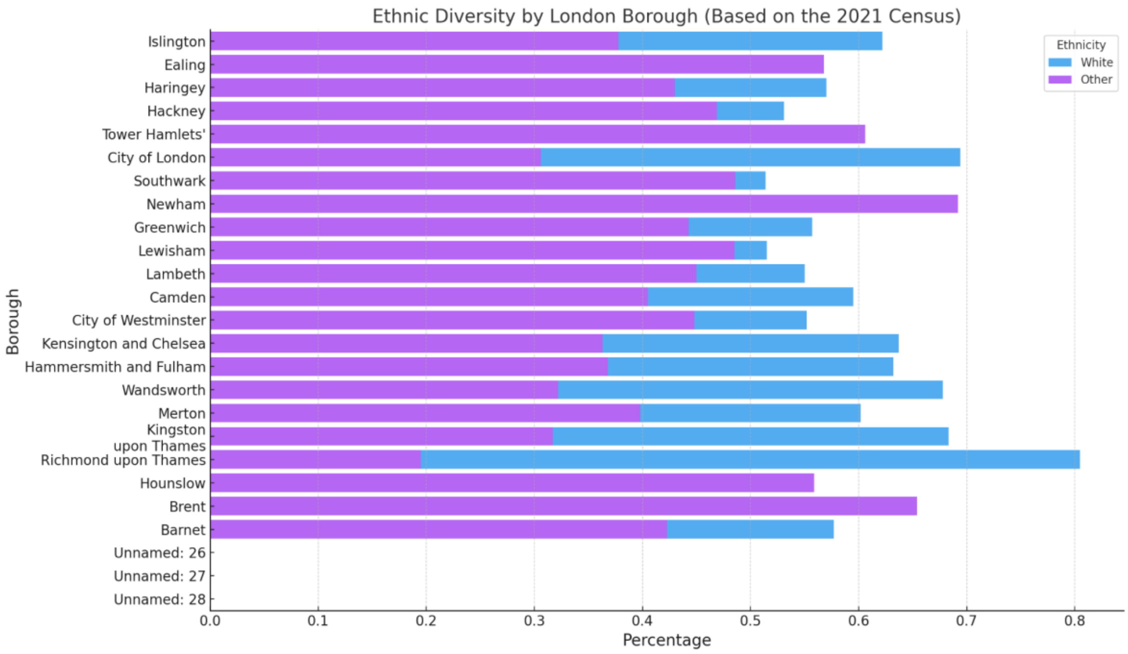


Figure 2: Ethic Diversity by London Borough 2021

Moving to the ethnicity of E-bike users, research found that White ethnic tend to use more bike in London (2CV, 2021). Additionally, the London Travel Demand survey (2019) shows that more than 60 per cent of people who cycled were male, and the majority of cyclist were represent in White ethic group. Lastly, the number of people positively impacts on the usage of E-bikes, which is consistent with the results of other international case studies (Zhang et al., 2023; Guidon et al., 2019).

3.1.2 Socio-economic

Numerous studies generally agree that the socioeconomic characteristics of individuals who use micromobility, such as bikes, E-bikes, and e-scooters, are more likely to be young, well-educated, male, and have a higher income (Daneil and Kay, 2021).

However, some studies present contradictory results regarding the socioeconomic characteristics of micromobility users, For instance, a study by Buck et.al. found that the bikeshare users are more likely to be female, younger, have lower household incomes. In 2019, the London Travel Demand surveys reported that individuals from lower-income households and disabled people are less likely to cycle. Several have investigated the demand for bicycle commuting across Greater London, UK, reveals that a decrease in demand with an increase in the number of cars per household. Though, the bike commuting rate is more dispersed in Inner London as the number of cars per household increase. The same study also found a significant effect of the lack of academic qualifications on decreasing the level of bicycle commuting. (McCreey-Philips and Heydari, 2023)

Even in international studies, the connection between E-bike usage and income and education levels is unclear. While a study in the U.S. demonstrated that E-bike users tend to have higher incomes and education (Popovich et al., 2014), an Austrian survey indicated the opposite trend (Wolf & Seebauer, 2014). But a survey in the Netherland showed that higher income but lower education increases the odds of using an E-bike (Plazier et al., 2022). The relationship between income level and E-bike use by country needs to consider the relative cost of shared E-bike. In New York city, the percentage of low-income people was found to have a negative impact on E-bike use, and high costs were pointed out as one of the reasons (Zhang et al., 2023). In the same vein, neighborhoods with higher income levels showed higher demand in Zürich and the relatively high service cost compared with public transportation were pointed out as the cause (Guidon et al., 2019). Ownership of a car is positively associated with E-bike usage, with car owners being 45.7% more inclined to use an E-bike compared to non-owners. This indicates that E-bike usage can complement car travel (Plazier et al., 2022). E-bike use is more likely among students and commuters than retirees (Plazier et al., 2022; Guidon et al., 2019), which is in line with the popularity of young to middle-aged people (Campbell et al., 2016).

3.1.3 Attitude

In 2021, The National Travel Attitudes Study conducted an online and telephone survey to analyze attitudes towards cycling in England. The report reveals that only a small proportion of the sample had access to E-bikes, with a mere 1 per cent reported that they have regularly use an E-bike, while 97 per cent stated they did not own or regularly use an E-bike. This aligned with the Attitude Towards Cycling Survey 2016, which illustrated a similar proportion (1 per cent) of people who only used E-bike (TFL, 2016). Interestingly, as electronic vehicles such E-bikes and e-scooters become trendier and more accessible, over one-third of the respondents without an experience of using E-bike expressed interested in riding one, while 19 per cent indicated that they would require more information about E-bike commuting (UK Official Statistics, 2021).

The main drivers for encouraging respondents to use an E-bike include cost discount, lower sales taxes, and a traffic-free environment. Many challenges of E-bike commuting scheme were also mentioned, such as E-bikes are too expensive, safety and theft concerns and a lack of information about E-bikes.

3.1.4 Spatial

In terms of empirical analysis, Cottell et.al, 2021 finds that a higher proportion of people cycle in inner London than outer London. Spatial analysis identifying cycling pattern in London also shows that the highest proportion of commuting cyclists are in Hackney and Islington boroughs (Bednarowska-Michaiel, 2023). In general, inner and south-west London borough have more cycling commuters than other boroughs. Additionally, the map from Strategic Cycling Analysis (2023) illustrates that the cycle network is denser in central boroughs neighbouring the Thames, inner London and west London.

The four E-bike sharing scheme operators in London; Lime, Forest, Tier, and Santander, primarily invest in dockless E-bike sharing, with the exception of Santander, which operates docked bikes. The operations are more concentrated in inner London boroughs. Maps from E-bike operators indicate that E-bike sharing is denser in inner London, particularly in the City of London, City of Westminster, Islington, Camden boroughs, where all E-bike providers operate. Consequently, with higher cycling investment in central London, inner Londoners have greater access to cycling infrastructure (Barber et.al, 2022), such as cycle lane, streetlight, street parking for bike/E-bike, and cycle hanger. Many boroughs are aware of the shift in cycling behaviour from dock to dockless, especially with electronic bike and scooter. Some have implemented and designed E-bike parking bays in their boundaries. For example, the Borough of City of Westminster had introduced more than 330 new dockless bike parking spots in their areas. However, due to the lack of aggregated information about dockless parking in London, it is difficult to draw conclusions about the correlation between the E-bike parking and user demand.

Previous studies have also identified concerns among London cyclists and potential users for opting E-bike, with the most significant concern related to safety issue, including speed limits (Lee and Nese Sener, 2023). In response to this issue, many London boroughs had imposed a default speed limit of 20 mph (greater than 75 per cent of roads with default speed limits) to reducing serious injured on the road.

The distribution of the cycle population and investment in related infrastructure mentioned above can be explained by spatial factors. Various research in other countries claimed that economic and social activity were key drivers of demand for shared E-bikes. It was shown that a number of workplaces, jobs, bars and restaurants, and recreation centers per unit area were positive and significant factors in the demand (Zhang et al., 2023; Guidon et al., 2019; He et al., 2019).

Public transportation service quality also has a positive impact on demand (Guidon et al., 2019; He et al., 2019). Demand for e-bicycle sharing was higher in areas well connected by public transportation and those close to the central station and urban trail stations, indicating E-bikes complement traditional public transportation. The bicycle network density had a positive impact on the demand for E-bikes (Guidon et al., 2019; He et al., 2019; Plazier et al., 2022).

Finally, according to the National Travel Attitudes Study (NTAS, 2023) in UK, more than half of the participants said that off-road and segregate cycle paths (52%)

and well-maintained road surface for cycling (51%) are encouraging factors for cycling including E-bike riding.

3.2 Distribution of the demand factors in London and expected demand

To understand the demand for E-bike ridership in London, the distribution of demand factors in each borough identified through literature review was investigated based on 2021 census data. The 22 boroughs are areas where Lime, a private operator, supplies shared E-bikes, and are expected to be in higher demand than other boroughs. The table below summarizes the distribution of demand factors in 22 boroughs in London. Each data of the demand factors for each borough is shown in Appendix 1.

Table 2: The demand factors in London

Factors		Max	Min	Average	Median
Weather/ Climate	Rainfall (day)	16.6	12.1	14.1	14.1
	Summer (day)	29	19.8	26.7	27
Spatial	Social activity (number)	2,550	430	982.3	917.5
	Public Transport Accessibility Level (level)	6b	1b	-	-
Socio-demographic	Age: Young-middle aged (16~34) people (%)	42.6	19.5	32.3	33.8
	Gender: Male (%)	55	46.8	48.6	48.4
	Ethnicity: White (%)	80.5	30.8	55.6	56.4
	Population Density (resident/km^2)	15,704	2,960	8,730	9,224
	Annual Mean Income (pound)	93,201	28,405	45,115	40,587
	Job density (total job/resident population aged 16~64)	98.7	0.4	5.6	0.8
	Education: level 4 Qualification or above (%)	74.2	40	52.7	51.9
	Bicycle as mode of travel (%)	7.5	1.2	3.8	3.6

*Rainfall: Annual average rainfall 10mm or above days, Summer: Annual average above 25 Celsius days, social activity: the number of restaurants, bars, recreation centres, and cultural facilities, PTAL: Public Transport Accessibility Level

Since Young-middle aged population, mean annual income, social activities, Population density, and PTAL have a large relative gap among boroughs, the distribution pattern of demand might be predicted based on this data.

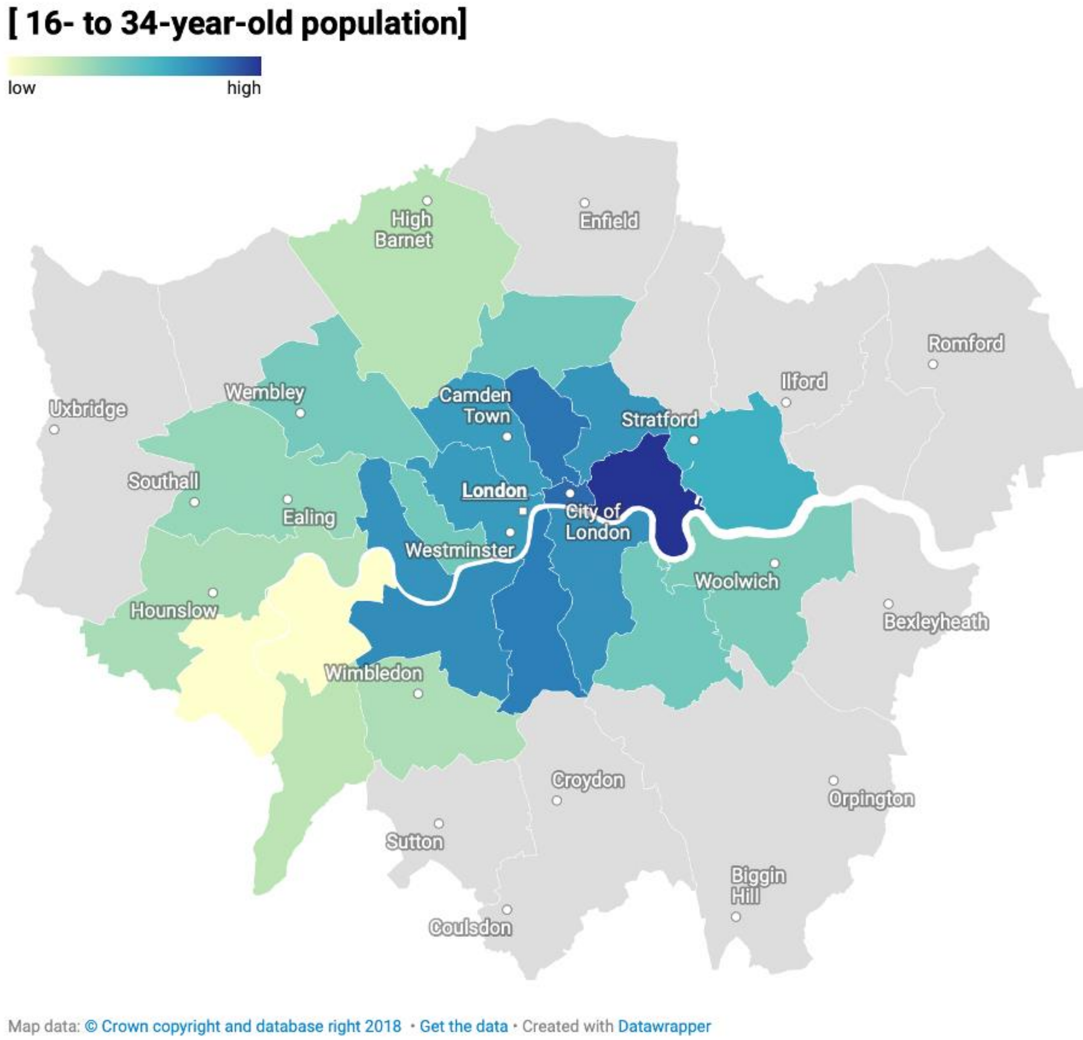


Figure 3: Shows the proportion of the younger population aged 16-34 in London's 22 boroughs, indicating that the closer the colour is to a deep blue, the higher the proportion of the younger population. The proportion of the younger generation can be expected to have a positive effect on the use of shared E-bike. The average proportion of the population aged 16 to 34 in the total 23 boroughs is 32.3%, and the maximum value is 42.6%, 2.2 times the minimum value of 19.5%. The proportion of younger generations are high in central London, such as Tower of Hamlets and City of London, and the proportion are low in outer London, such as Richmond upon Thames and Kingston upon Thames.

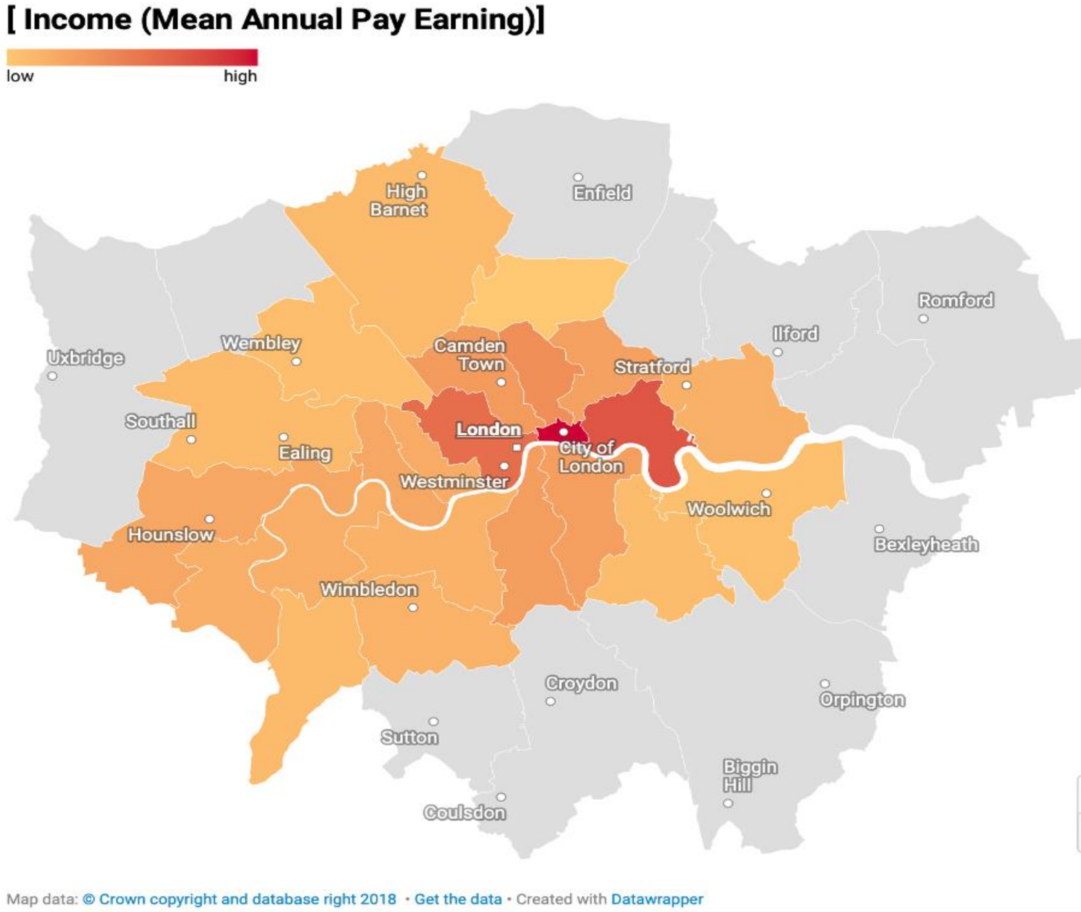


Figure 4: Shows the average annual pay earnings of the 22 boroughs in London, indicating that the closer the colour is to a dark brown, the higher the average income. Though the relationship between income and usage of E-bikes is unclear, income levels are expected to have a positive effect on shared E-bikes in the UK, considering the relatively high cost of using shared E-bikes compared to public transportation costs. The average income difference between boroughs is so wide that borough, with the highest average income, is 3.3 times higher than borough, with the lowest one. The average annual incomes are high in central London, such as Tower of Hamlets and City of London, and the incomes are low in outer London, such as Haringey, and Brent.

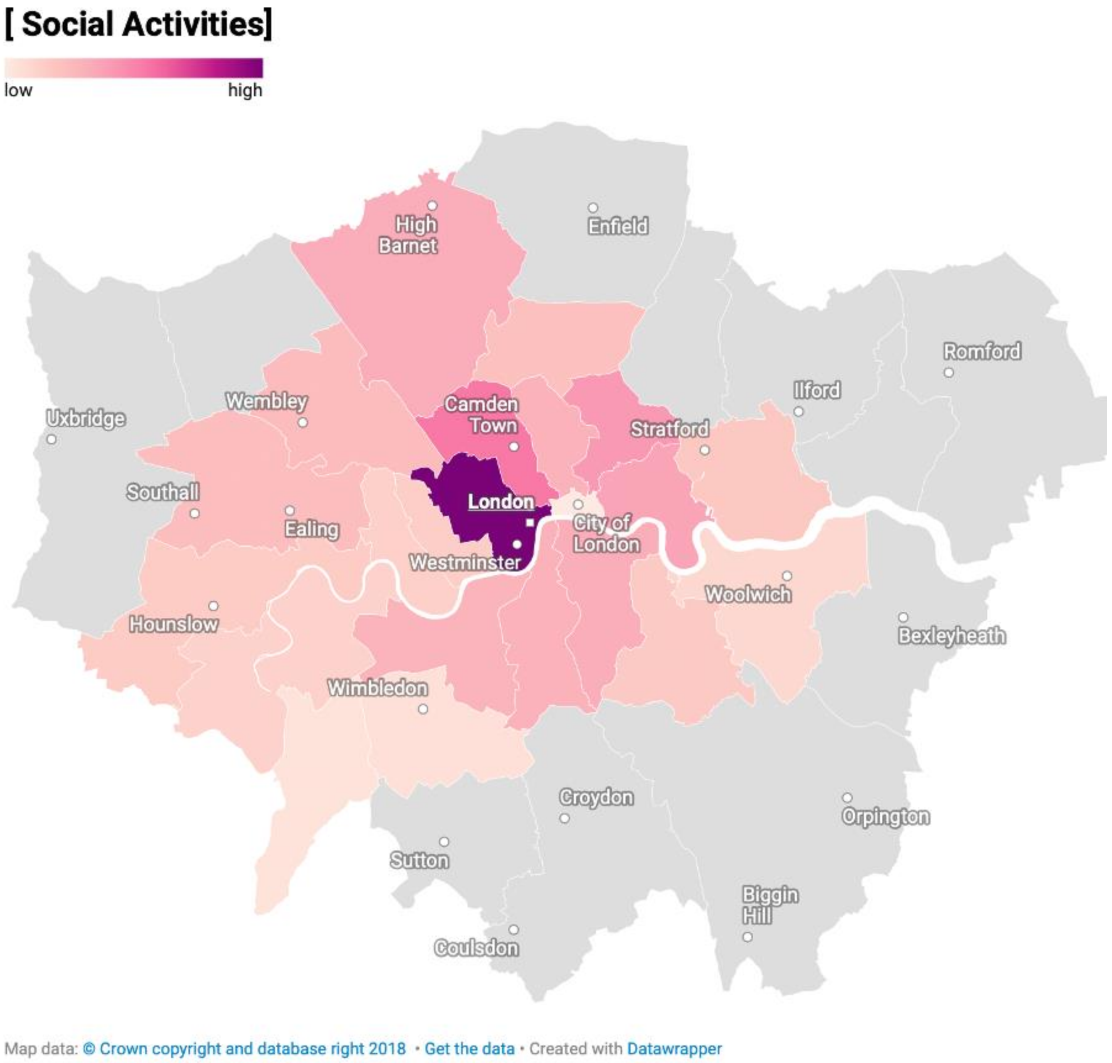


Figure 5: Shows the distribution of social activity spaces in 22 London boroughs, indicating that the closer it is to the purple colour, the more social activity spaces are distributed. Social activity spaces refer to restaurants, bars, recreation centres, and cultural facilities, and according to various literatures, the more such spaces, the higher the demand for shared E-bikes. They are concentrated in the city of Westminster, Camden, and the south of the Thames.

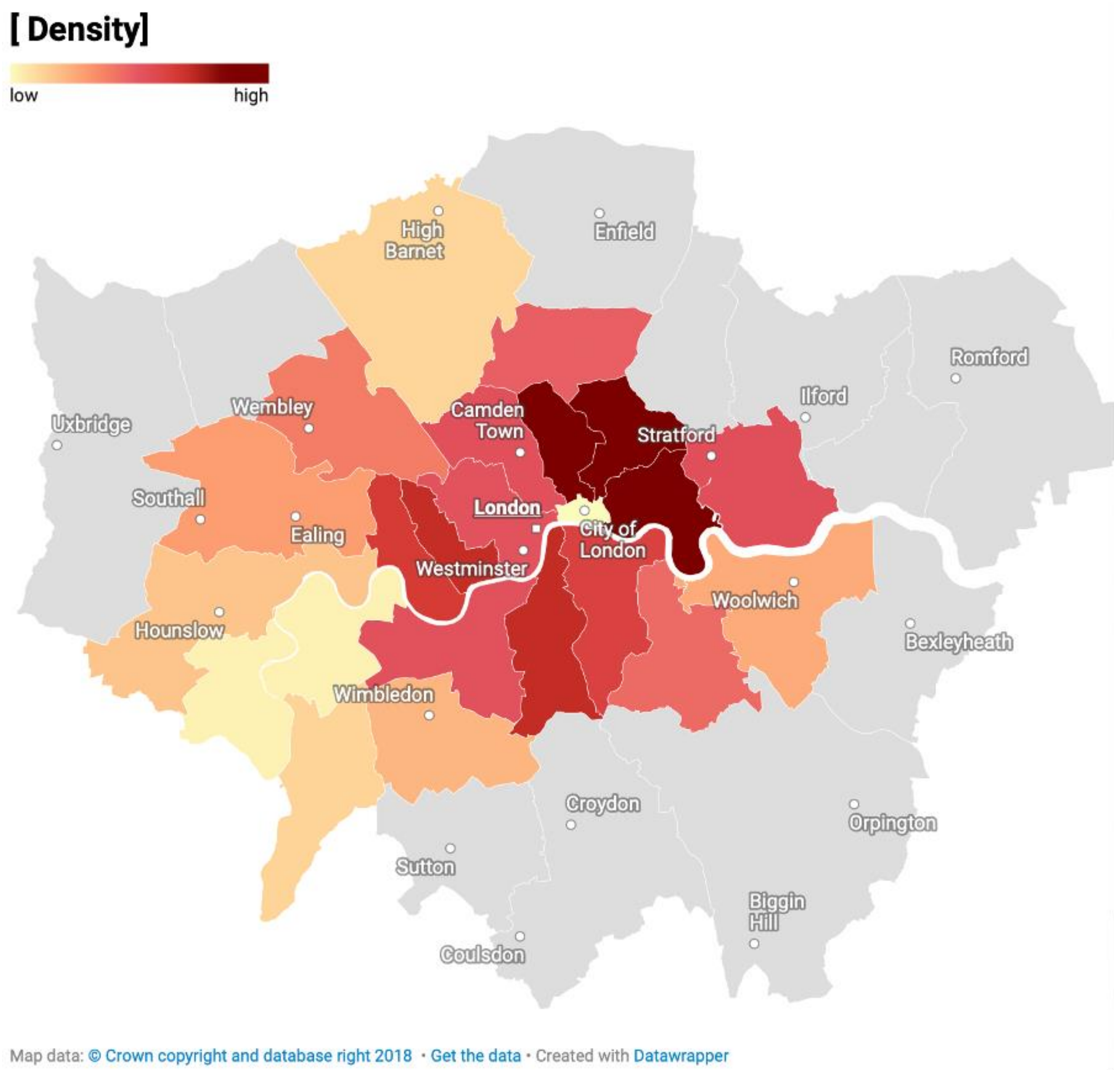


Figure 6: Shows the density of population in 22 London boroughs which measured by residents per kilometre square, the map illustrates that the closer it is to the red colour, the higher density of resident. As shown in the map, high density of residents is in Islington, Hackney, and Tower hamlets. Based on literature review from both London and international cases, many studies indicate that demand for E-bike are denser in urban area which also related to transport accessibility which usually more developed in city centre.

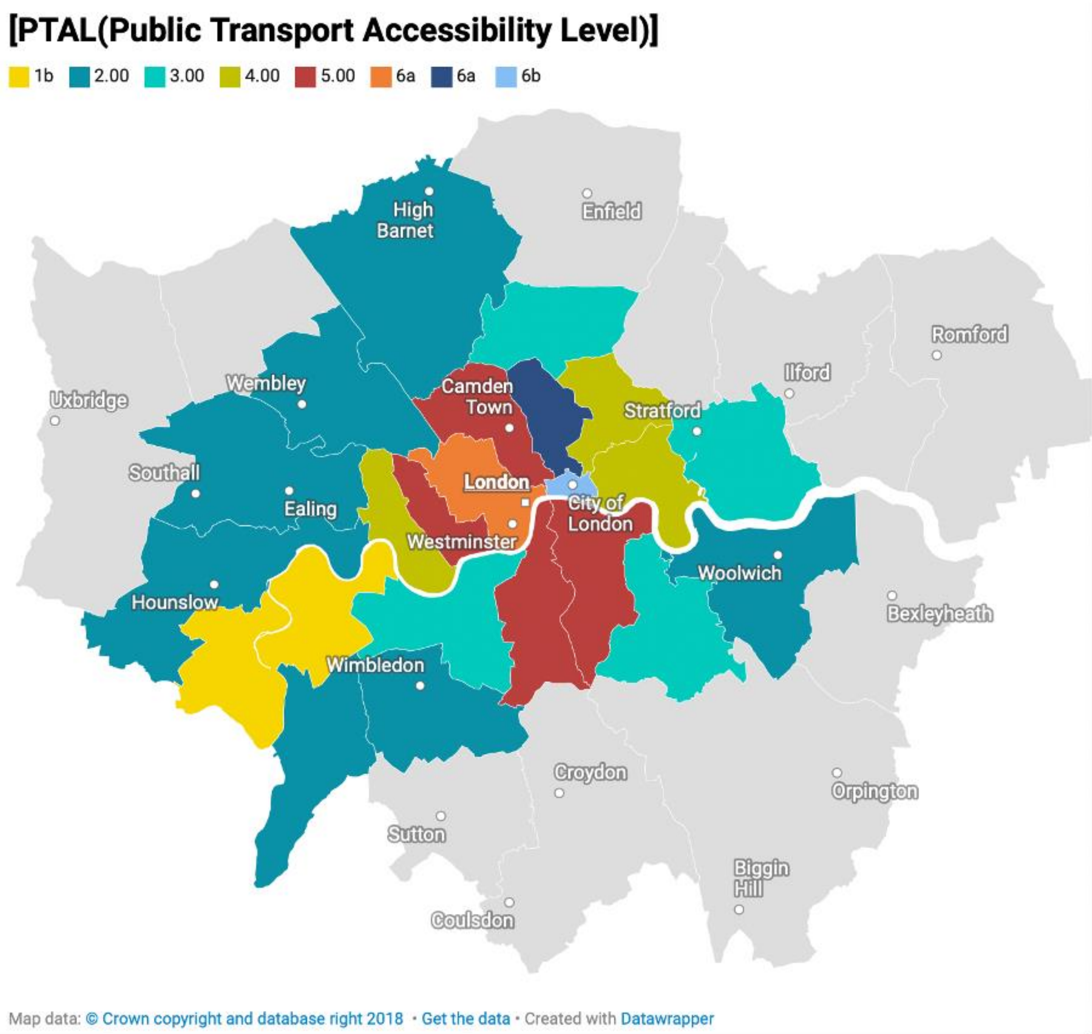


Figure 7: Shows the Public Transport Accessibility Level in 22 London boroughs which is graded between 0 and 6b, where a score of 0 is very poor access to public transport, and 6b is excellent access to public transport. As expected, City of London is rank as 6b (excellent access to public transport), while the neighbourhoods, such as, Islington, Westminster, Southwark, Lambeth, and Kensington are ranked one-level below (6a). However, sub-urban areas show the pretty low level of public transport accessibility. Some studies claimed the inequality in accessing to public transportations which heavily invest in urban area this relates to higher demand for E-bike in city area as cycling infrastructures are available.

Until now, significant demand factors have been considered individually, but now the overall demand pattern can be expected for each borough by considering the demand factors altogether. The table below shows the top four boroughs and the lowest borough for each of the five significant demand factors. Some boroughs are ranked in the top 4 or bottom borough in duplicate. Based on this, it can be expected that Tower Hamlet's, City of Westminster, City of London, Islington, and Lambeth have higher demand and Richmond upon Thames have lower demand than other boroughs. However, there are limitations in that each demand factor may not be significant in London and that we do not know the weight of each demand factor.

Table 3: Top 4 Boroughs in 4 factors.

Factor	Top 4 Boroughs				Bottom Borough
Young-middle aged (%)	Tower Hamlets (42.6)	City of London (39.2)	Islington (38.5)	Lambeth (38.0)	Richmond upon Thames (19.5)
Annual Mean Income(pound)	City of London (93,201)	Tower Hamlet's (74,976)	City of Westminster (65,875)	Islington (52,670)	Haringey (28,405)
Social Activity (number)	City of Westminster (2,550)	Camden (1,585)	Hackney (1,320)	Tower Hamlet's (1,210)	City of London (430)
Population Density (resident/km^2)	Tower Hamlet's (15,704)	Islington (14,566)	Hackney (13,596)	Lambeth (11,840)	City of London (2,960)
PTAL(Level)	City of London(6b)	City of Westminster (6a)	Islington(6a)	Lambeth, Camden, etc. (5)	Richmond upon Thames(1b)

4. Quantitative Analysis

4.1 Demand model analysis

Following our qualitative review, we are now better able to apply our forecasting model to the specific areas that we believe would leverage the most significant demand.

In urban mobility, tube stations serve as vital nodes that significantly influence commuting patterns and, consequently, the demand for shared transportation services such as e-bicycles. Recognizing the importance of these hubs, our project aims to pinpoint the busiest Transport for London (TfL) stations within each borough as focal points for assessing shared e-bicycle demand. This section outlines the rationale and method behind selecting these stations, forming the foundation upon which our demand function analysis is constructed.

4.1.2 Selecting Busiest Stations

The definition of "busiest" in the context of tube stations encompasses various metrics, including passenger numbers, entry and exit figures, and overall station traffic. To accurately identify these hubs, we draw upon available data from TfL and relevant transport studies, which provide insights into the stations with the highest footfall within the boroughs under consideration. While real-time data access and the latest TfL statistics are beyond our immediate reach, a well-informed approach, based on existing transit patterns and the prominence of key stations, guides our selection.

Below is an illustrative table highlighting the busiest tube stations across selected London boroughs, based on educated estimations and known commuting trends up to the most recent updates:

Table 4: Borough and Busiest Tube Stations

Borough	Busiest Tube Station
Islington	Highbury & Islington
Ealing	Ealing Broadway
Haringey	Turnpike Lane
Hackney	Stratford (partly in Newham)
Tower Hamlets	Canary Wharf
City of London	Bank/Monument (complex)
Southwark	London Bridge
Newham	Stratford
Greenwich	North Greenwich
Lewisham	Lewisham (DLR)
Lambeth	Waterloo
Camden	King's Cross St Pancras
City of Westminster	Westminster
Kensington and Chelsea	South Kensington
Hammersmith and Fulham	Hammersmith
Wandsworth	East Putney
Merton	Wimbledon

Some boroughs, such as Kingston upon Thames and Richmond upon Thames, lack London Underground stations, relying instead on National Rail and London Overground services. Moreover, the inclusion of Underground, Overground, and DLR stations in our analysis reflects an intention to capture the broadest possible spectrum of commuting behaviors, particularly focusing on those areas that facilitate significant commuter traffic.

The stations listed serve not just as transit points but as critical indicators of potential demand for shared e-bicycles. By concentrating our analysis around these hubs, we aim to uncover patterns of last-mile connectivity, exploring how the availability of Lime vehicles correlates with the sociodemographic landscape of each area. This focused approach allows us to generate a nuanced understanding of demand, informing strategies to optimize shared e-bicycle deployment and enhance urban mobility solutions.

4.3 Results

4.3.1 Observed Number of Vehicles vs. Population Density

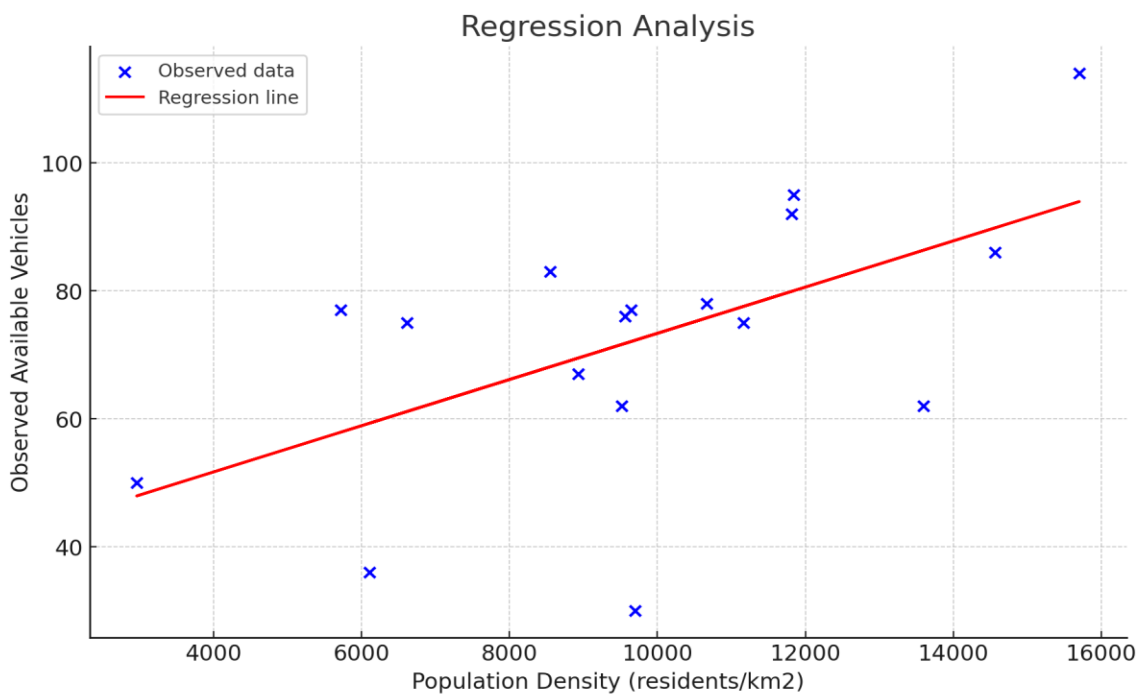


Figure 8: The linear regression analysis between the number of observed available vehicles and population density (residents per km²) has resulted in an R2 value of

approximately 0.326. This means that around 32.6% of the variance in the number of observed vehicles can be explained by the variance in population density. The p-value obtained is approximately 0.017, which is less than the conventional alpha level of 0.05. This suggests that there is a statistically significant association between population density and the number of available vehicles. However, since the R2 value is not very high, other factors not included in this model might also play a significant role in explaining the number of available vehicles.

4.3.2 Observed Number of Vehicles vs. Jobs Density

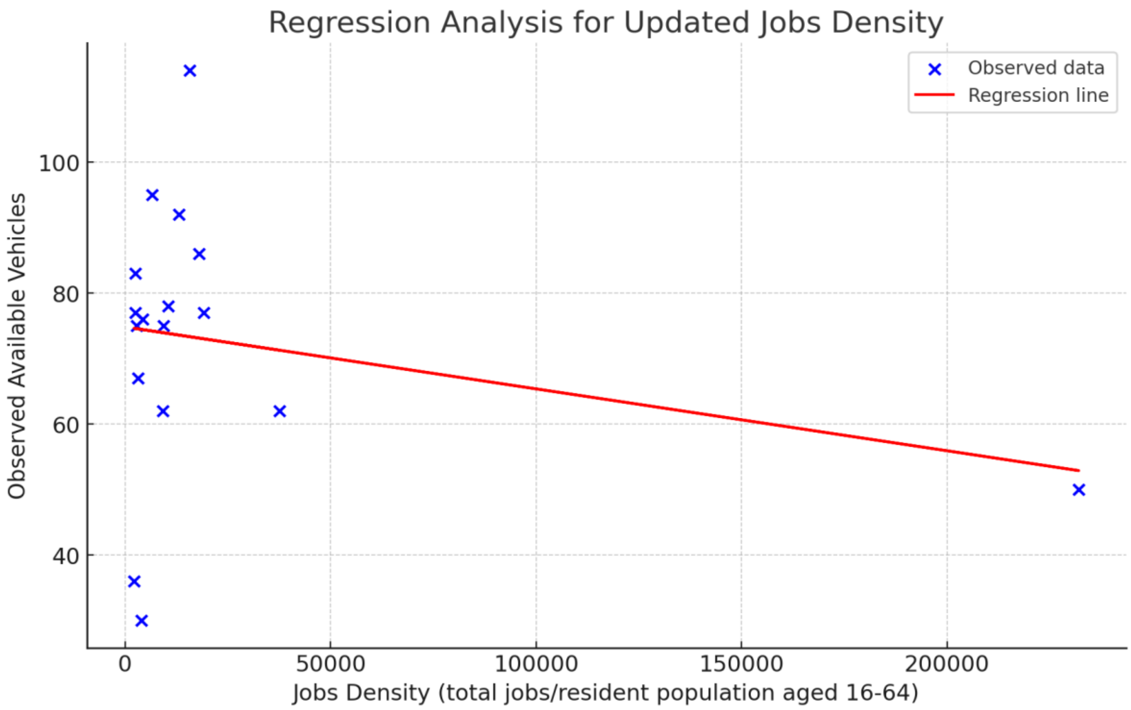


Figure 9: This regression analysis between the number of observed available vehicles and job density (total jobs per resident population aged 16-64) with the new data has an R2 value of approximately 0.062. This indicates that only about 6.2% of the variance in the number of observed vehicles can be explained by the updated jobs density variable.

The p-value for this regression is approximately 0.336, which is well above the conventional alpha level of 0.05. This indicates that there is no statistically significant relationship between job density and the number of available vehicles within this data set.

The regression line displayed on the plot reflects the estimated relationship based on the updated data, but with a low R^2 and a high p-value, it suggests that job density is not a reliable predictor for the number of available vehicles in this scenario either.

4.3.3 Observed Number of Vehicles vs. Average Annual Earning

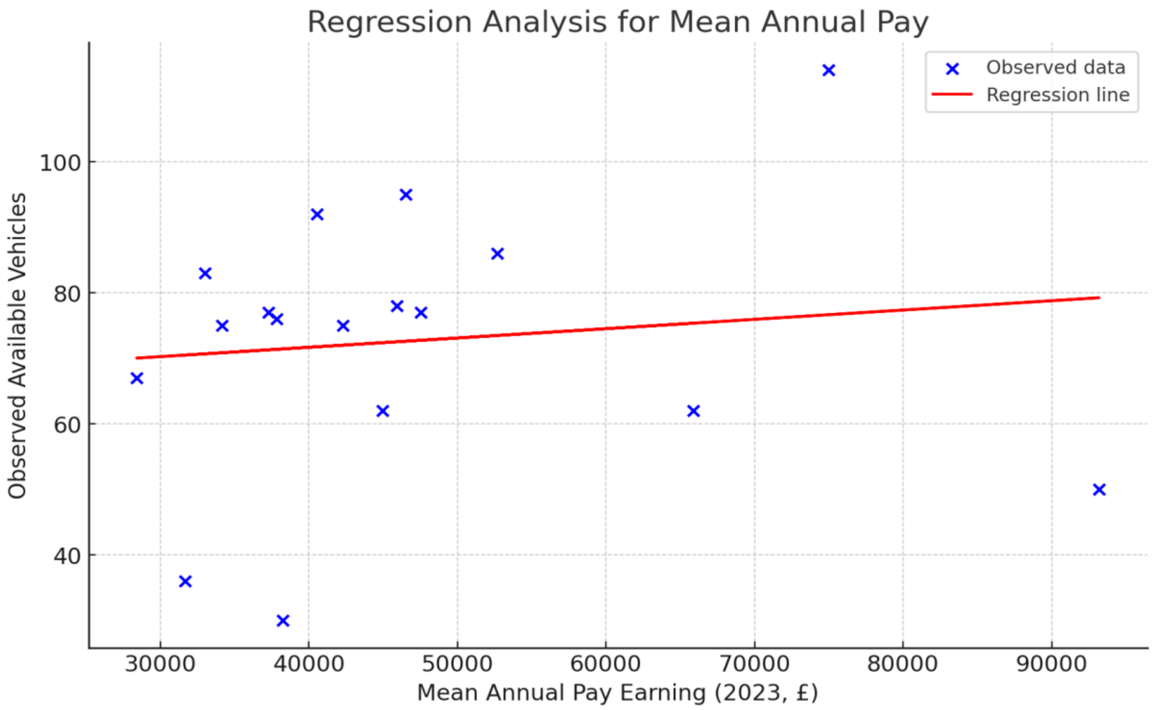


Figure 10: The regression analysis between the number of observed available vehicles and mean annual pay earnings (in pounds for 2023) resulted in an R2 value of approximately 0.013. This indicates that only about 1.34% of the variance in the number of vehicles observed can be explained by the mean annual pay earnings, which suggests a very weak explanatory power of this model for the variable in question.

The p-value for this regression is approximately 0.658, which is much greater than the conventional alpha level of 0.05. This indicates that there is no statistically significant association between the mean annual pay earnings and the number of observed available vehicles, based on the data provided.

The regression line depicted in the plot demonstrates the estimated relationship between the mean annual pay and the number of observed vehicles but given the very low R2 and the high p-value, this relationship does not appear to be statistically significant.

4.3.4 Observed Number of Vehicles vs. Rate of Recycling Households

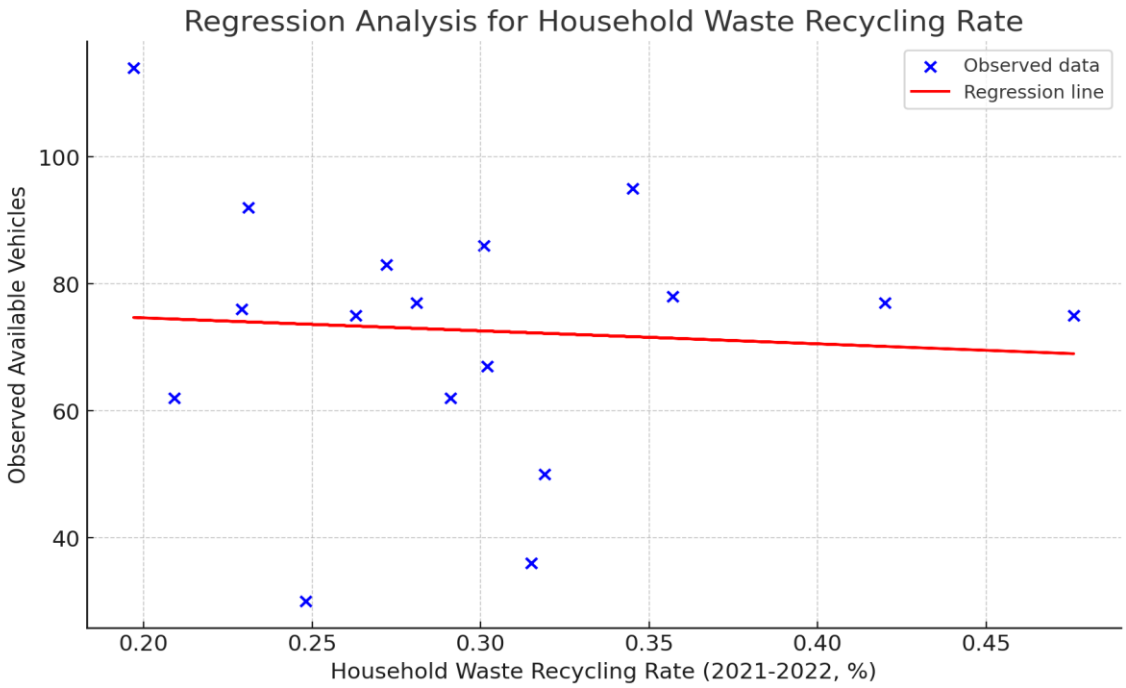


Figure 11: The regression analysis between the number of observed available vehicles and the household waste recycling rate (for 2021-2022) yielded an R2 value of approximately 0.0052. This indicates that only about 0.52% of the variance in the number of observed vehicles can be explained by the recycling rate, suggesting an extremely weak relationship between these two variables.

The p-value for this regression is about 0.784, significantly above the standard alpha level of 0.05. This high p-value indicates that there is no statistically significant relationship between the household waste recycling rate and the number of observed available vehicles, based on the provided data.

The regression line in the plot demonstrates an estimated relationship, yet the very low R2 value and the lack of statistical significance indicated by the p-value suggest that the recycling rate does not serve as a reliable predictor for the number of available vehicles within this set of data.

This strategic shift in focus is not merely a compromise but a steppingstone toward deeper insights. It positions our study as a valuable resource for subsequent research endeavors aimed at dissecting demand patterns across London's boroughs. Moreover, should future investigations succeed in accessing precise data on the actual number of vehicles demanded in a specific zone, the findings from our current study will serve as a critical benchmark. These estimations, despite their inherent limitations, could enable researchers to extrapolate demand across other zones, thus broadening the scope of shared mobility insights.

The City of London - An Outlier in Shared E-Bicycle Demand Forecasting

The City of London emerges as a distinct outlier in our demand model. This deviance is rooted in several key attributes that differentiate it from its counterparts, challenging the uniformity of socio-demographic correlations and demanding tailored consideration in any demand forecasting model.

The City of London's geographical footprint, at a mere 2.9 square kilometers, starkly contrasts with the average borough size of 27 km² within the studied cluster. Such diminutive spatial dimensions introduce anomalies when assessing various forms of density metrics. Population or enterprise density measures, pivotal to understanding and predicting shared e-bicycle demand, become disproportionately inflated due to the reduced denominator value—thereby skewing comparisons with other boroughs.

Compounding this issue is the City of London's residential population. With only 8,500 residents, it stands in sharp relief against the group average of 246,000. This significant population discrepancy underscores a disparity that transcends mere numbers, reflecting a vastly different urban rhythm and lifestyle that does not align neatly with the demand patterns observed in larger boroughs.

The financial profile of the City of London's residents further cements its status as an outlier. The mean annual earnings within this borough, at approximately 90,000 pounds, far exceed the group's average of 46,000 pounds. Such economic distinction could ostensibly influence transportation preferences and the propensity to utilize shared mobility solutions, such as Lime's e-bicycle service.

Moreover, the enterprise density in the City of London is remarkably high, with 7,500 registered enterprises, dwarfing the group average of 1,200. This density not only highlights the area's economic concentration but also potentially indicates a vastly different demand dynamic for shared e-bicycles, driven by the commuter population rather than residents.

When synthesizing these factors—the borough's diminutive size, its low residential population, elevated mean earnings, and extraordinary enterprise density—the prospect of a smooth and meaningful linear correlation is significantly impeded. These unique characteristics make the City of London an outlier that resists the typical socio-demographic explanatory variables employed in demand forecasting for shared e-bicycle services.

The presence of such an outlier necessitates careful exclusion or the application of specialized statistical treatments to avoid skewing the analysis and conclusions drawn from the wider set of boroughs. It is imperative to recognize and account for the City of London's distinctiveness to ensure the integrity and applicability of demand forecasting models in the shared urban mobility domain.

In conclusion, the City of London's atypical socio-demographic profile presents unique challenges in correlating Lime's service data with traditional borough characteristics. Any attempts to incorporate this borough into a standard linear forecasting model must be approached with caution, lest the model's relevance and predictive power across the central London boroughs be compromised. Recognizing and addressing these outlier effects is critical in advancing the sophistication and accuracy of shared e-bicycle demand forecasting.

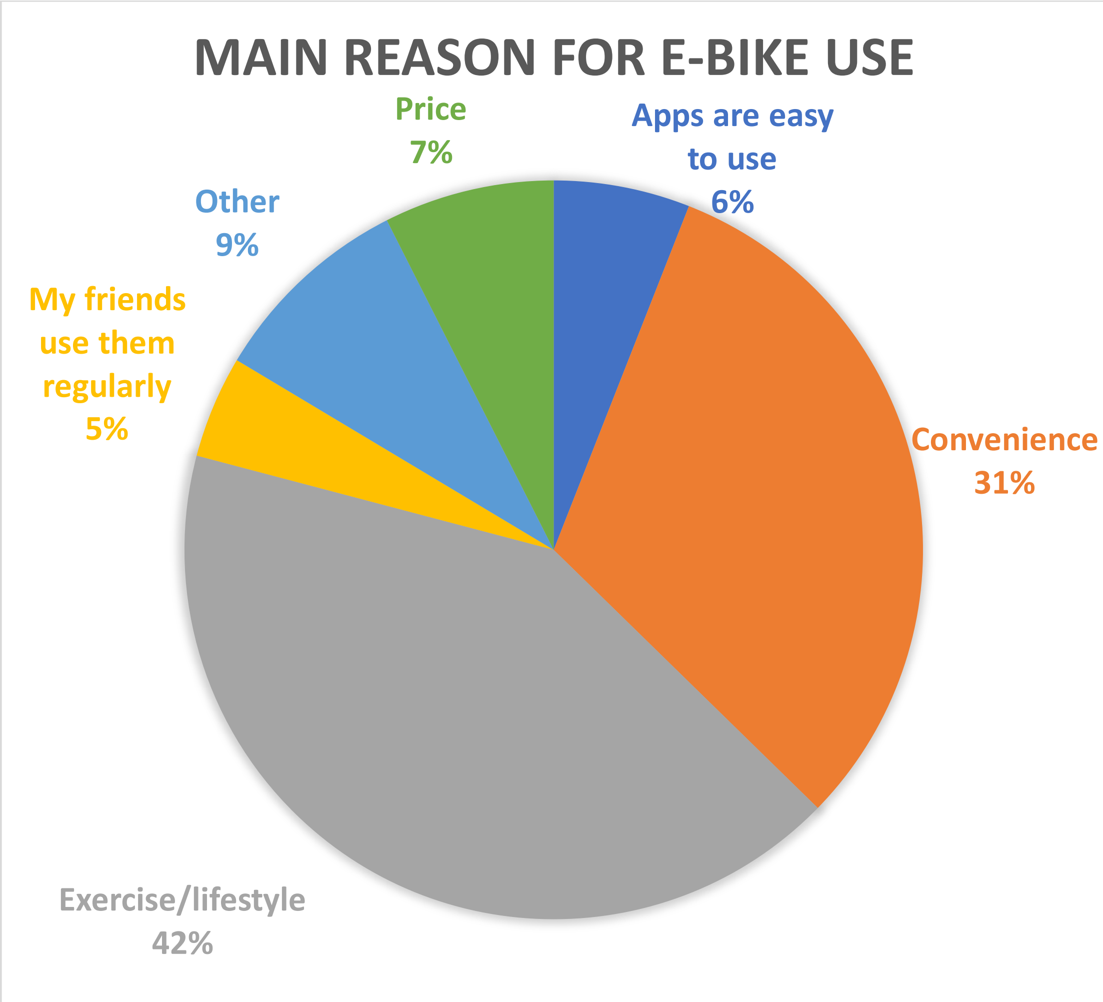
5. Consumer sentiment analysis

In addition to our quantitative analysis, we also undertook a survey (Appendix 4) near five tube stations analysed in our quantitative model. These stations were Temple, Westminster, Whitechapel, Highbury and Islington and Southwark. The purpose of the survey was to better understand consumer sentiment towards e-bikes and to give an indication of what exactly drives e-bike demand, as well as how robust this demand is. The survey received 68 responses in total from current e-bike users.

This survey captures how robust *current* demand is and gives an indication of the level of risk of that demand decreasing. It does not give an indication of the drivers of demand for the London population as a whole, and thus doesn't give future potential demand. The survey questions were mainly drawn from similar surveys undertaken by LSE cities (Rode et al, 2015) or were written guided by the mentioned factors that drive E-bike demand.

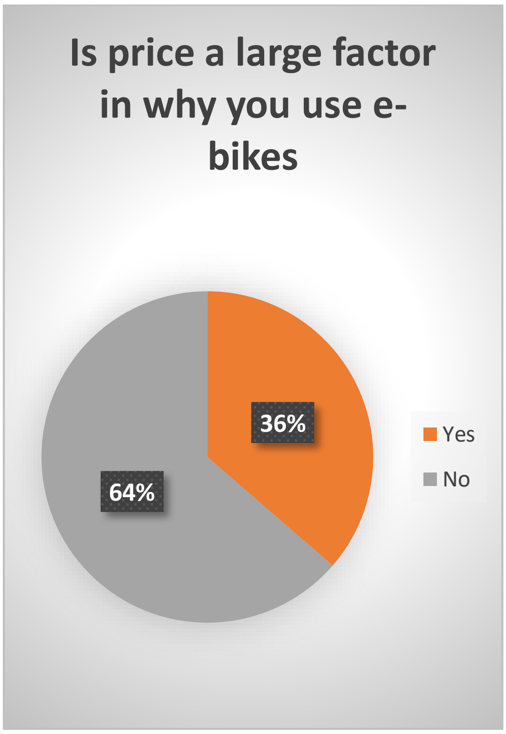
Of the 68 respondents, 73% were male, a significant plurality was between the ages of 25 and 34, with the next largest group between the ages of 45-55. 62% and 22% stated that they lived in zone 2 and 3 respectively, with 13% stating they lived in zone 1. Economically, there was a significant focus of middle and upper middle professionals. The next largest group included service workers.

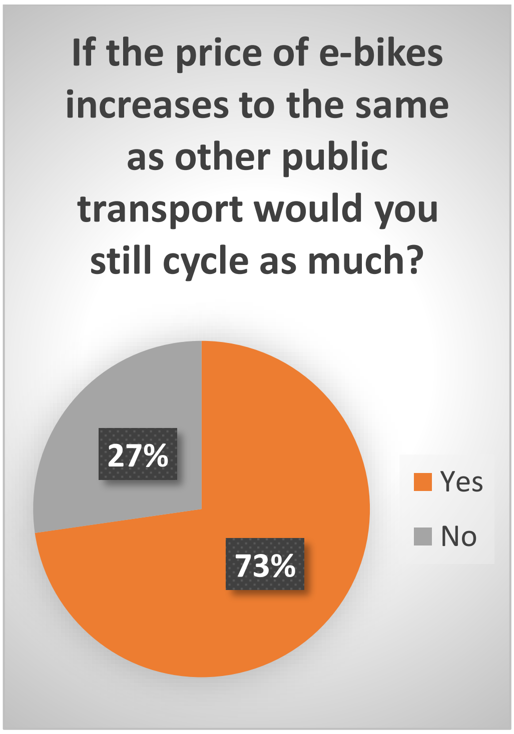
5.1 Price Elasticity



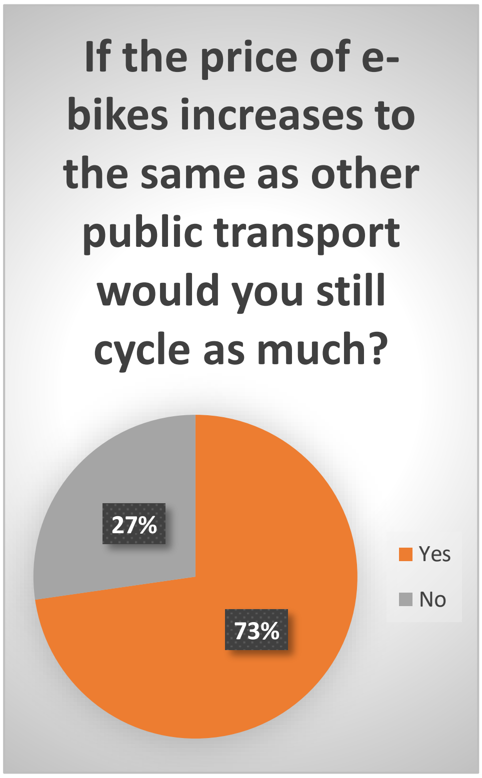
Perhaps the most shocking result that came out of our survey's findings was how much price is not the driving factor behind most e-bike users' demand. From this analysis, demand seems to be quite inelastic to price fluctuations.

Users cited convenience, exercise and environmental factors as the reason why they used rental E-bikes much more so than price. This indicates that future demand may in fact be quite robust. It also may hint that the rental E-bike market is currently acting as a luxury good for many users and that there may be significant untapped demand for a separate market which values low cost, micromobility transport similar to that of the Santander scheme.





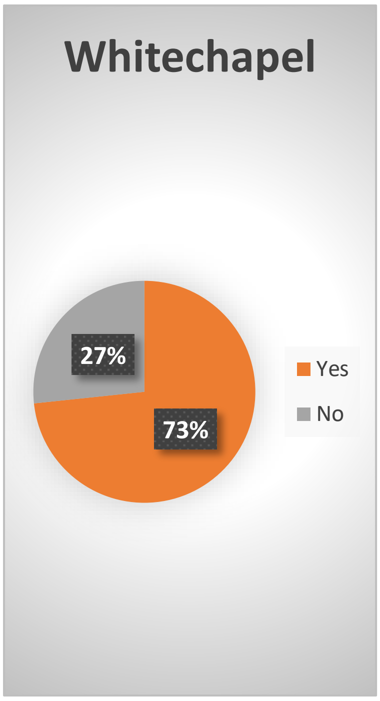
5.2 Borough specific price elasticity

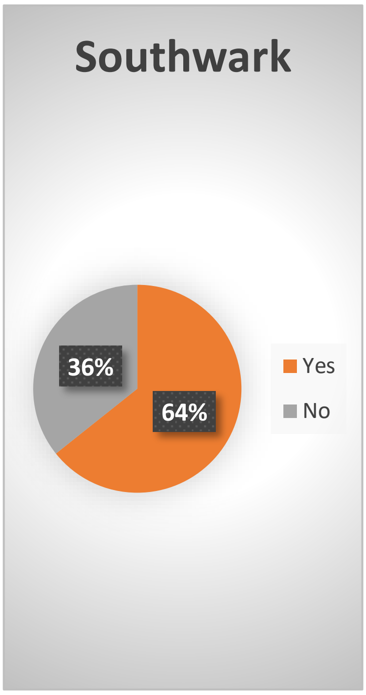


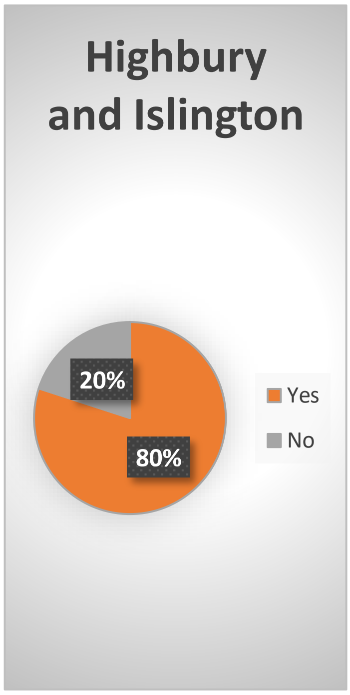
Examining price elasticity across the boroughs analysed, we can see that E-bikes' inelasticity is also consistent across boroughs, but most pronounced in wealthy boroughs such as Westminster and Highbury and Islington. It's clear that users of E-bikes receive more than just travel benefits and the basic service they would receive from transport alternatives.

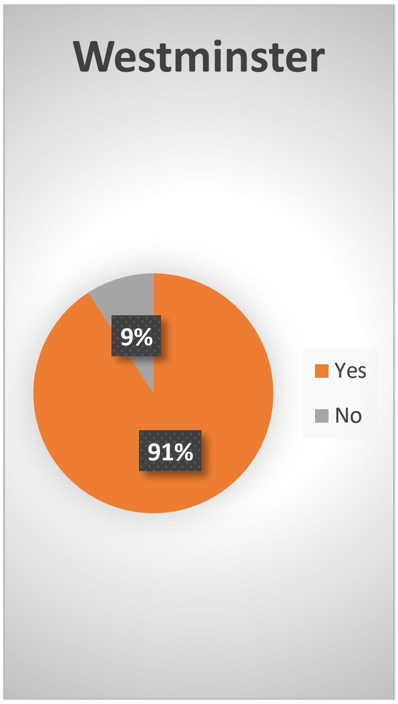
E-bike users also receive intangible benefits such as exercise which they value greater or at least as much as the current price of regular transportation. This further indicates that those who use the rental dockless E-bike market are not basic consumers but actually purchasing luxury goods which they are willing to pay above typical transport costs.

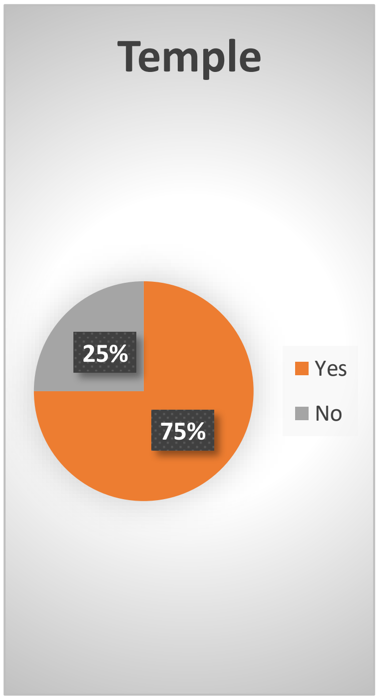
Question: In the price of E-bikes increases to the same as other public transport, would you still cycle as much





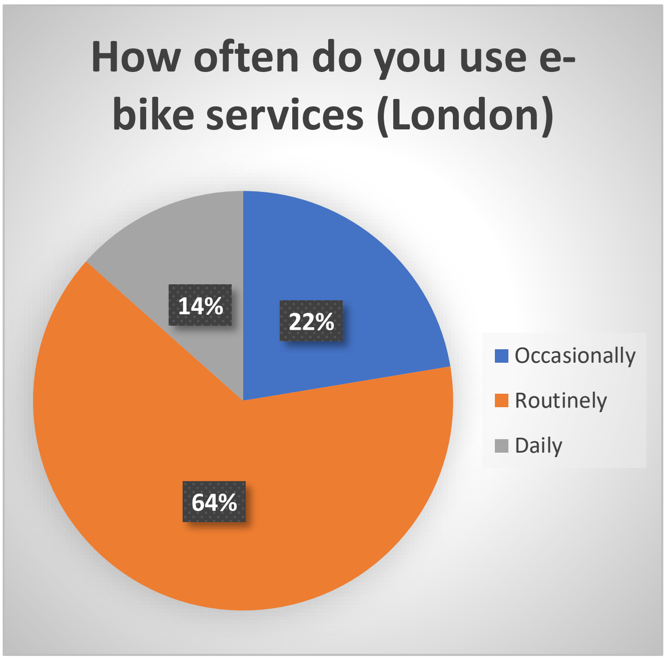






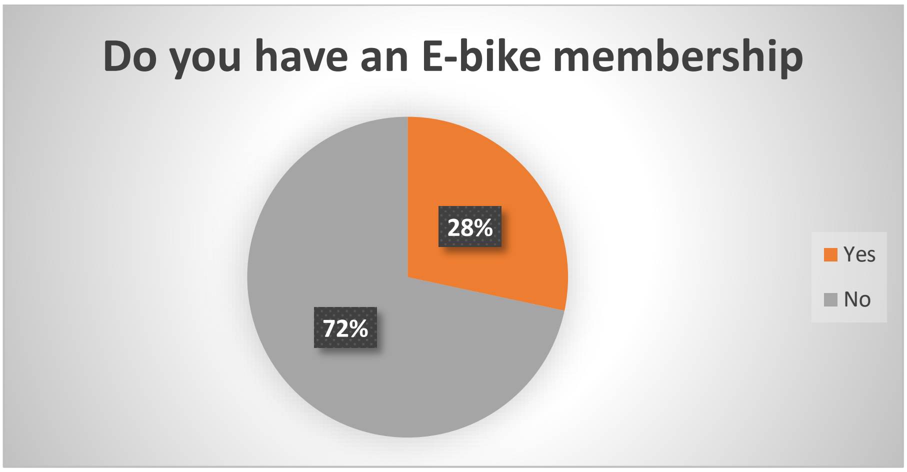
5.3 Type of user

Through our survey we also examined what type of users availed of E-bike services. We asked whether E-bike users rented bikes only occasionally, or whether they had made micromobility a part of their transportation routine.



We found that 64% of users availed of E-bikes routinely and 22% daily.

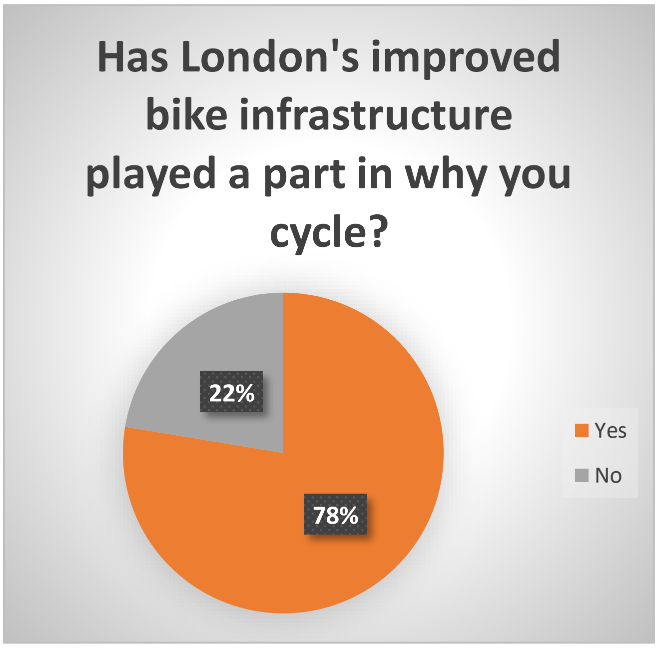
Such "habitual effects" can create a feedback loop where current demand is made more robust the more people take up cycling. These findings indicate that, unlike other cities dominated by tourism which can be a seasonal market, e-cyclists in London seem to be genuine, regular commuters. This has too important conations. First, it would indicate that demand should not suffer from major seasonal 'floods' or 'droughts'. Second, according to research from Morton (2020) routine E-bike users are much more likely to not be affected by poor weather conditions across a daily/weekly routine. Given London's notoriously rainy weather, this is positive information that demand will remain somewhat robust.



Despite the high percentage of "routine" E-bike users, one interesting fact was the lack of users with a single E-bike membership. It does not seem that there is significant brand loyalty or preference and competitive factors across E-bike companies seems to be quite weak. This is in contract to cities like Paris, where residents have a strong affiliation with the public bike service, velib. There may be opportunities for TfL to exploit this lack of competitive loyalty in developing a unified market and driving improved standards and pricing.

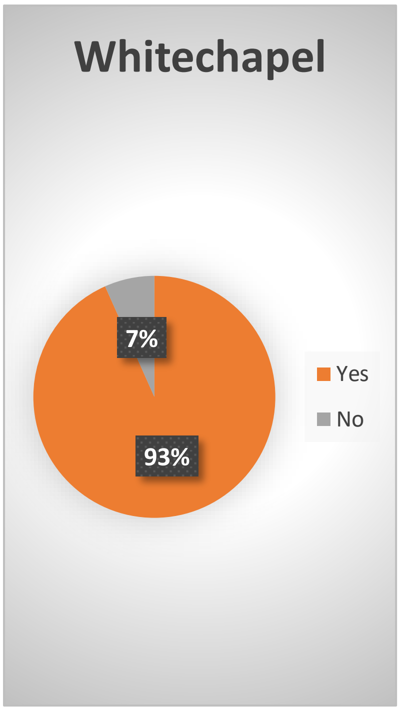
5.4 Infrastructure's effect on demand

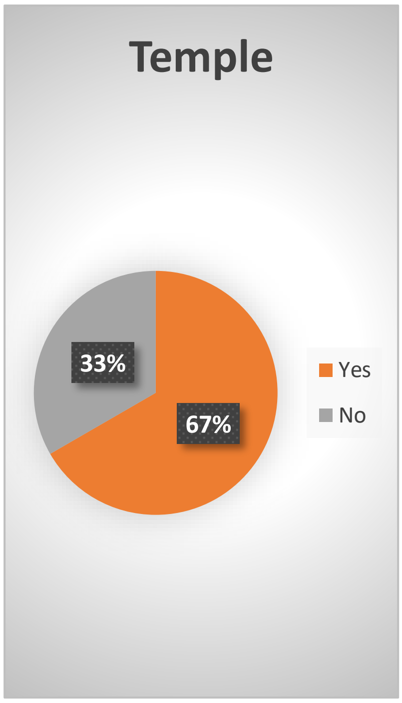
Our survey agrees with the large body of academic work regarding road infrastructure supply inducing demand (Schneider, 2018). 22% of those surveyed stated that improved infrastructure in their commute directly influenced their decision to take up cycling.

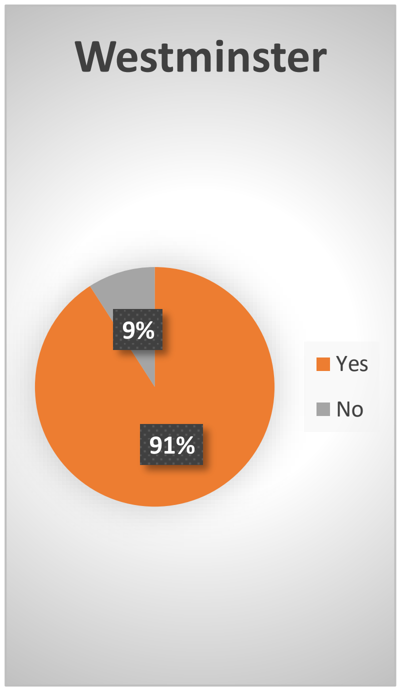


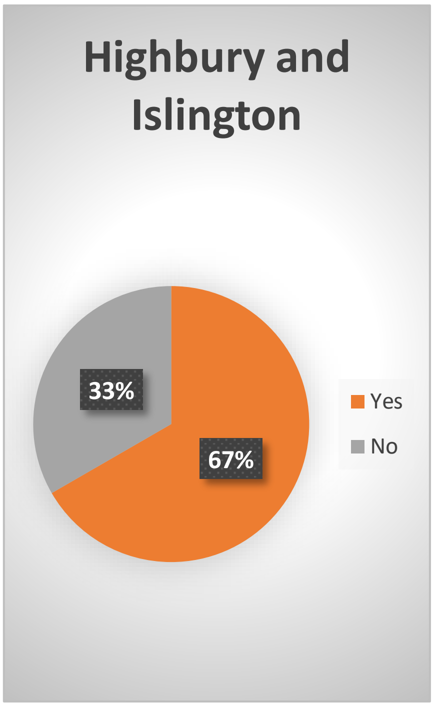
This is particularly pronounced when examining the borough-by-borough results, with over 91% of Westminster and Whitechapel agreeing cycling infrastructure incentivised them. These two areas have seen some of the most infrastructure investment in London, so the empirical evidence clearly correlates with the work done by the city here. Clearly the evidence suggests that to induce systemic demand and go beyond current market equilibrium, investing in cycling infrastructure is a surefire and long-term solution.

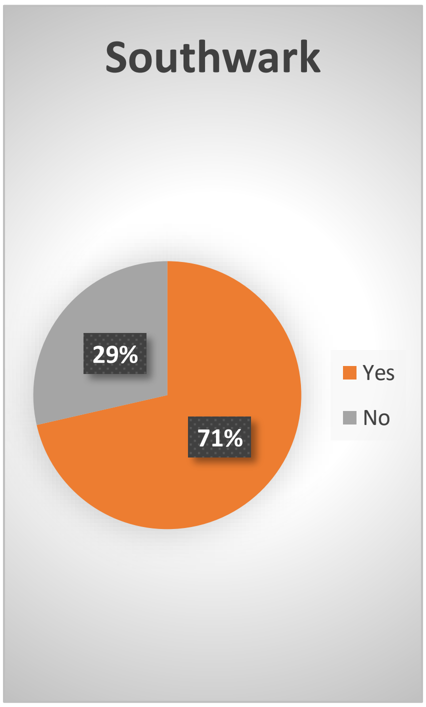
Question: Has London's improved bike infrastructure played a part in why you cycled





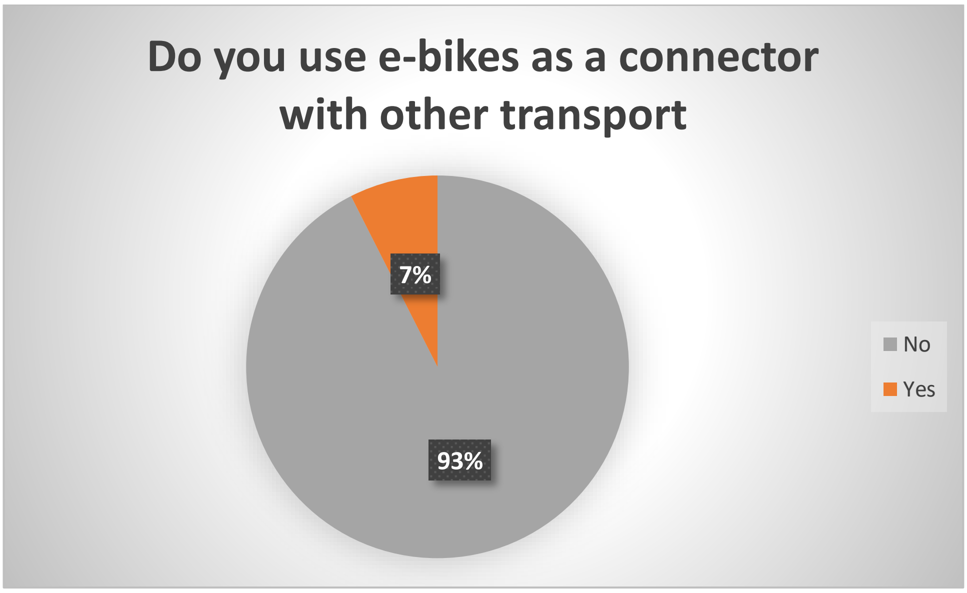






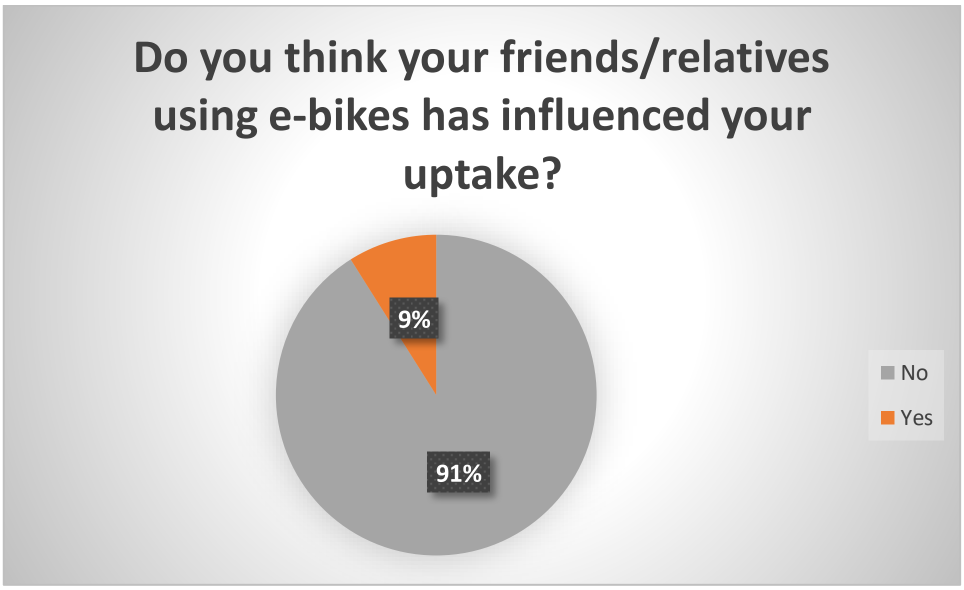
5.5 The "last mile"

We found weak evidence of the "last mile" theory, that being that micromobility can act as a connector between multiple transport hubs. This may not be the case in the outer boroughs.



5.6 Network effects

We found very weak evidence that network effects may play a role in London's e-bike market. This makes sense as one of the main drivers behind the "Network Effect" idea is the growth of micromobility tourism while, as discussed, a significant majority of E-bike users in London are regular commuters.



Our survey highlighted several factors about potential demand. First, demand is quite inelastic and it's conceivable that the E-bike market may be seen as a luxury good. Second, users tend to be routinely availing of E-bikes. This indicates that demand should be robust to temporal or climate/weather/seasonal effects. Third, infrastructure plays a large role in inducing new demand and should be examined as a way to increase future demand. Further study in this area may be needed.

5.7 TfL's questions regarding the forecasting model following our presentation.

Following our final presentation to TfL on our demand forecast, the team posed further questions as the how to model may elaborated to incorporate the following questions:

"How will market react to TfL's engagement on centralised operational standards?"

"How would we incorporate weather/seasonal effects on demand?"

"How will market react to TfL's engagement on centralised operational standards?"

Transport for London (TfL) has expressed interest in entering the shared E-bike market, prompting inquiries regarding the potential impact on existing providers, particularly Lime. Our study embarked on assessing Lime's operational efficiency and market response, utilizing available vehicle counts within the Lime app as a proxy for demand in various boroughs. This subsection outlines our findings and insights into the possible interplay between TfL's market entry and Lime's strategic positioning.

Central to our analysis was the presumption of Lime operating at an optimal level of efficiency, where the number of available E-bikes reflects genuine demand across locations. Our inability to establish a significant correlation between the sociodemographic characteristics of each borough and vehicle availability may suggest a deviation from presumed operational efficiency. It raises the question of whether Lime's current market performance aligns with an efficiently served demand.

Considering the above, it remains challenging to project how Lime would respond to TfL's entrance into the shared E-bike market. If Lime is currently operating profitably, the prospect of additional competition may not pose a strategic concern, and their market presence could remain unchanged. Conversely, should Lime be operating suboptimal and incurring losses, TfL's entry could compel a varied reaction, ranging from competitive restructuring to market withdrawal.

Another consideration is the potential for Lime to welcome TfL's involvement. TfL's objective to expand shared E-bike coverage and promote micromobility could catalyse overall market growth, benefiting all stakeholders within the ecosystem. In this scenario, Lime may find an advantageous opportunity in the rising tide of E-bike utilization, which could offset any competitive pressures introduced by TfL's presence.

In conclusion, the absence of concrete efficiency metrics and market size estimations renders Lime's anticipated reaction to TfL's market entry indeterminate. We would suggest a cautious approach to forecasting Lime's strategic response. Future market analyses, enriched with comprehensive financial and operational data, will be imperative in delineating a more definitive landscape of the shared E-bike market in London and the role of TfL within it.

"How would we incorporate weather/seasonal effects on demand?"

Transport for London (TfL) has inquired about the potential fluctuations in shared e-bicycle usage corresponding to changes in weather conditions, particularly during rainfall. Our response to this inquiry emphasizes the necessity for comprehensive data collection over an extended timeframe and the importance of detailed panel data inclusive of weather metrics.

To accurately forecast the demand for shared e-bicycles under varying meteorological scenarios, an extensive dataset spanning multiple seasons is imperative. London's weather, characterized by its variability, requires a longitudinal study to capture the full spectrum of weather patterns and their impact on transportation choices. The complexity of London's climate means that short-term data collection may not adequately represent the influence of weather on micromobility usage.

Our approach advocates for the integration of real-time weather conditions into the panel data collected via the Lime application. This enriched dataset should include precise measurements of weather variables at the time each data point is captured, particularly noting the presence and intensity of rain. The granularity of such data would enable us to apply econometric models to discern the sensitivity of shared e-bicycle demand to different weather conditions.

With a robust panel dataset in place, advanced statistical techniques can be employed to quantify the relationship between weather conditions and e-bicycle usage. This would not only provide insights into user behaviour during inclement weather but also allow for the development of predictive models that can anticipate demand shifts triggered by meteorological changes.

One key thing to note however is the type of users who currently use E-bikes in London. Our consumer sentiment analysis indicates that there are regular users, who have made cycling into their weekly or daily routine, and not tourists who are more susceptible to weather or seasonal affects.

In conclusion while our consumer sentiment indicates that demand may be robust to seasonal affects, a more comprehensive data collection strategy, encompassing detailed weather conditions, is crucial to test this. Such an approach would yield a nuanced understanding of the interplay between weather and micromobility, empowering TfL to anticipate demand fluctuations and adapt service provision accordingly. This proactive stance ensures service resilience and user satisfaction, regardless of London's capricious weather.

6. Policy options

6.1 Moving towards a new framework.

Following our quantitative and consumer sentiment analysis, we can see that there is sufficient demand for rental e-bikes in many of inner London and a significant portion of the suburban areas of London. This demand for the rental e-bike market is quite robust and is expected to increase, rather than decrease in the years ahead as cycling infrastructure improves.

However, a major caveat is that we haven't found holistic demand across the Zones 2 and 3, an aspect that particularly of interest to TfL. What is obvious is that the radius around London is not a homogonous level of population density, or indeed the other many factors that drive demand. This poses challenges and risks for TfL moving forward with the third-party providers, namely should it move forward in a market that may make a financial loss when all boroughs interested in the scheme are included.

Specifically, the heterogeneous demand poses questions as to what governance framework is optimal for the current E-bike rental market. Following a review of international best practices in e-bike contracting arrangements (see appendix), we concluded three possible ways forward for the E-bike rental market.

6.1.1 Option 1: Open market (status quo)

First, there is the potential to maintain the status quo as an open market to any and all third-party providers. In this scenario, TfL continues to have no formal arrangements with third party providers and these providers will only legally have to satisfy requirements for rules of the road, as well as insurance measures. Some boroughs may use their market power to enforce E-bike providers to avail of parking bays and create ad-hoc formal relationships as they currently do, however there will be no legal obligation for them to do so. For the majority of these third-party providers' relationship with cities, this is in fact the normal contracting arrangement. If the national legislation does not change, this relationship also remains the simplest, albeit least optimal immediate solution.

The major drawbacks of this scenario are threefold. First, TfL continues to have no control over operational and safety standards, a key strategic goal of the Mayor's Office. TfL will remain uninformed on what the main operational challenges are, as well as playing an active role in driving change to manage these challenges which third party providers may not prioritise. This contrasts staunchly with how TfL managed to drive operational and safety standards through the procurement of the E-bike market. This includes ensuring wheel size was of a certain safer size and that parking bays were utilised fully (TfL, 2023).

The second drawback is lack of guiding hand TfL may have in ensuring market provision is more efficient. In the open scheme, markets may remain over and undersupplied by multiple independent providers.

Finally, in the open scenario there is also an information cost in that TfL, which is generally expected to be aware of London's entire transportation infrastructure, continues to make decisions without the full working knowledge of a hugely disruptive industry in the rental E-bike market. Not fully understanding this market in its holistic decision making will likely cause challenges for TfL in the long run.

6.1.2 Option 2: Procurement

The second scenario involves moving towards a staggered set of procurement contracts, similar to those delivered through the E-scooter trial. This would involve TfL creating a formal application and procurement process with a range of market leaders. Successful permittees would have to comply with TfL conditions, namely around safety and operational standards as well as market supply. Permittees would be allowed to retain pricing ability and profits.

This option carries low financial risk and in many ways is the most attractive option for TfL's strategic goals. First, they would now be the main drivers and have final say over operational standards and processes – a key strategic goal as mentioned and one they have proven to deliver on before through the e-scooter programme over the course of several procurement stages where they focused on performance, over pricing. Second, they did this through no extra cost to those customers.

The second attraction is the data collection this staggered procurement process would allow. Through this, TfL would better understand the E-bike market and make better strategic decisions in both micromobility and transport as a whole, however the procurement process gives significant pricing flexibility to E-bike providers to ensure that market distortions from overcentralisation is minimised.

Finally, procurement is also attractive as TfL and Council boroughs would be able to standardise and receive funding in the way of charges on the E-bike providers in the same way as the E-scooter trial, as opposed to the competitive process between Boroughs currently.

The main drawback of this scenario largely relates to its potentially long roll out. Legislation to deliver such a procurement is still stalled in the Department of Transport, and even after that it will take time to formalise contracts with multiple third-party providers.

Another drawback is the lack of control TfL have over strategic economic goals – for example, this scenario largely retains the focus of E-bike market on those users who view it as a luxury service, however TfL may be interested in expanding the service or subsidising it for its environmental and social benefits.

6.1.3 Option 3: Controlled contract

Finally, the third option would be for TfL to pursue a much more market-controlled approach in the form of a public-private partnership. In this scenario, TfL may set or subsidise pricing and/or geographical service. This would allow TfL to deliver on strategic goals such as a wider range of boroughs serviced, which they could cross subsidise with the more profitable boroughs.

The major opportunity of this controlled contract is that TfL can essentially act on this very quickly and without approval from the national government. An additional positive is TfL's ability to prioritise strategic economic goals referring to the micromobility market – that being potentially lower prices and a greater number of users. Finally, if demand is sufficient, profits may be able to be retained in TfL and used to subsidise wider elements of the transport infrastructure.

While this scenario potentially carries the most reward, it also certainly carries the most financial and reputational risk. TfL could incur a large loss if demand is not sufficient and given the current underestimation of demand in certain boroughs this could be likely. Another drawback is that TfL would have to invest significant effort into understanding pricing and other revenue strategies. We have provided international best practices to this endeavour in the following section (6.4).

Table 5: Summary of E-bike operators and their price strategies in EU

Country / Company	E-bike Operator	Contract arrangement
International	Lime	Open (Multiple) Procurement (Paris, Berlin, London, Warsaw)
International	Dott	Open (Multiple), Procurement (Paris, Berlin, Spain)
International	Tier	Open (Multiple)
International	Human Forest	Open (London E-bikes), Procurement (London e-scooters)
Germany	Deutsche Bahn's Call a Bike	Procurement
	Nextbike	Contract
France	Vélib' Métropole (Paris)	Contract
	Smovengo(Lyon)	Contract
Netherlands	OV-fiets	Contract
	Swapfiets	Open
Denmark	Bycyklen (Copenhagen)	Procurement
	Donkey Republic	Open
Sweden	Styr & Ställ (Gothenburg)	Procurement
	Malmö by Bike	Contract
Belgium	BluE-bike	Contract
	Villo! (Brussels)	Contract
Spain	Bicing (Barcelona)	Contract
	Sevici (Seville)	Contract
Italy	BikeMi (Milan)	Contract
	Mobike	Procurement
Austria	Citybike Wien	Contract
Finland	CityBike Finland (Helsinki)	Procurement
Poland	Veturilo (Warsaw)	Procurement
Czech Republic	Rekola	Contract
Portugal	Gira (Lisbon)	Contract
Ireland	Dublinbikes	Contract
Luxembourg	Vel'oh	Contract
Slovakia	Slovnaft BAjk (Bratislava)	Contract
Hungary	MOL Bubi (Budapest)	Procurement
Greece	EasyBike	Contract

6.2 Revenue strategies for a controlled contract

According to the UK's National Travel Attitudes Study (NTAS) in 2021, 93% of those surveyed had never ridden an electric bicycle. However, at least 35% of those who had never ridden were interested in riding an electric bicycle if they had the chance. To make the most of the social benefits of electric bicycles, a strategy to drive this potential demand is needed. In our survey, current users are less sensitive to the price, but the price effect cannot be overlooked for potential users expected to be relatively low-income. Many studies have also pointed out that high prices for low-income people act as a barrier to using shared E-bikes (Zhang et al., 2023). Additionally, other concerns were raised, such as safety, bike infrastructures, and E-bike accessibility. To address these issues, this paper recommends three strategies:

1. **Pricing strategies models**: this includes of three new pricing strategies models: flexible price strategies, negative price in dockless bike sharing systems, and incentive strategies.
2. **E-bike friendly environment strategies**: this involves improvement infrastructure, road safety and the optimalization of number E-bike. The strategies aim to enhance the user experience and attract new E-bike users.
3. **Additional strategy**: of advertisement revenue.

   These strategic recommendations are aimed at creating a more user-friendly E-bike system and addressing the concerns highlighted by our survey respondents.

6.2.1 Flexible price strategies

Based on study Duz and Corno (2021), the paper compares two pricing strategies: a fixed price approach - a fixed cost per bicycle rental - and a flexible pricing approach – where user decide the level of electronic assistance and is charged accordingly (the model-based assessment on demand-respond measures by Bormann and Eser (2016)). The result shows that flexible pricing can establish a lower bound in terms of usage rate that guarantees economic sustainability and grant more degrees of freedom to the users. With these flexible pricing strategies, we can increase demand for using E-bike in non-bike-intense area and make it more affordable for users.

6.2.2 Negative prices in dockless bike sharing systems

To achieve last-mile strategies, some studies have suggested an innovative dynamic pricing scheme with negative price (Zhang et al., 2019): users will receive financial rewards from E-bike operator. The negative price scheme aims to provide not only dynamic price for users but also to address issues of E-bike oversupply in specific areas and create more E-bike available in undersupplied area. The results from initial promotion stage of negative pricing strategies illustrates that the approach can provide a solution for bike repositioning problem. Its performance is also better than fixed price strategies in several aspects, such as user attraction and fare revenue. In Zürich, Switzerland, users who decide to end their bookings in the designated area (called bonus zones) will be given an additional five minutes of booking time. In addition, users who finish their trips at charging stations and plug in charging cables will be given a five-minute bonus (Guidon et al., 2019). JUMP, the operator of dock-less shared E-bike scheme, has also incentivized users to return an e-bicycle with a low battery charge to the designated spots for recharging (Fukushige et al., 2022). Moreover, the negative pricing strategies could also help in mitigating congestion in car-oriented urban transport system development, aiming at a society cantered on alternative ways of transportation (Caggiani et al.,2017). Aligned with findings by Jin et.al, the use of dynamic negative pricing strategies (pickup and return rewards) can generate significant cost reductions in an operating environment with a high traffic intensity of bike return outside the central location and a high overall traffic intensity of bike returns relative to bike pickups in the system (Jin et al., 2022). This system can encourage dockless user to complete the last mile objective (Zhang et al., 2019).

6.3.3 Incentive pricing strategies: Off-peak price policy

Based on a dynamic pricing model that adjusts to users' demands and E-bike supply during peak hours or high-demand periods, implementing dynamic prices during off-peak hour can encourage bike redistribution, ensure supply availability, and maximize demand. The study of shared bicycle ridership data from Beijing, China, suggests that changes in price at various times of the day impact the usage of bicycling-sharing (Li et al., 2019). The key finding indicates that lowering the price during the specific hours increases both usage and profits. Moreover, these strategies can also maintain an efficient of distribution of E-bike cross the operating area (Zhang et al., 2019). Additionally, a case study in Madrid, Spain, on a shared electric bicycle scheme (BiciMad) illustrates that a strategy to integrate public transportation and electric bicycles - by reducing the membership subscription fee to yearly pass holders of public transportation - can offer price benefits, attract more users, and achieve last-mile strategy goal (Guidon et al., 2019; Julio et al., 2022)

6.3 E-bike friendly environment strategies.

According to the National Travel Attitudes Study (NTAS, 2023) in UK, off-road and segregate cycle paths (52%) and well-maintained road surface for cycling (51%) are much more encouraging factor for cycling than cheaper rental costs (17%) and better bicycle hire facilities (12%). In addition, safety issues are recognized as a major obstacle to E-bike use in areas where women's use of electric bicycles is lower than that of men (Melia & Bartle, 2021; Julio et al., 2022)

6.3.1 More infrastructure for E-bike

As many studies commonly point out that poor infrastructure hinders bicycle use (Melia & Bartle, 2021; Julio et al., 2022; Guidon et al., 2019), it is necessary to continuously expand bicycle lanes. People in the UK are also generally in a favorable position on the expansion of bicycle lanes regardless of whether they use them. According to the National Travel Attitudes Study (NTAS, 2021) in UK, even if the road space for cars was reduced, 64% of people supported creating dedicated cycle lanes in their area, while only 19% opposed it.

6.3.2 Safer Road conditions for E-bike

Maintaining safer road conditions is also an important factor for encouraging E-bike usage. Prioritizing proactive prevention on the road network is also important to encouraging E-bike usage. Motion sensor or GPS system equipped in the E-bike could yield useful data on potholes, falls and close-calls to map the places where crashes are most likely to happen (The international transport forum, 2020). Monitoring the damage to the road network is needed to quickly repair potholes and other damages that create risks for E-bike users (The international transport forum, 2020)

6.3.3 Optimal Supply of shared E-bike

Sufficient E-bikes shall be provided within walkable distance of the user's departure point. As a result of the analysis of empirical data in Zürich, Switzerland, the probability of users' selection increased as vehicle density increased, and this effect was particularly greater in dock-less mode (Reck et al., 2021). In the same context, the results of a study in Lyon, France, also showed that the average fleet size elasticity of demand was positive, although it was less than 1 (Manout et al., 2021). However, it is important to maintain an appropriate supply as studies commonly point out that the effect of increasing demand decreases as supply increases.

6.4 Additional strategy: Advertisement revenue

If shared E-bikes are used as a means of advertising, additional income can be generated along with E-bike rental. This can be used as a resource for the sustainable expansion of shared electric bicycles. E-bike baskets and bodies, as well as dedicated app screens, can all become tools for advertising, exposing advertisements not only to users but also to non-user citizens. Seoul, South Korea, which directly operates shared conventional bicycles, has allowed advertisements to from the end of 2022 to expand their scheme sustainably.

Example of an advertisement using shared bikes in South Korea

7. Conclusion and areas of future study

London's E-bike rental market remains a promising opportunity to deliver on the growing urban transport demand in a sustainable, cost efficient and pollutant-free way. Our analysis which sought to forecast demand in the E-bike rental market shows that there is a significant demand to currently sustain a market in inner London and several boroughs in the inner suburban areas (zones 2 and 3). We believe this demand to be robust and unlikely to drop in coming years if prices increase. Indeed, we believe this demand has the potential to systemically increase if current investment in cycling infrastructure is maintained in London.

According to our analysis, however, there also remains risks for TfL in moving forward. Namely, the lack of concrete data and market understanding available to the third-party providers. Not having access to this understanding puts TfL at a fundamental disadvantage when negotiating a long term, market-controlled contract. This may lead to perverse incentives on the part of the third-party providers and potential for cost spiralling or inefficient service provision is clear. It is for this reason that we believe the most prudent and successful option in the long run will be pursue a procurement process similar to that of TfL's staggered e-scooter trials. This will be a useful process to better understand the E-bike market in its entirety. It is also important to note that this scenario doesn't preclude TfL from later opting into a controlled contract or providing its own expanded E-bike service, either to service the market currently held by third party providers, or given the indication that E-bikes may be a luxury good, providing a new market in a budget E-bike rental service.

Future areas of study may look to quantify current measured demand in terms of revenue in each borough and examine whether the profit margins that exist in the high demand boroughs may be significant enough to offset the losses in less profitable boroughs. The parameter to set could either to have an aggregate profit margin to reinvest in the wider transport infrastructure or simply to ensure a future micromobility was at least cost neutral. Other areas of study may include measuring the externality benefits of TfL incentivising greater micromobility and the case for a tax funded subsidy on the basis of social or environmental benefits.

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Terms of Reference

Having met with Transport for London's (TFL) strategic finance and innovation teams three times over the course of the year we discussed their main interests and needs in micromobility.

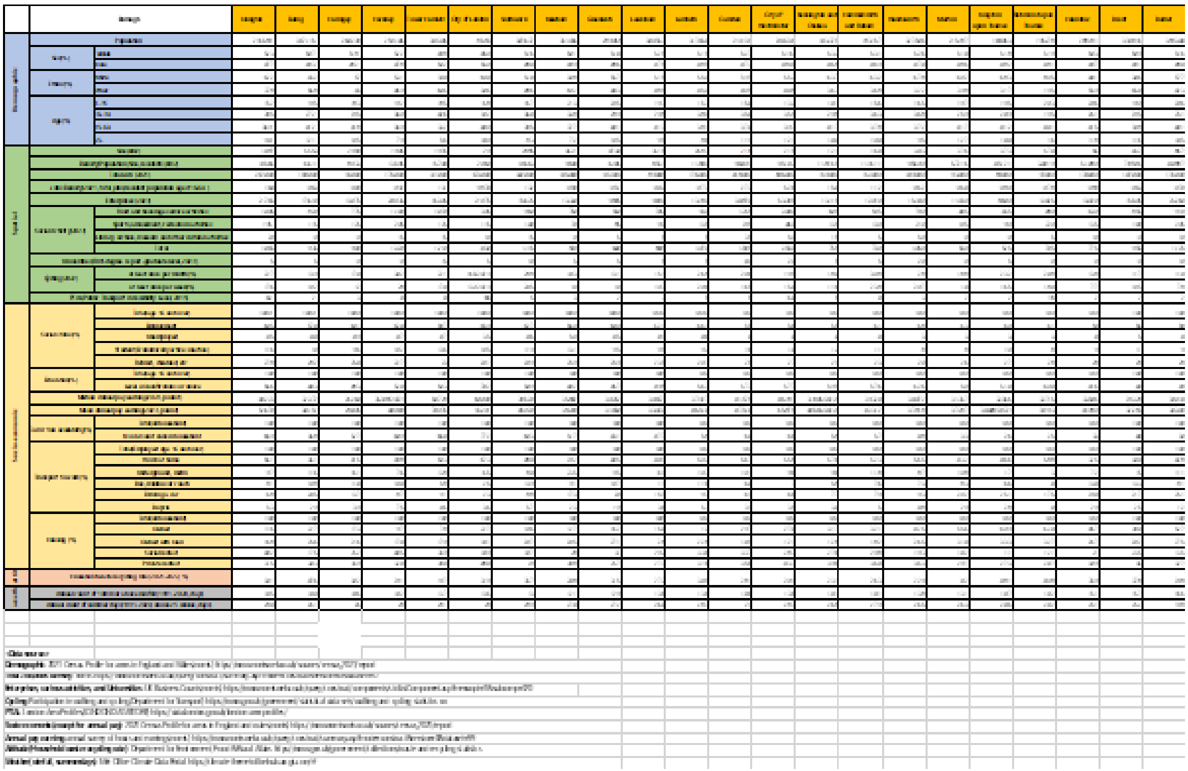
We gathered that TFL are keen to explore ways to formalize and better coordinate their relationship with dockless, third party e-bike service providers. In response, we suggested ways in which TFL could move forward. Our proposals varied from TFL providing a fully public service, to contracting the service to a select number of third-party providers, or work to better coordinate Micromobility's regulatory framework to organize the delivery and performance of the service in line with TFL's goals.

We also discussed the institutional governance of TFL's operating mandate. Namely how it is under the purview of the Greater London Authority, but also interacts with local boroughs who currently agree the contracts with private e-bike providers, and the national government, who provides regulation.

There are several areas for which TFL requires further research to move forward. TFL is unsure of the levels of demand for e-bikes across the Greater London Area, and how that demand changes based on price fluctuations or infrastructure investment. For this reason, we agreed with TFL that we would undergo research to provide a demand model for e-bikes to explore these questions.

Appendix

Appendix 1. Distribution of demand factors by 22 boroughs in London



Appendix 2: Contract comparison for e-bike market framework

Country / Company	E-Bike Operator	Contract arrangement
International	Lime	Open (Multiple) Procurement (Paris, Berlin, London, Warsaw)
International	Dott	Open (Multiple), Procurement (Paris, Berlin, Spain)
International	Tier	Open (Multiple)
International	Human Forest	Open (London e-bikes), Procurement (London e-scooters)
Germany	Deutsche Bahn's Call a Bike	Procurement
	Nextbike	Contract
France	Vélib' Métropole (Paris)	Contract
	Smovengo (Lyon)	Contract
Netherlands	OV-fiets	Contract
	Swapfiets	Open
Denmark	Bycyklen (Copenhagen)	Procurement
	Donkey Republic	Open
Sweden	Styr & Ställ (Gothenburg)	Procurement
	Malmö by Bike	Contract
Belgium	Blue-bike	Contract
	Villo! (Brussels)	Contract
Spain	Bicing (Barcelona)	Contract
	Sevici (Seville)	Contract
Italy	BikeMi (Milan)	Contract
	Mobike	Procurement
Austria	Citybike Wien	Contract
Finland	CityBike Finland (Helsinki)	Procurement
Poland	Veturilo (Warsaw)	Procurement
Czech Republic	Rekola	Contract
Portugal	Gira (Lisbon)	Contract
Ireland	Dublinbikes	Contract
Luxembourg	Vel'oh	Contract
Slovakia	Slovnaft BAjk (Bratislava)	Contract
Hungary	MOL Bubi (Budapest)	Procurement
Greece	EasyBike	Contract

Appendix 3: Original letter of interest from TfL

MICROMOBILITY - AN INTRIGUING POLICY AREA

TfL uses the phrase 'micromobility to cover e-bike and e-scooter hire arrangements. This is an active area of policy development now and contains a range of policy problems. New technologies can be disruptive to existing arrangements, and the arrival of global companies (like Lime or Human Forest) presents opportunities and threats to cities across the world.

- London has an existing cycle hire scheme based on conventional bikes and a docking structure. This operates within central London, is contracted out and requires a small subsidy.
- In London, the UK national government sets the legislative framework; the regional government (the Mayor and TfL) holds the local transport budget, expects to control regulation, and owns the existing scheme; the 33 boroughs control parking bays and pavements. The national Government expects to bring forward targeted legislation but it is unsure when this will happen
- Owning an e-scooter is legal, but it is not legal to ride them either on the road or on a pavement. Enforcement is proving a problem. There is an exemption where e-scooters are hired through an approved scheme and Tf is running an experiment here. E-bikes are legal on the road and legal to own.
- There have been a number of private sector entrants into the e-bike and e-scooter market. In some cases they have agreements with boroughs over parking bays and pay a city charge for those. In many cases vehicles are simply left on pavements where they can prove an obstacle to pedestrians.
- TfL has some information about costs for e-bike hire schemes. The bulk of costs are operational and relate to managing and moving the fleet of bikes. Capital costs and parking charges represent a smaller element.
- There is very little information on demand and little research here available to TfL. Modelling so far has tended to look at supply, with densities varying in different parts of the city, and then at likely utilisation. TfL also has very limited information on the social/environmental benefits of micromobility, so it is harder to build a justification for market intervention or subsidy.
- If things go right, micromobility could provide an attractive complement to public transport managing the last mile' from rail stations and providing individual flexibility. If things go wrong, there could be worsening parking problems in an unregulated market and/or strong pressure for significant public sector provision with subsidy and fare control.

Current questions for TfL include:

- What should its role be? Just a safety regulator? Or possibly economic regulation as well, perhaps restricting entry to the London market to a limited number of firms? Or like the docked scheme in the centre is there a role for TfL to intervene and subsidise provision?
- What's the likely geographical coverage from the market? Early modelling suggests that private firms will want to operate in dense areas (central and inner London) but not in outer London. Does this matter?
- The same point about density may mean that boroughs in inner London can recover their costs for parking bays from operators but other boroughs may not be able to.

Other cities around the world face similar issues. There seems to be little shared information. Many areas of transport policy involve major investment schemes which take years to deliver - but ends and means are relatively well understood. Micromobility is by contrast one where ends and means are still fluid and where a new market is developing day by day. There is both challenge and immediacy for policymakers.

Appendix 3: Sentiment Analysis Survey

E-Bike Survey

E-bike current usage

The following questions relate to how much you currently use e-bike sharing services. Your information will remain anonymous. Thank you.

How often do you use e-bike services?

☐ Never ☐ Occasionally ☐ Routinely ☐ daily

How long are your trips?

☐ <15m ☐ 15m ☐ 30m ☐ 45m ☐ 45m <

Do you use e-bike services as a connector with other public transport or cars (eg tube, bus, overground)?

☐ No ☐ Yes (public transport) ☐ Yes (cars)

Why do you use e-bike services? Please number in order of most important (1 = most important)

Environmental reasons ☐

Price ☐

Exercise/lifestyle ☐

Apps are easy to use ☐

My friends use them regularly ☐

Other (please specify) ☐

Do you have an e-bike membership?

☐ Yes (Lime) ☐ Yes (Dott) ☐ Yes (HumanForest) ☐ No

E-Bike Survey

Factors that determine your usage

Is price a large factor in why you cycle over other forms of public transport?

☐ Yes ☐ no

A. At what level would a price increase impact your e-bike usage?

☐ 2% ☐ 5% ☐ 10% ☐ 50% ☐ 100% (double)

B. If the price of e-bikes increased to the same as other public transport would you still cycle as much?

☐ Yes ☐ No ☐ Maybe

C. Have you felt cost of living increases in e-bike or other transport costs?

☐ Yes (e-bikes) ☐ Yes (other transport) ☐ No

D. If you have an e-bike membership, what were the main factors in your choice? Please number.

Competitive price ☐

Availability of bikes in my area ☐

Quality of bikes ☐

Company environmental focus ☐

Other (please specify) ☐

Has London's improved bike infrastructure played a part in why you cycle?

☐ Yes ☐ no

Do your friends/relatives use e-bike services?

☐ Yes ☐ no

Do you think your friends/relatives using e-bikes has influenced your uptake?

☐ Yes ☐ no

Would you be interested in joint e-bike accounts?

☐ Yes ☐ No

Are there any other factors that would make you cycle more/less? Please specify.

E-Bike Survey

General questions (your information will remain anonymous)

What is your email? (you will not be emailed)

Age.

☐ 18-24 ☐ 25-34 ☐ 35-45 ☐ 45-55 ☐ 55-65 ☐ 65+

Gender.

☐ Male ☐ Female ☐ Non-binary ☐ Prefer not to say

How would you describe where you live?

- Inner city (zone 1) ☐
- Inner London (zone 2-3) ☐
- Suburban/commuter (zone 3-4) ☐
- Outer London/rural (zone 5+) ☐

What is your dominant mode of transport?

- Public transport ☐
- Walking ☐
- Cycling ☐
- Car ☐
- Other ☐

What is your current occupation?

Who do you work for?

What is your main professional field or area of interest?

Thank you!

E-Bike Survey