Department of Mechanical and Aerospace Engineering

An Examination of the Process Required to Determine Electric Scooter Usage and their Electrical Load Demand

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Chapter 1 – Abstract

The transport industry is a major contributor of carbon dioxide (CO_2) and greenhouse gas (GHG) emissions in the EU. As a signatory to the Paris Climate Agreement, the UK government is attempting to reduce CO_2 and GHG emissions. The UK government is faced with introducing new transport policies to achieve this goal. Personal Light Electric Vehicles (PLEVs) such as skateboards (e-skateboards) and standing scooters (e-scooters) are a relatively new form of transport that have become popular in the Western world. Current legislation in the UK prohibits these transport methods from access to public roads and pathways. A review of the law in the UK is ongoing and it is expected that e-scooters and e-skateboards will become common transport methods in urban environments.

As a relatively new mode of transport, there is no previous academic research on how the electrification of scooters impacts energy systems. New electrical transport loads could lead to issues with power distribution, power quality, voltage imbalances and balancing of the National Grid. This paper focuses on the process required to determine the extent of the use of e-scooters in an urban environment and what impact the demand for e-scooters causes to the grid. The process includes a review of literature and how it applies to e-scooters, the development of a model that first determines demand for e-scooters as a transport method and then the electrical load required to charge them, the completion of sensitivity analysis on the model and the development of a randomised controlled trial to gather data.

The model developed was for a hypothetical town called “E-Village”. The model integrated factors such as town characteristics, weather and consumer behaviour to generate a demand for e-scooters as a form of transport. Once the demand was ascertained, the electrical load was calculated based on battery size and the range of distance for the e-scooter. A simulation where 10% of the population used e-scooters for commuting and demand was 100% resulted in a total energy demand of ~1.5 MWh, a peak load of ~140 kW and a ~2.4% increase in the E-Village domestic electricity requirement.

Chapter 2 – Table of Contents

2.1 Table of Figures

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2.3 List of Abbreviations

BEV – Battery Electric Vehicle

BLDC – Brushless Direct Current

CO_2 – Carbon Dioxide

DoD – Depth of Discharge

DSM – Demand Side Management

DVLA – Driver and Vehicle License Agency

EV – Electric Vehicle

GHG – Greenhouse Gases

ICE – Internal Combustion Engine

LEV – Light Electric Vehicle

MDS – Maximum Design Speed

NO_x – Nitrous Oxide

OFGEM – Office of Gas and Electricity Markets

PBC – Perceived Behaviour Control

PHEV – Plug-in Hybrid Electric Vehicle

PIV – Plug-in Electric Vehicle

PLEV – Personal Light Electric Vehicle

PM – Permanent Magnet

PV – Photovoltaic

QR – Quick Response

RCT – Randomised Controlled Trial

RES – Renewable Energy System,

SoC – State of Charge

SoH – State of Health

TPB – Theory of Planned Behviour

V2G – Vehicle to Grid.

Chapter 3 – Acknowledgments

I would first like to thank Professor Joe Clarke, Dr Paul Tuohy and Dr Daniel Costola for their input and guidance during the initial research phase of this paper. Their input was greatly appreciated. I would also like to thank all my class colleagues for making this course so enjoyable. Lastly, to my family, friends and dog, thank you.

Chapter 4 – Introduction

Over recent years there has been a great deal of attention given to climate change and the factors that contribute to temperature increases and sea level rises. International policy, such as the Paris Climate Accord or “Paris Agreement”, has been legislated and designed to focus on carbon dioxide (CO_2) and greenhouse gas (GHG) emissions in order to limit temperature rises to 1.5 °C of pre-industrial levels (Bauer & Menrad, 2019). Because of this, both the United Kingdom and Scottish governments have focused on reducing their CO_2 and GHG emissions in line with the Paris Agreement.

In the European Union, transport is the largest energy consumer and accounts for 27% of GHG emissions in the EU-28 (Hill, et al., 2019) (Letnik, et al., 2018). In Scotland, 37% of GHG emitted in the country were associated with transport (Transport Scotland, 2018). Typically, in Scotland and the rest of the UK, vehicles are powered by conventional Internal Combustion Engines (ICE). ICEs produce particulates and pollutants such as nitrous oxide (NO_x) and contribute to poor air quality and a decrease in the health of the general public. In the UK, deaths associated with pollution are the second highest avoidable type of death (Business, Energy and Industrial Strategy Committee, 2018).

The UK government has embarked on making road transport more environmentally friendly. Ultra-low carbon vehicles including electric vehicles (EVs), have been promoted as well as more sustainable modes of transport such as cycling (Hill, et al., 2019) (Department for Transport (DfT), 2013). Despite this, in 2017 new passenger vehicles registered in the EU saw an average increase of 0.4 gCO_2/km to 118.5 gCO_2/km when compared with 2016. Having said this, newly registered vehicles have seen a decrease overall of 27.2 g CO_2/km since 2009 (European Environment Agency, 2018). This can be seen in Figure 1.

By 2020 newly registered vehicles must have emissions of 95 g CO_2/km with an aim to reduce this to 65 g CO_2/km by 2030 (Hill, et al., 2019). Although this shows progress, the UK government may be forced to radically shift how we travel in order to reduce CO_2 and GHG emissions in line with their declared targets in the Paris Agreement.

Average CO2 emissions (gCO2/km) from new passenger cars, by fuel

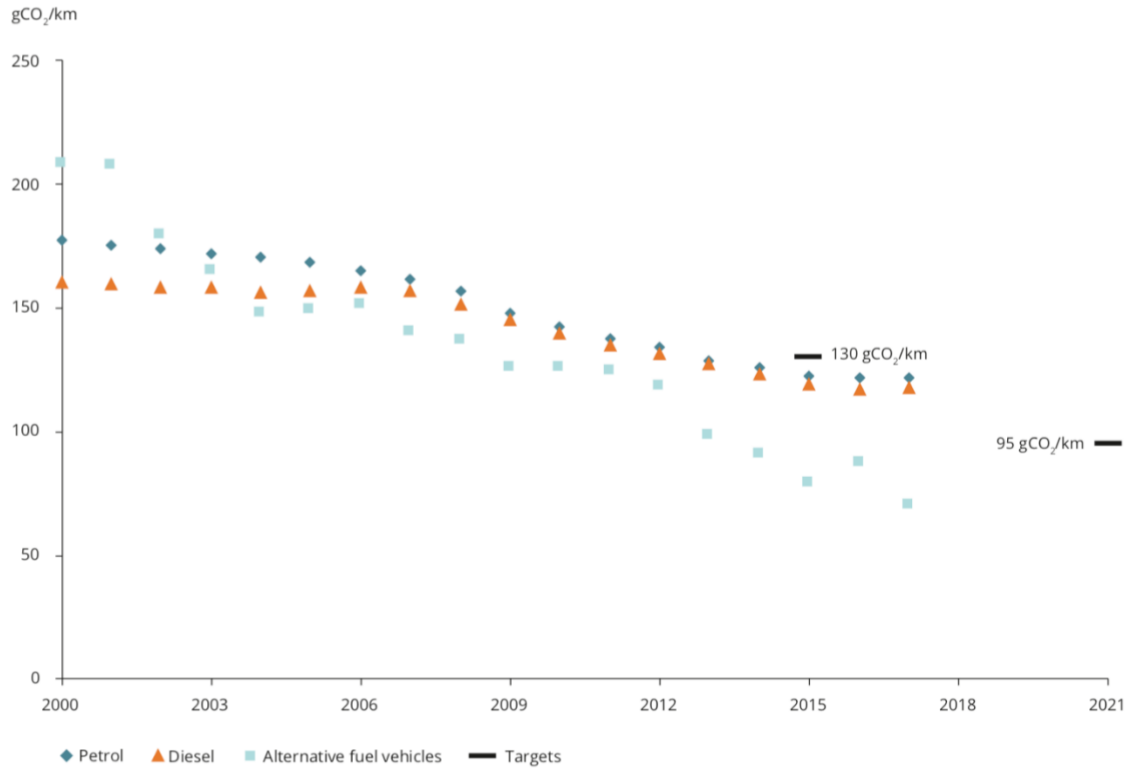


Figure 1: Taken from European Environment Agency (2018) showing average gCO2/km of newly registered vehicles in the EU.

In urban environments globally, transport causes congestion and is arguably a key issue with the transport system in its current form (Metz, 2018). Congestion contributes to a decrease in air quality in densely populated areas of cities and has economic consequences for owners of vehicles and the GDP of countries (Metz, 2018) (Barcellos de Paula & Marins, 2018). The negative impact of congestion and ICEs on the environment, health and economies of countries highlights the need for drastic change in the transport system.

The UK government has recently been reviewing urban transport. In March 2019, the Department of Transport released a report stating that new technologies such as electric micro-scooters and electric skateboards (defined below) would be reviewed for their potential to help improve air quality, reduce CO_2 emissions and ease congestion in urban environments. The use of such transport methods has become increasingly popular in the United States and western Europe.

4.1 Background

Transport is undergoing a period of rapid technological evolution, particularly in urban environments. As described above, EVs are becoming increasingly popular as part of a drive to reduce CO_2 emissions and improve air quality. In the UK, battery electric vehicles (BEVs) saw a 60.3% increase in new vehicle registrations from 2018 to 2019 (The Society of Motor Manufacturers and Traders , 2019). In addition to EVs, consumers are exposed to many types of transport services in major cities due to a paradigm shift in transport and mobile phone technology (McKenzie, 2019). Ride-sharing services, shared bicycle schemes and shared electric scooter schemes have become increasingly popular as smartphone technology simplifies the process of travelling around cities.

Table 1: Adapted from The Society of Motor Manufacturers and Traders (2019), showing: The number of registered vehicles in the UK based on fuel type in 2019 and 2018 and the change in percentage. Where: BEV - Battery Electric Vehicle; PHEV - Plug-in Hybrid Vehicle; HEV - Hybrid Electric Vehicle; MHEV - Mild Hybrid Electric Vehicle.

Vehicle Type	2019	2018	Change (%)
Diesel	344,877	428,006	-19.4
Petrol	840,436	812,295	3.5
BEV	11,975	7,470	60.3
PHEV	14,923	21,200	-29.6
HEV	49,217	42,009	17.2
MHEV Diesel	44,293	702	511.5
MHEV Petrol	3,524	2,312	52.4

The general public is becoming increasingly aware of the consequences ICEs have on air quality in cities and their overall impact to the global environment. Therefore, consumers are increasingly becoming more willing to change the way in which they travel for commuter and recreational journeys in order to be environmentally conscious. This was reflected in a recent study in Finland where previously nonelectrified modes of transport such as bicycles, scooters and skateboards are becoming popular electric travel methods for “last mile” journeys (Hyvonen, et al., 2016). In this paper a “last mile” journey is defined as a short distance journey that could be completed by either foot or a light transport mechanism (e.g. skateboard). These modes of transports are known as Personal Light Electric Vehicles (PLEVs) (defined below)

(Hyvonen, et al., 2016). As the popularity of EVs continues to grow, one could safely assume that so too will the use of PLEVs. During 2016, China produced 34 million e-bikes contributing to the already 200 million in circulation (Garche & Moseley, 2017).

PLEVs have several advantages in urban environments. PLEVs provide relatively quick modes of transport at a relatively affordable cost. Since they are electric, they do not emit particulates and pollutants, helping to increase air quality. In addition, they may help to alleviate congestion by taking cars and buses off the road. Conversely, questions have risen about the safety of the PLEVs (Trivedi , et al., 2019) (Allem & Majmundar, 2019). There is also the issue of city planning and how PLEVs can be incorporated on roads and pavements. In addition to these issues, PLEVs create a new stochastic electrical load on the National Grid. Although there has been an uptake in these technologies, they remain a minor contributor to the way in which we travel. However, it is expected that this will change in future and understanding the demand they could dictate is important for urban planning purposes.

Understanding how people choose to travel in urban environments is key to determining what electrical load PLEVs may have on the UK National Grid. It is likely, due to government legislation, that future transport methods will result in a large increase in electricity demand to power electric transport. Previous research has focused on BEVs, plug-in hybrid electric vehicles (PHEV’s) and plug-in electric vehicles (PIV’s) (Munkhammar, et al., 2015) (Brand, et al., 2017). In addition, studies have been looking into implementing demand-side management (DSM) for charging electric vehicles using domestic renewable energy systems and smart grids (Brand, et al., 2017).

Despite the changes in transport and mobile phone technology mentioned previously, and the increase in popularity of e-scooters and skateboards in the US and western Europe, there is no research or governmental reports examining the potential impact that PLEV transport loads have on a grid. The question of the impact that these modes of transport will have on the grid is a complex issue that is affected by many factors.

4.2 Aim and Motivation

A key motivation for this paper is the lack of academic research or governmental reports on what impact the newly electrified PLEV loads have (or could have) on the UK National Grid. Understanding the load is essential for quality of power, grid size and DSM, to name just a few. As discussed in section 5.1.1, in the UK, PLEVs are currently banned from public roads and footpaths. However, the report released by the Department of Transport in March 2019 stated that the legality of e-scooters and other PLEVs on roads and pavements would be reviewed. In Santa Monica, US, dock-less e-scooters were dumped on streets without any local authority consent or planning (Trivedi , et al., 2019). This led to animosity between residents and scooter companies such as Bird and Lime. Setting aside the city planning and safety issues that were created by the apparent spontaneous release of e-scooters, there was no understanding of what electrical load e-scooters would demand from the grid and if this would impact the grid's power quality and balancing.

As mentioned above, understanding the use of transport methods is complex and is based on various factors that are difficult to understand due to their stochastic nature. A review of these factors can be found in section 5.5. Understanding the demand for a particular transport type is key to understanding the electrical load associated with a transport type. There are many different types of PLEVs, however this paper focuses specifically on electric scooters (e-scooters).

The aim of this paper is to develop a process that could be followed to critically evaluate the impact that e-scooters could have on the UK National Grid if their legal status is changed. This will be based on their potential future usage and resulting electrical load.

4.3 Project Objectives

This paper seeks to critically evaluate the process required to determine the demand and therefore the electrical load that PLEVs could have on the UK National Grid. This process will include:

- A review of literature to identify key factors that affect the use of e-scooters.

- Examination of the complex nature of factors and how they are dependent on one another will be completed.
- A simple e-scooter demand model will be created using Excel.
- The creation of a framework for a Randomised Controlled Trial (RCT).

4.4 Scope

There are many types of PLEVs already in use in the US, Europe, Asia, South America and Australia. A review of the different types of PLEVs is conducted in section 5.1. As mentioned above (section 4.2), this paper focuses on the use of e-scooters as they are the most likely PLEV to be introduced to UK roads and pathways because of their popularity in the United States and western Europe.

E-scooters are a relatively new concept. The technology involved is constantly evolving; battery and motor size are key components that companies are constantly competing with one another to improve. A literature review of the batteries and motors is conducted; however, the potential improvements are not. This is due to the commercial secrecy of companies regarding new technologies.

The simple model created in Excel will focus on e-scooter usage and the electrical load demand required for a theoretical town. The impact on theoretical grid size and peak demand is considered. The impact that this load will have on power quality, distribution and DSM is not considered.

Due to the complex stochastic nature of many factors influencing transport method behavior, the model will focus primarily on town characteristics, environmental concerns and weather. However, as mentioned previously, all identifiable factors are reviewed. They will be incorporated in the examination of factors and how they are dependent on one another.

4.5 Methodology

The process of determining the electrical loads of e-scooters can be separated into the following steps (a diagram is provided in Figure 2):

- Review existing literature on PLEVs and other transport methods.
- Identify factors that affect the use of e-scooters in urban environments.
- Integrate key factors into an Excel model to determine the impact on e-scooter usage and electrical load demand.
- Complete sensitivity analysis to analyse the model.
- Based on literature and model determine a structure for a randomised field trial.

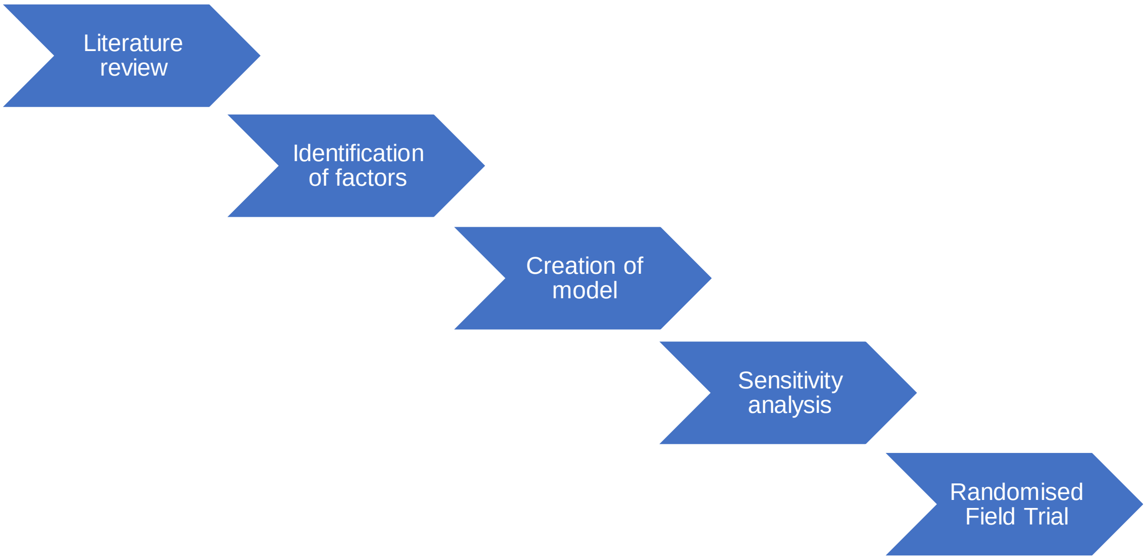


Figure 2: Showing the methodology conducted in this paper.

Chapter 5 – Literature Review

5.1 Introducing Personal Light Electric Vehicles (PLEVs)

In recent years rechargeable batteries and motors have become more technologically advanced and costs have reduced. This has resulted in a trend of electrifying transport for shorter journeys that previously could have not been completed by an electrified transport method (e.g. bicycles, micro-scooters and skateboards). In addition to the adaptation of old transport methods new transport concepts, such as "hoverboards" like the type produced by Segway, are being commercially produced. The developments in battery and motor technology, and the commercial production of hoverboards and Segways, has driven change in how people travel on a daily basis (Hyvonen, et al., 2016). The current fashionable trend of PLEVs suggests that their popularity, at least in the short term, will only continue to grow.

Figure 3: A stock image of a hoverboard in use.

Figure 4: A stock image of an electric skateboard, its motor and battery.

From an initial review of literature there appears to be no agreement on the definition of PLEVs across different academic papers or governments. In Germany, PLEVs must have handlebars and a standing platform (Federal Ministry of Transport and Digital Infrastructure, 2019). In addition to this they have a maximum design speed (MDS) of 20 kph (12.4 mph) and should be insured. In the UK, it is less clear what is established as a PLEV as they are unusable due to their current illegality on public roads and pathways. For the purpose of this paper a PLEV has been defined as a light vehicle (e.g. bicycle, micro-scooter or skateboard) that has a motor that is powered by a battery. A PLEV has an MDS of 15 mph and other characteristics are defined in Table 2.

Table 2: Showing the defined characteristics that a PLEV has for the purpose of this paper.

Speed	**Wheels**	**Battery**	**Motor**
≤ 15 mph	1, 2, 3 or 4	Yes	Yes

The current range and speeds of PLEVs means that they are unable to be used for longer journeys. However, as mentioned briefly in section 4.1, PLEVs could have an ability to reduce congestion in urban environments by providing relatively quick transport for “last mile” journeys. In comparison to cars they are relatively inexpensive to rent or buy. It could be argued that PLEVs may play an important role in improving air quality as they could reduce the number of ICE cars in cities.

While the advantages laid out above in this and previous sections show PLEVs are of benefit to society there are undoubtably negative consequences. An example may be that the batteries required for PLEVs will require the mining of several different elements leading to environmental consequences. If combined with the increase in minerals required for the batteries in BEVs there may be significant impacts. In conjunction with environmental consequences, there are social concerns for PLEVs as road users. Examples of the social concerns includes vandalism and unsocial parking of scooters. This creates issues for local and national governments thinking of integrating PLEVs into the urban transport mix (McKenzie, 2019) (Trivedi , et al., 2019).

As mentioned briefly in section 4.2, in the US a start-up electric micro scooter company called Bird released thousands of scooters on the streets of Santa Monica making them available to rent at a relatively low cost (Trivedi , et al., 2019). The company combined smartphone technology with simple battery and motor technology. Consumers use an application on their smartphones to find a suitable scooter nearby (McKenzie, 2019). By scanning a quick response (QR) code the scooter unlocks itself and is available for use at a comparatively low cost. Although a relatively simple idea, it is estimated that the company is now worth more than US$1 billion (Salinas, 2018). Other scooter companies are also becoming just as popular and profitable. Lime, another scooter company, is estimated to be worth US$2 billion and is backed by large venture capitalist firms (Schleifer, 2019).

Figure 5: A stock image of Bird dock-less e-scooters available to rent in the United States.

The financial weight behind these companies shows that e-scooters have become a new mode of transport in cities across the world. It seems reasonable to assume, due to their popularity and easy rideability that e-scooters will become the most common PLEV type in urban environments. Therefore, this paper focuses on e-scooters and the likely electrical load they will demand. This paper will focus on both privately owned e-scooters and e-scooters that are part of a shared rental scheme (like that offered by Bird and Lime).

5.1.1 Electric Scooters in the UK

In contrast to other European countries like France and Germany, electric scooters have so far not become part of how people travel in UK cities. This is due to the illegality of e-scooters and other PLEV technologies on UK public roads and pathways and this is stopping companies like Bird or Lime from expanding their services to the UK. The Driver and Vehicle License Agency (DVLA) state that all vehicles should be taxed, registered and insured. E-scooters and other PLEVs are not accepted by the DVLA as a registered vehicle and therefore cannot go on

UK roads. Although defined as a PLEV technology in this paper, e-bikes are an exception and are legal on UK roads as they have pedals.

The UK law and government policy in its current form does not promote electric transport in cities. As mentioned previously, the UK government is reviewing how e-scooters and other PLEV types could be part of the strategy to reduce CO_2 emissions and pollutants associated with travel from ICEs in cities (Department of Transport, 2019). The resulting reduction of pollutants and particulates in cities from the use of e-scooters could significantly improve air quality and reduce the number of deaths associated with pollution.

Attempts are being made to improve air quality in cities. In Edinburgh, the open streets movement – a trial scheme where the town centre is shut to all vehicles for one day a month – has been a relative success. However, people still need to travel around the city during this time and businesses could suffer from reduced footfall. E-scooters could provide transport for the general public in the UK for short journeys.

Companies such as Lime and Bird are actively lobbying the UK government to change the law. This, in combination with the air quality benefits and the popularity that they have, means it is extremely likely that e-scooters will become part of how we travel in the UK. Due to the laws in place restricting the use of e-scooters, the UK is in a unique position. The country has the ability to assess all advantages and disadvantages of e-scooters. With sensible and logical planning, the disadvantages could be mitigated.

If the law changes to allow the use of e-scooters on public roads, there will likely be a dramatic increase in PLEV usage in urban environments. As a consequence, there will be a large increase of a stochastic electrical load on the UK National Grid. With no academic research on the use of these technologies, the nature of this electrical load is unknown. This is a complex question and is a futuristic concept. The likelihood is that any studies focusing on determining the likely electrical load will be inaccurate due to the stochastic nature of the factors that impact the use of transport. Therefore, this paper focuses on developing a process for understanding the load e-scooters will have on the grid if UK government policy changes.

5.2 The Technology of Electric Scooters

E-scooters have relatively simplistic technology. Similar to BEVs, the scooter is fitted with a motor and a battery. The motor is powered by the batteries and drives the wheels. The motor typically powers the front wheel however new technology is evolving and scooters are beginning to be fitted with dual power motors.

Many start-up companies have been battling to gain a market share in the e-scooter industry. As Bird and Lime have become the most well-known sharing services, other companies have focused on private ownership. These companies have focused on high quality scooters with more powerful motors and greater battery capacity for extended distance ranges. Boosted, a

Figure 6: A newly developed e-scooter that is dual powered, capable of travelling at 25 mph and at hills with a 25 °gradient. The scooter has been developed by a technology start-up called Boost.

company that is primarily known for electrifying skateboards, has recently released a high specification e-scooter. The e-scooter can be seen in Figure 6 and can reach 25 mph, climbing hills with an inclination of 25° or more and has a range of 22 miles.

Haerri, et al. (2008) was the first academic paper to document the electrification of two wheel standing scooters. This scooter had a 3-phase powered 100W permanent magnet (PM) (brushless DC, (BLDC)) motor, a micro-controller, a bi-directional flow interface and energy buffers made up of supercapacitors to help harvest energy from the riding of the scooter. A schematic diagram taken from Haerri, et al. (2008) can be found in Figure 7.

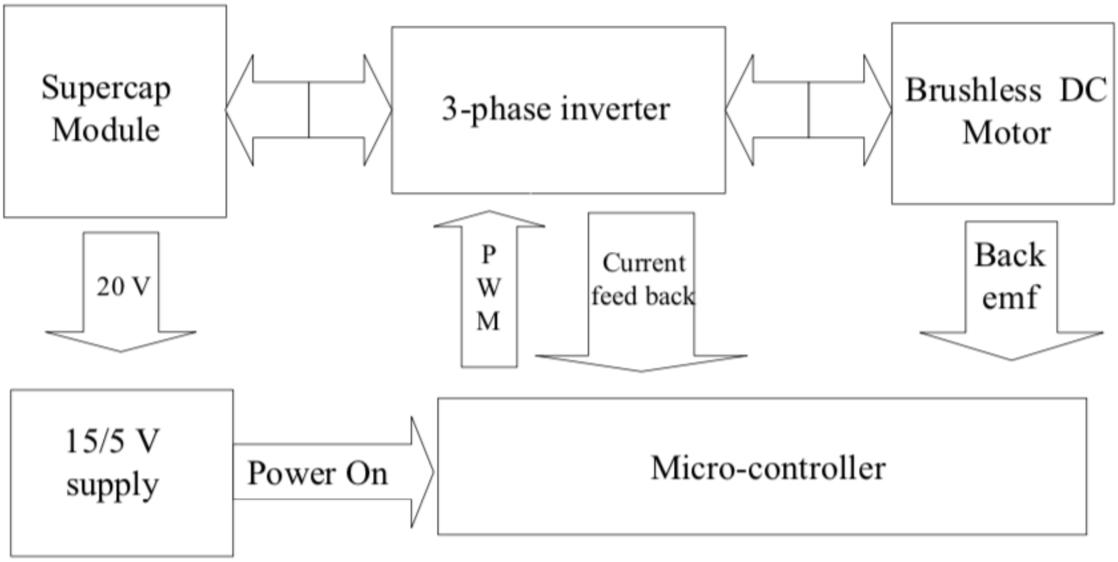


Figure 7: Showing a schematic diagram of the first academically documented electric micro scooter by Haerri. et al., 2008.

The original scooter was designed with cost in mind. The BLDC 3-phase motor used a low-cost windings arrangement with the out rotor containing the PMs and an inner stator completing the motor. The design uses a super-capacitor for energy storage. The super-capacitor was charged either by a kicking motion or downhill movement. Once the supercapacitor was charged to 5V the rider can request power to assist movement. A diagram of the PM motor drive with the supercapacitor module can be seen in Figure 8.

Since then there has been little documentation of the technology used in e-scooters as manufacturers withhold information for commercial purposes. Despite this, a review of newly patented scooter technology for the purpose of this paper shows that inventors and entrepreneurs are continually developing these technologies. New designs include scooters

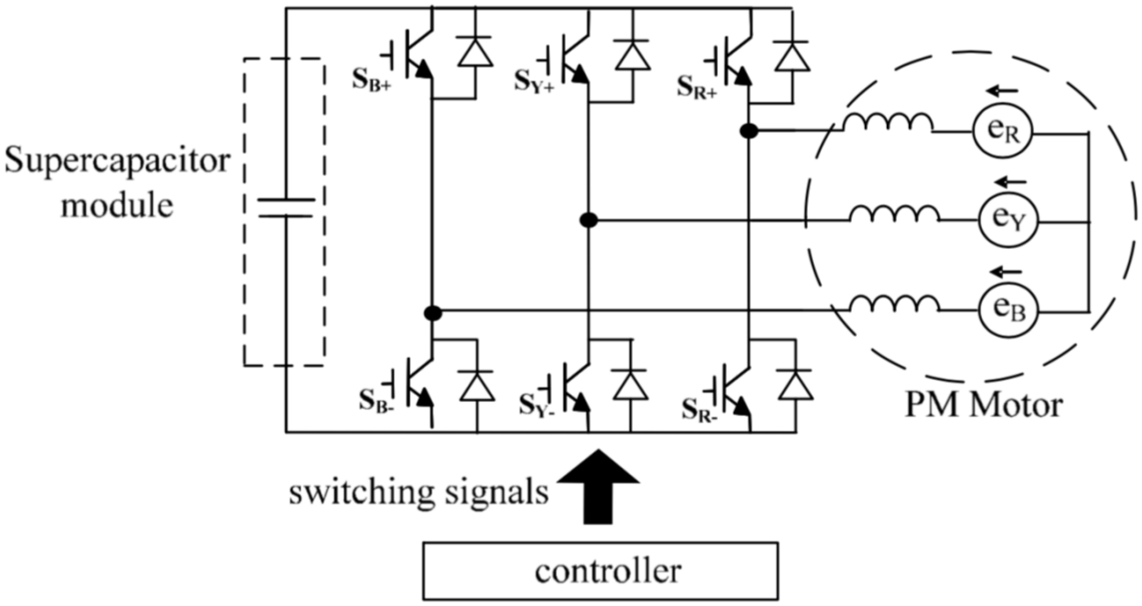


Figure 8: Showing the PM motor drive with the supercapacitor module from the prototype scooter documented by Haerri, et al., 2008.

which have photovoltaic (PV) systems charging batteries and powering motors on the go (Biao, et al., 2018). Although an interesting concept, the likelihood of these types of scooters succeeding in both a technical and commercial sense seems unlikely with current technology.

New scooters being released by transport technology companies have greater motor power and are now significantly more powerful than the prototype from Haerri, et al., 2008. The Boosted scooter in Figure 6 is dual powered by 1500 W motors. Little documentation is freely available describing the technical specifications of the batteries that are used in the scooters although it is known that they do utilise regenerative braking like many BEVs. A review of batteries can be found in section 5.2.1.

5.2.1 A Review of Battery Technology for Scooters

Electric Scooters utilise portable rechargeable batteries. Rechargeable batteries may also be known as secondary batteries (Burheim, 2018). Secondary batteries can either charge or discharge but are commonly referred to when they are discharging. A battery has an anode and a cathode. During discharge the anode is the oxidation reaction and the cathode the reduction reaction. When charging, the opposite applies (Burheim, 2018).

It takes current and time to charge a battery (Burheim, 2018). The charging capacity of a battery is reported as current per mass of electrode material (Burheim, 2018). The C-rate refers to the charging time. When referring to the amount a battery is charged, we use state of charge (SoC). Where 0% is empty and 100% is the battery fully charged. A C rate of 1 is applied when it takes 1 hour for a battery's SoC to change from 0 to 100%. When the battery is discharging a minus is placed in front of the C rate. Discharging of a battery is also referred as Depth of Discharge (DoD). Batteries are also given a state of health (SoH). The state of health is particularly important for shared electric scooter companies. The continual charging and discharging of the batteries will result in a reduced charge available for use in the battery. This means that the battery has a lower SoH for higher currents.

Table 3: Adapted from Burheim (2018), showing key capacity factors for well-known battery chemistries.

Capacity Factor	**Lead Acid**	**NiCd**	**NiMeH**	**ZEBRA**	**Li-ion**
Energy (Wh kg^{-1})	20 – 40	40 – 60	50 – 70	100 – 150	150 – 250
Power (W kg^{-1})	5 – 200	10 – 150	10 – 100	150 – 250	100 – 500
Cycles (000s)	1 – 5	1 – 3	1 – 3	1 – 2	1 – 20
Energy Eff. (%)	60 – 90	80	80	90	90 – 98
Temperature Range (°C)	-10 to 50	-20 to 45	-20 to 45	90 to 250	-20 to 50
SoC Window %	0 – 100	0 – 100	0 – 100	N/A	20 – 90

Energy density and power density are the primary factors that influence battery capacity. Other factors include temperature, efficiency and SoC window. A review of the ranges for each factor affecting battery capacity can be seen in Table 3. Lithium-ion batteries have been the most commonly used rechargeable batteries since the turn of the millennium as they have a high energy and power density coupled with a high efficiency rating. However, a Li-ion battery should never be charged above 90% or discharged below 20%. This means that Li-ion batteries have only 70% of usable power. Key for e-scooter sharing companies is the number of cycles that a Li-ion battery can be charged and discharged. Using Li-ion batteries extends the life of the commercial life span of the battery before it needs replaced in comparison to other battery types.

5.2.2 Batteries, Scooters and the Environmental Footprint

There are several concerns with the environmental footprint that batteries have. The extraction of minerals and the emissions associated with production of batteries is a common argument against new battery technologies. However, one study by a major car manufacturer depicted in Burheim (2018), shows that their GHG footprint in comparison to gasoline and diesel is significantly less over the lifecycle of the product (Figure 9).

To the best of this author's knowledge, there are no academic reports on the footprint that e-scooters have as a whole on the environment. Some news reports have claimed that Bird and Lime, the scooter sharing companies, need to replace the whole scooter every two months. However, within the analysis presented by Hollingsworth, et al. (2019), discussed in section 5.2.4.1, e-scooters were given a life span of between 6 months and 2 years. If this were found to be true, this would obviously have massive implications for the footprint e-scooters have on the environment.

5.2.3 Battery Technology Technical Specifications

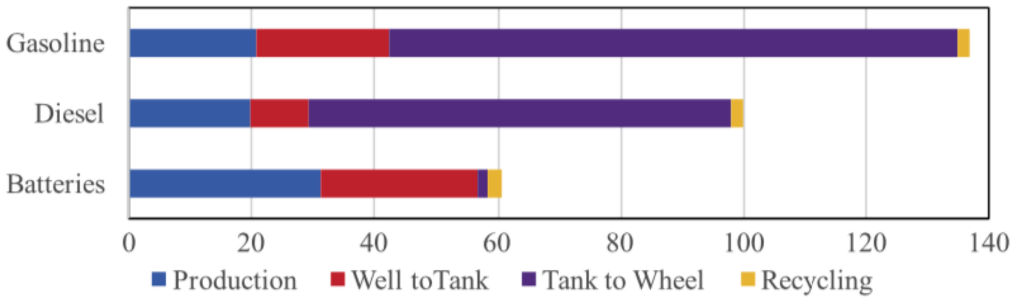


Figure 9: The life cycle greenhouse footprint of different propulsion technologies - From Burheim (2018).

As mentioned previously, there is little documentation available for technical specifications of the batteries used in either shared scooters such as Bird and Lime or the scooters sold for private use from companies such as Boosted. When considering the electrical load that a scooter would demand on a grid, the energy content of the type of battery is a key component. In this paper, we use a Li-Ion battery Bosch Powerpack 500 battery (Table 4). The battery is intended to be used for an electric bicycle however the technology is the same in an electric scooter. In this paper, to determine the total energy content of a battery we use Equation 1.

Table 4: The technical specifications of a Bosch Battery Powerpack 500 for their e-bike range - adapted from (Riese & Muller , 2016)

Powerpack 500	
Voltage	36V
Rated Capacity	13.6 Ah

Equation 1: Energy Content of a Battery

$$Energy\ Content = Voltage\ \times\ Rated\ Capacity$$

The capacity of the batteries directly impacts the range of a scooter. Therefore, the range of e-scooters differ between manufacturers. A review of different manufacturers' websites shows that scooter range is between 15 and 25 miles.

5.2.4 Charging Electric Scooters

The current method of charging shared electric scooters is exceptionally inefficient from both an energy system perspective and a business perspective. In the US, self-employed contractors collect scooters where they have been left and receive a fee for each scooter collected. Scooters that are harder to retrieve garner a higher fee. Once the scooters have been collected, the contractor charges the scooters at their home. The scooters are then returned to a specific location after they have been charged. It is most likely that the scooters are charged on a domestic tariff rate meaning that the cost companies have to pay contractors is higher than if they were to agree a rate with an energy provider or implemented a form of renewable energy system. It is also understood that charging takes place during the evening hours, which may contribute to peak demands.

The current charging system only considers scooters as an electrical demand and not as a source of energy to supply the grid during periods that the scooters are not required. Using scooters as an electrical supply as well as an electrical demand is more commonly known as Vehicle to Grid (V2G) (Ma, et al., 2012). Since the demand of a single scooter is stochastic, there is little use for private owners and V2G. However, shared scooter companies could benefit from V2G since they have large numbers of scooters, and the aggregate level or power required could be determined (Ma, et al., 2012). It is beyond the scope of this paper to consider V2G in the Excel model.

When considering the charging structure and the fact that a single shared scooter's life span is between 6 months and two years (Section 5.2.2) (Hollingsworth, et al., 2019), it is essential to question the sustainability of e-scooters and whether or not they are good for the environment. A review of sustainable transport and its definition can be found in section 5.4.

5.2.4.1 The Environmental Impact

In early August 2019 a paper was published focusing on the environmental footprint of e-scooters' whole life cycle (Hollingsworth, et al., 2019). The review of the environmental impacts included materials/components, manufacturing, transport of the scooters to the country of use, their use and their end-of-life. The paper found that e-scooters were associated with 202 gCO_2/mile for their whole life cycle. According to Hollingsworth, et al. (2019), the collection of e-scooters by contractors contributed to 43% of the total CO_2. In addition to the findings of this study, it could be assumed that the environmental impact of e-scooters during the charging phase is dependent on the CO_2 emissions associated with the UK National Grid. If the National Grid is being powered by CO_2 intense fuel sources such as coal, then the CO_2 emissions associated with e-scooters will be much higher than if the grid is being powered by renewable sources such as wind.

5.3 Modelling Electric Scooter Use and the Impacts on the Grid

As discussed above, there is no specific research that looks at the electrical load e-scooters have on the grid. In order to determine the electrical load of e-scooters, we can draw parallels from studies looking at the electrification of other transport mechanisms e.g. cars and trains (Grenier & Page, 2012).

An electrical load is an active component from an electric system that consumes electric power. Through Equation 1 we can determine the energy required to fully charge a scooter battery. However, the process to determine the demand for e-scooters as a transport method is complex and includes several different factors as many elements are stochastic.

5.3.1 The Importance of Modelling

Modelling new transport methods and the electrical loads they may require is vital. Understanding the usage of a transport type can help with city and grid network planning. It can also help with investment decision-making for energy projects. Due to current environmental concerns about ICEs, new electrical transport modes are considered a positive by the public and governments (Department of Transport, 2019). However, there are several different impacts that a newly electrified transport method could have on a grid. Understanding whether or not the energy system is likely to be affected by the newly electrified transport type is a key step in the process of modelling e-scooters.

One impact from the electrification of scooters may be the increase in generation of electricity to match the new demand. An example of this increase in generation can be seen in (Duke, et al. (2009) and Grenier & Page (2012) where it was concluded that if 2 million BEVs were in use a power increase of 1350 MW from 9667 MW to 11,017 MW was required to balance the grid. This is clearly a significant increase in network capacity of 13%. Although this increase in BEVs would result in better air quality for cities they would still be powered by the generation of electricity using CO_2 intense fuels. In order to maximise the reduction of CO_2 emissions from transport, any increase in grid size will need to be met by renewable sources. However, renewable sources such as wind and solar are non-despatchable, that is to say they cannot be switched on and off whenever required (Boait, et al., 2019). This makes matching the supply with demand exceptionally difficult and DSM incredibly important to maintain a balance grid.

Other impacts that new loads may have on the UK National Grid include distribution issues. Several previous studies have looked at the consequence of charging BEVs and light electric vehicles (LEVs) on the local distribution network. Consequences include a cap on EVs that can be charged without infrastructure upgrades and overloading of the distribution transformer (Grenier & Page, 2012). Other studies show that the increased use of BEVs will result in a violation of demand supply matching and statutory voltage limits. Where the electrical loads are not distributed between three phases of power, power quality problems and voltage imbalances may be present in the grid (Putrus, et al., 2009).

Since there is no understanding of the impact that e-scooters may have on the UK National Grid, there are no policies or procedures in place which could prevent issues such as power distribution and voltage imbalances. Some of the impacts depicted above such as voltage imbalances are highly complex and are beyond the scope of this paper. The supply increase required for a grid (like that seen in Duke, et al. (2009) and Grenier & Page (2012)) is included within the Excel model, however power distribution and power quality are not considered.

5.4 A Review of Sustainable Transport

In the EU, the official policy is to reduce the CO_2 emissions and GHG associated with transport. “Sustainable” transport has been examined as a method that may be consistent with this policy. The term sustainable has several different definitions in different contexts and is often a term used without the correct definition and may not fully be understood by the general public. For the purpose of this paper, the evaluation of whether or not electrified scooters can be considered sustainable is based on environmental, social and economic indicators. These indicators are based on previous research; the definitions of each indicator can be found in Table 5.

In the context of developing a process for evaluating electrified scooters’ impact on the UK National Grid, the challenges faced in the transport sector may be resolved using sustainable transport. For instance, issues within the transport sector include; air pollution, climate change, congestion, energy intensity and natural resource consumption, energy security, equity of access, habitat fragmentation and land consumption, noise and road safety (Bongardt , et al., 2011). If a mode of transport could be considered sustainable it may lessen one or more of these issues, making it more likely for a particular mode of transport to be used when travelling.

Table 5: Showing the definitions of the sustainability indicators evaluated for the purpose of this paper. Adapted from (Bongardt , et al., 2011) and (Rajak, et al., 2016).

Sustainability Indicator	**Definition**
Economic	The transportation is viable from a business perspective (income > expenses). Operates efficiently and fairly.
Environmental	CO_2 emissions, pollutants and GHGs are limited. Land use and noise are minimized.
Social	Access and development of transport are met safely in a manner that does not affect future generations.

Using the definitions in Table 5, this paper will assess how e-scooters fit on a scale of sustainability (section 10.5). From Table 5, it could be concluded that if e-scooters were to be considered sustainable they would need to be economically and ethically viable for business, not impact or exploit people's wealth or wellbeing and not contribute to local/global CO_2 emissions/GHGs/pollutants.

5.5 Factors Affecting Transport Mode Choice

The way in which a person travels on a daily is dependent on many factors. Understanding these factors is key for determining the likely electrical load that e-scooters would have on the UK National Grid. Some of the key factors that affect transport mode choice are: economics, social psychology, physical, political and climate (Iftekhar & Tapsuwan, 2010). This list is not exhaustive and since e-scooters are relatively new to the transport mix, it is likely that factors that affect their use are unknown thus far.

5.5.1 Economic Factor

It could be argued that the economics of a society have a significant impact on the type of transport mode selected by an individual (Iftekhar & Tapsuwan, 2010). Household income, employment status and employment type are key constraints leading to a particular choice of transport type. In addition to this, the cost of transportation is a key factor during the decision-making process. The cost of transport includes but is not limited to, parking fees and petrol prices. A previous study in Australia found that 50% of students in Melbourne would drive to university if the overall cost was cheaper (Collins & Chambers, 2005). In addition to this, the elastic nature of fuel prices have a significant impact on the use of cars for transport, with increases in operation costs resulting in decreasing use of cars (Hensher & Stanley , 2009).

5.5.2 Built Environment Factors

The components of the physical environment in a city of rural setting have a substantial impact on how we travel (Iftekhar & Tapsuwan, 2010). Many previous studies have shown that an increase in distance and the sparsity of an urban environment results in the increased use of cars, bicycles and public transport for journeys (Schwanen, et al., 2001). Previous research also shows that bringing destinations closer together through an extensive cycle lane infrastructure can increase the use of bicycles, scooters and skateboards (Choi, 2018). In addition to this, congestion within a built environment can impact how people travel on a daily basis, with one study showing that 70% of people would be likely to switch to public transport if it were quicker than travelling by car (Iftekhar & Tapsuwan, 2010).

The built environment, aesthetics and crime statistics for an area impact how people choose to travel (Choi, 2018) (Zhang , et al., 2019). For example, a member of the public may be less likely to travel by bicycle if there is a high chance that it could be stolen or vandalised or if the area in which they are travelling is aesthetically deprived. The topography of an area is also an important factor when considering what type of transport mode an individual would use. A study in San Francisco found that residents in an area of undulating topography were more likely to drive for commuting purposes (Schwanen & Mokhtarian, 2005), however, it is important to acknowledge that this was not the sole indicator studied within this paper.

5.5.3 Demographic Factors

The demographic of an urban environment, town or rural setting contributes towards how an individual selects how they wish to travel (Schwanen & Mokhtarian, 2005). When considering demographic as a factor on transport demand, aspects such as; number of adults in employment, gender of those in employment, household income, physical fitness of household, age of adults and children in a household all need to be considered (Schwanen & Mokhtarian, 2005). An example of how demographic impacts the demand of a transport type is that in San Francisco a single female is more likely to use a ferry or bus to travel to work than any other type of transport (Schwanen & Mokhtarian , 2005).

5.5.4 Government Policy Factors

Within the transport sector, there are three levels of governance that effect how we travel; local, national and international. It could be argued that international politics sets an overall policy objective and creates a domino effect of policies. The Paris Agreement, signed by the world's largest economies and CO_2 contributors, has a direct impact on national government policies. For example, as mentioned previously, the UK government has been reviewing e-scooters and other PLEVs as methods of travelling in urban environments. This is a direct implication of the Paris Agreement as governments seek to decrease CO_2 emissions. However, the demand for e-scooters and similar transport types may be dependent on other local factors such as the cycle lane infrastructure. Cycle lane infrastructure would be considered a local policy issue. This can be seen in South Africa where the use of "sustainable transport" is dependent on local policy (Kane, 2010).

5.5.5 Climate and Weather Factors

There is a stark difference in the definitions between climate and weather. Put simply, climate is an extended period of time of a particular weather type. Weather effects an area on a daily basis; e.g. how much precipitation there is and what the temperature is. When predicting transport usage into the future, the climate is a key factor to consider. However, if you wish to determine short term usage then weather is a better factor to consider.

In the UK, temperatures are beginning to increase and with this extreme weather events such as floods and heatwaves are becoming more common. These weather events effect people's livelihoods, the economy and transport mode choice (Iftekhar & Tapsuwan, 2010). In Australia, temperature, precipitation and air quality are the climate and weather factors that affect transport mode choice.

A higher temperature is considered to increase the number of cyclists on the roads in comparison to colder days (Iftekhar & Tapsuwan, 2010). A study of commuters in Australia found that air quality is a major barrier for walking or cycling to work and results in a 13% reduction in these transport mode types one days when air pollution is bad (Badland & Duncan, 2009).

5.5.6 The Theory of Planned Behaviour

The psychology of how people choose to travel on a daily basis is a complicated question that research has been seeking to address for many years (Donald, et al., 2014). Much of the present research has used the theory of planned behaviour (TPB); assessing what means of transport people use and why. Only few studies have extended this research into what people use the transport for, e.g. commuting to work (Donald, et al., 2014). The TPB relates to a behavioural intention and how much an individual is motivated to perform that behaviour (Ajzen, 1991). The TPB uses perceived behavioural control (PBC) to measure attitude and subjective norms to predict behavioural intentions. According to Donald, et al. (2014), the environmental concern of an individual is not included with the model of the TPB when selecting a transport mode choice. For the purpose of this paper, environmental concern is defined as those who are conscious of climate change.

The TPB and PBC of people’s transport mode choice for a particular journey is an important factor to consider when predicting electrical loads from e-scooters on the grids. Whether a person is likely to use an e-scooter for a specific journey type may depend on several different factors, such as environmental consciousness. Donald, et al., 2014, extended the TPB to incorporate environmental concern and showed that it reduces a person’s habit to drive and increases the habit of using public transport. However, no studies exist on the TPB with regards to PLEVs. It is beyond the scope of this paper to determine how likely an individual is to use a PLEV or e-scooter, but the results discussed in Donald, et al., 2014 for public transport are used with the mathematical model to predict the use of PLEVs based on environmental concern. The results show that an individual, who is environmentally concerned and usually travels by car, is 24 times more likely to change their habit of personal car use and 11 times more likely to change their current habits and use public transport.

5.5.7 Connectivity of Factors

The literature and examples outlined above highlight the complexity of predicting the public's behavior when selecting how to travel on a daily basis. This is because decisions made by consumers are not entirely made based on one factor. There are often several different factors leading to a decision. Different factors can cross over and have related consequences. An example may be that the demographic of a household (household income or employment) could be affected by local and national government policy. Similarly, as mentioned previously, cycle lane infrastructure could be affected by local policy.

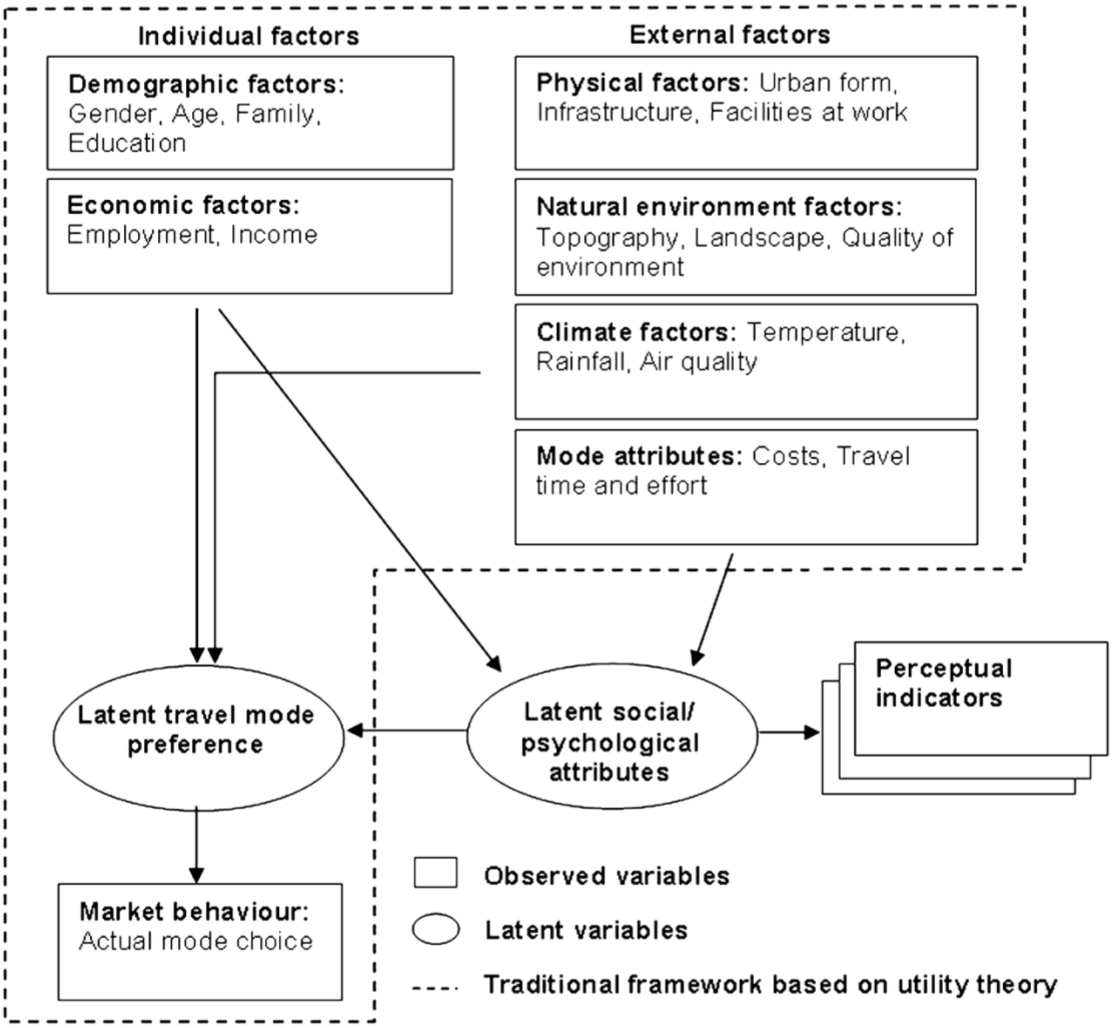


Figure 10: Taken from Iftekhar & Tapsuwan (2010), showing how individual factors and external factors are intertwined with social and psychological attributes in determining how a person travel.

Figure 10: Taken from Iftekhar & Tapsuwan (2010), showing how individual factors and external factors are intertwined with social and psychological attributes in determining how a person travel., shows how the factors discussed above can be split between individual and external factors. Both the sets of factors can have an effect on social and psychological factors such as environmental consciousness through the theory of planned behavior (Donald, et al., 2014) (Iftekhar & Tapsuwan, 2010). A combination of the preferred travel mode and the social/psychological attributes lead to the actual transport mode choice. Modelling this is complex. When considering the factors that lead to e-scooters, the complexity increases due to the lack of understanding of their demand.

In addition to the complexity that is brought due to the connectivity of factors, it is also highly conceivable that previous research has not considered a factor that plays either a minor or major role in influencing transport selection type with specific regards to e-scooters.

5.6 A Review of Randomised Controlled Trial

With regards to determining the use of transport, there is substantial literature which focuses on the choice of methodology (Melia, 2015). A review of randomised controlled trials (RCTs) is conducted in this section as any future use of PLEVs should be exposed to such a scenario before a national roll out.

Trials are an important source of information for determining how consumers will use transport methods (Golob, 1998). An RCT is considered a scientific experiment that reduces the certain biases when examining the usefulness of a new subject. It is argued that RCTs produce reliable results when modelling transport usage in comparison to other research methods (Golob, 1998). In the context of PLEVs in the UK, conducting an RCT is beyond the scope of this paper. However, the design of an RCT is clearly an important step in understanding the usage of a transport type. The creation of an RCT is conducted in Chapter 9.

5.7 The UK and the National Grid

Many of the possible impacts of new electrical loads have been discussed previously in section 5.3.1. This section evaluates the UK National Grid in general and introduces data, such as the average use of electricity per household, that is used in Chapter 6 and Chapter 7 to determine impacts that may be relevant to the introduction of e-scooters as new electrical loads.

5.7.1 The National Grid – A General Overview

The UK national electricity grid is tasked with transmitting the supply of electricity to different points of demand. The grid is a displacement system, in that where power is consumed at one point, it must be replaced at another. This key service is done in a manner that maintains security of supply, the minimisation of transmission losses and the practice of lowest possible prices. The supply of the UK National Grid is made up of several types of energy sources; Figure 11. However, according to Department for Business, Energy & Industrial Strategy (2019) the main supply of energy in 2018 came from gas and nuclear. Nuclear sources provide a baseload of power for the grid and gas provides dispatchable (energy available on demand) cover for times during peak demand.

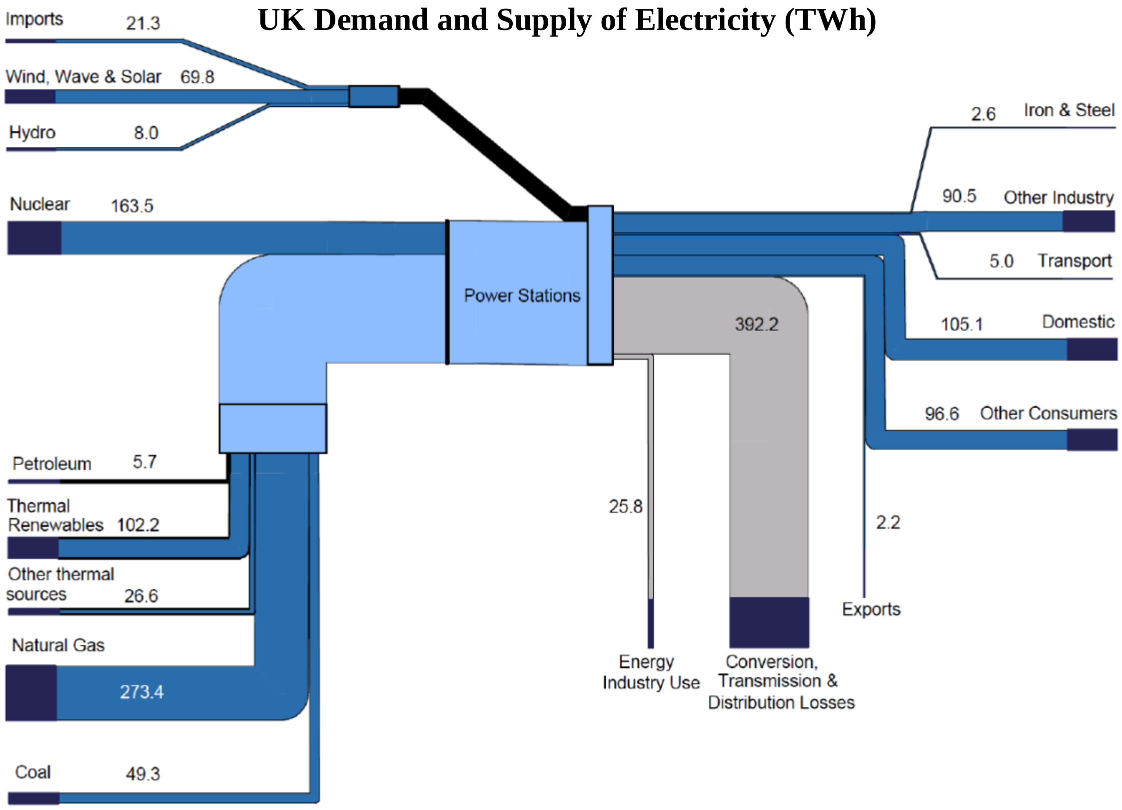
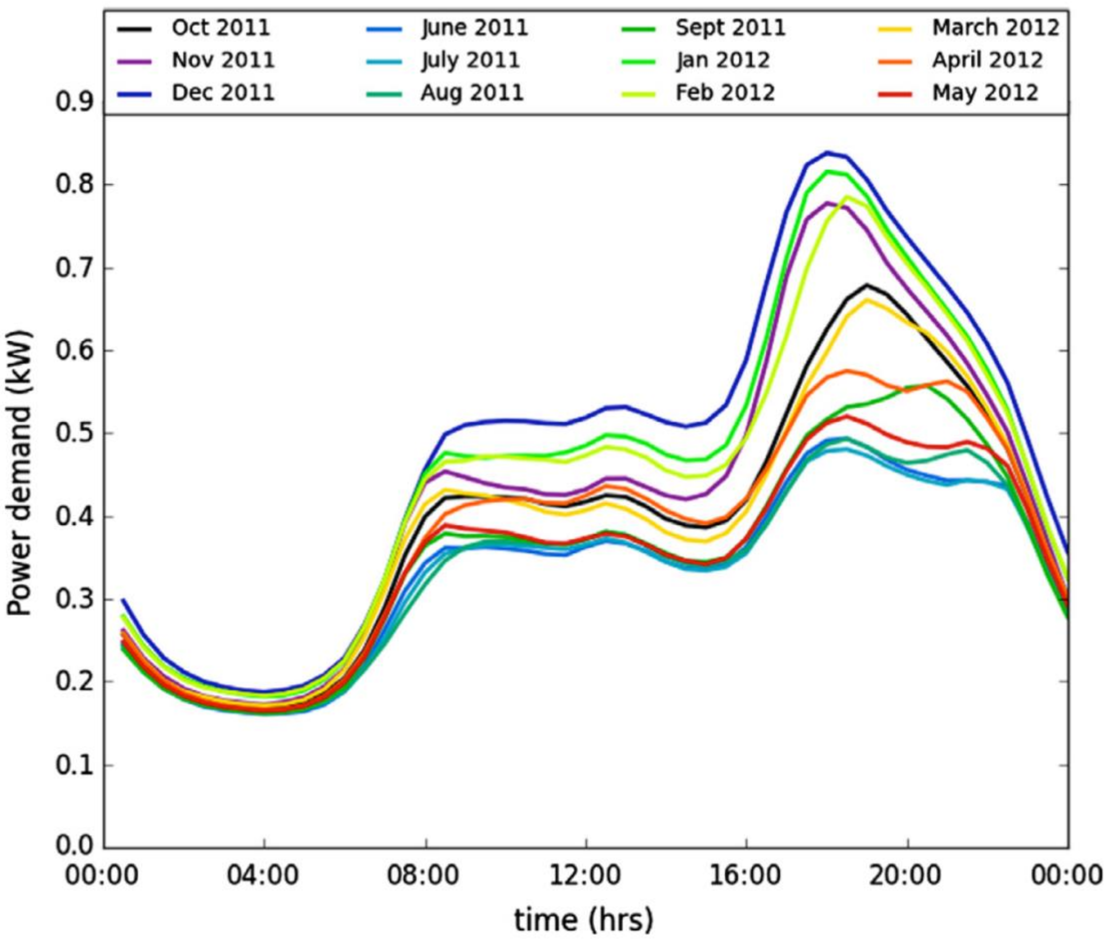


Figure 11: Taken from Department for Business, Energy & Industrial Strategy (2019) showing the break down of energy supply and demand for the UK.

There is an increasing proportion of renewable energy being installed on the UK National Grid as countries such as Scotland aim to achieve their 2020 targets (Munro, 2019). Many renewables such as wind, wave and solar are non-dispatchable (they are not available on demand) and this adds to the complication of maintaining a balanced grid during periods of peak demand. Peak demand on a daily basis occurs in the early evening. This is well known and documented through research (Powells, et al., 2014). Figure 12 shows a mean daily demand of electricity for smart meter customers in the UK. This is a typical pattern of electricity by time of day in the UK.



Peak Demand of Electricity in UK Smart Meter Customers

Figure 12: Taken from Wardle et al., (2013) (through Powells, et al., (2014)) showing the daily mean demand for electricity from smart meter customers from 2011 to 2012 in the UK.

5.7.2 The Demographic and Domestic Electricity Usage of the UK

According to the Office for National Statistics (2019), the UK has a total population of 66 million and household numbers of 27 million. This results in an approximate ratio of 2/5 (household to population). When modelling in Chapter 7, this ratio is used. In conjunction with this, an examination of the Office of Gas and Electricity Markets (Ofgem), data for domestic daily electricity usage has been conducted. The data shows that an average household uses approximately 10.7 kWh per day. This results in 2.9 GWh per day for the entire country. The average electricity used per household is also used within the modelling phase in Chapter 7.

Table 6: Shows the population and number of households in the UK according to the Office for National Statistics (2019). This shows that there is an approximate ratio of 2/5 (households to population).

UK Population and Household Number	
Population	66 Million
Households	27 Million

Chapter 6 – Examination of Factors that Affect Electric Scooter Usage

In this section, we evaluate the factors that specifically affect electric scooter usage and examine in detail the consequences that each factor has on one another. Using the literature discussed in section 5.5, this paper has evaluated the key factors thought to impact e-scooters. This is the first step in understanding e-scooter usage and begins the process of determining the electrical load that e-scooters may demand of the UK National Grid. It allows the complexity of the question to be demonstrated clearly and show the inability to predict the usage accurately due to the stochastic nature of many of the elements. In this section we assume that e-scooters can either be owned privately or through a shared system.

6.1 An Overview of Factors

Since there is no academic research on the demand for e-scooters as a transport method and the electrical load they demand on the grid, it is difficult to understand the factors that affect e-scooter usage accurately. By examining the factors highlighted in the literature review (section 5.5) we can draw parallels with other transport mode choices. As discussed in section 5.5, there are several different factors that lead to the use of a particular mode of transport. From the examination of Figure 10 we know that factors that affect a transport mode choice can either be individual or external. Both individual and external factors interact with the psychological and social factors (section 5.5.6). However, there may also be knock-on effects, as highlighted in section 5.5.7, where government policy at different levels may affect aspects such as demographic or economics.

The factors detailed in Figure 13 are for those thought to affect the usage of e-scooters in urban environments. The usage has a direct impact on the electrical load demanded and it is therefore key to understanding any impact to the grid. Figure 13 is based on that seen in Figure 10 from Iftekhar & Tapsuwan (2010) and has been adapted to reflect factors that impact the electrical load that e-scooters demand from the UK National Grid from their usage. As is seen in Figure 10, Figure 13 shows that both external and internal factors affect how a consumer behaves when choosing whether or not to use an e-scooter. Also shown in Figure 13 is that individual and external factors can also impact electrical loads without consumer behaviour being included. An extreme example of this may be if government policy dictated that everyone had to use e-scooters as their mode of transport in urban environments.

The first step in understanding whether or not there is any electrical load is understanding the demand for e-scooters as transport methods. The second step is understanding whether or not the electrical load impacts the grid in any way. Figure 13 shows two factors considered for grid impact, charging of the transport and the components of the grid. The charging of the transport considers aspects such as: the time of day that most people may be charging the scooters (either peak or off-peak times). The components of the grid reflect characteristics such as the size of the grid and whether or not the grid has dispatchable energy available. Each of these are discussed further in the section below.

6.2 Examination of Factors for E-Scooters

Each of the factors shown in Figure 13 can be examined in greater detail highlighting the consequences of each element of a factor. Examining the factors in greater details highlights key issues that impact the usage of e-scooters. This an important step in the process of understanding the electrical load that may be demanded from e-scooters as factors that have a stronger weight in relevance can be identified. This allows future computational models and the RCTs to pick key areas to examine and study in greater detail.

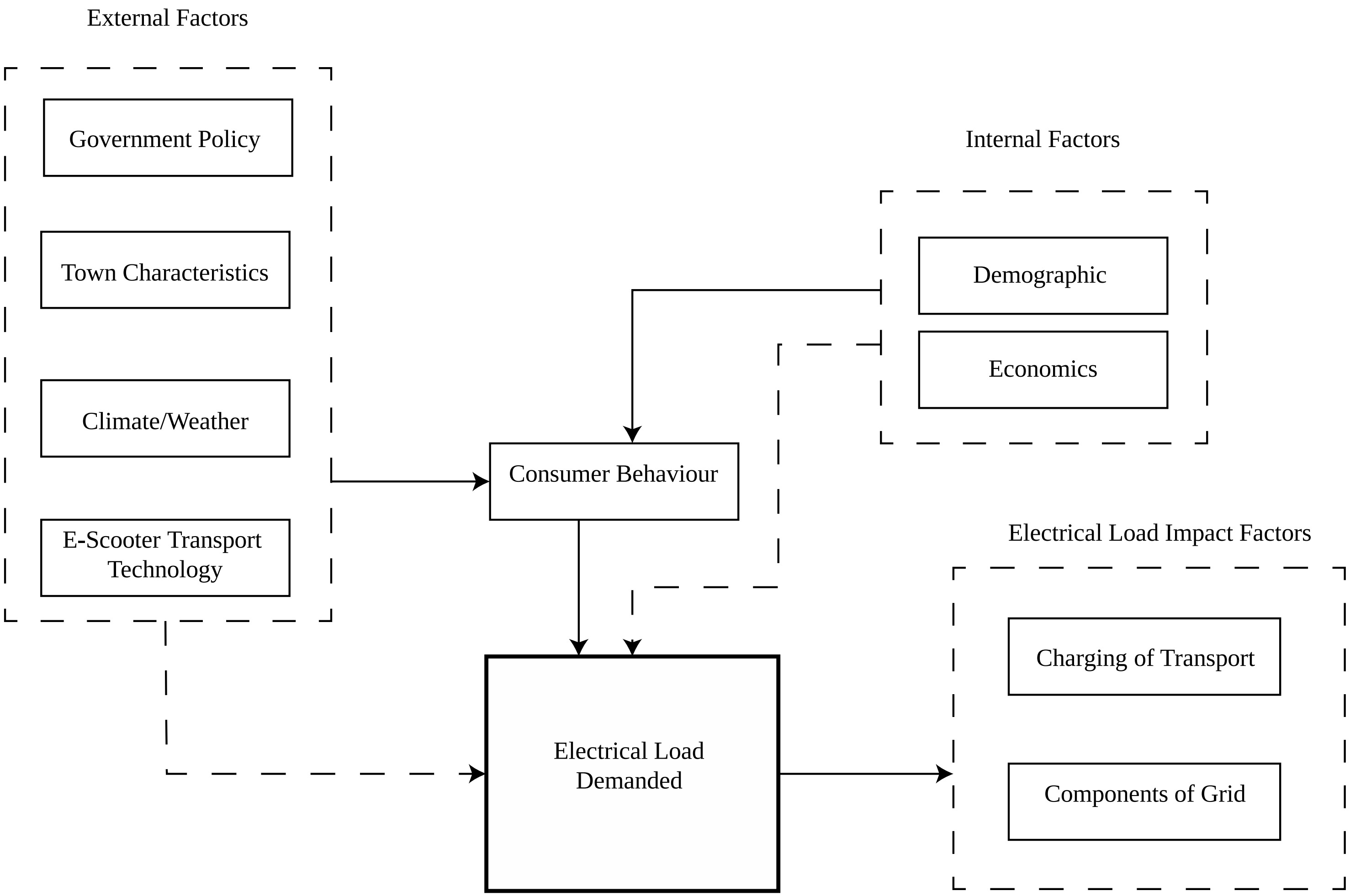


Figure 13: Showing the internal and external factors that affect consumer behaviour and how this links to the electrical load demanded from scooter usage. The impacts from the electrical grid are also shown (charging of transport and components of the grid).

6.2.1 Government Policy

As mentioned previously in section 5.5.4, government policy can be split into three different levels; international, national and local. This can be seen in Figure 14. Figure 14 shows the policies at each level that may have an impact on e-scooter usage based on previous research.

In trying to predict the future usage of e-scooters in the UK we must consider all three levels of government. As we know from Choi (2018), by improving cycle lane infrastructure in cities there is an increase in the number of cyclists. If we assume the same is true for e-scooters then it becomes an exceptionally important factor for predicting future e-scooter usage and therefore the electrical load they may demand. In conjunction with this, if a city or town had existing cycle lane infrastructure in place then they would be more likely to have higher electrical demand for the e-scooters once national government policy changed to allow e-scooters on roads.

Another key policy area identified is air pollution in cities. Although a local issue, air pollution is part also of a wider issue within transport that is tackled at a higher level. If a government were to attempt to improve air quality in cities by implementing policies such as congestion charges (in other cities other than London) there may be an uptake in those who choose e-scooters as their mode of transport. We can make this assumption based on Iftekhar & Tapsuwan (2010) in section 5.5.5.

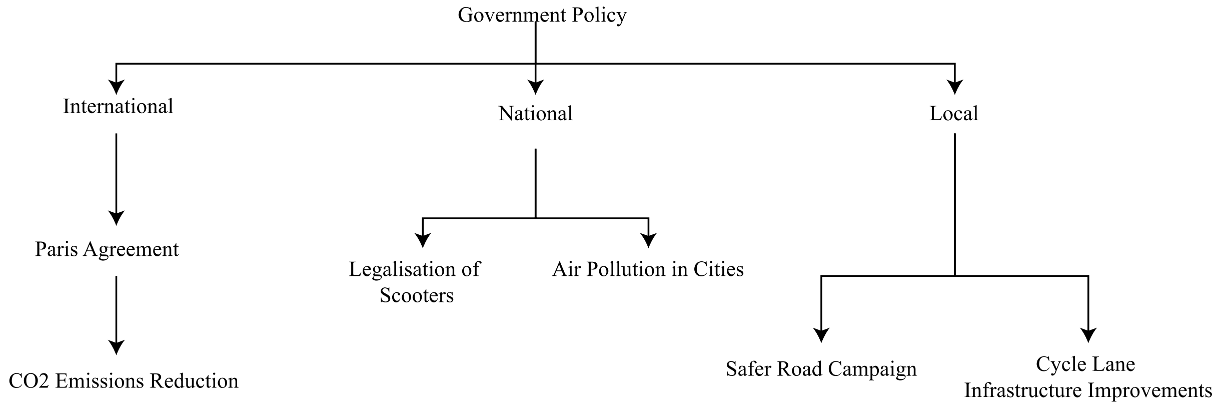


Figure 14: Showing three levels of government policy that could affect e-scooter usage: International, National and Local (Council led). Each level of government has policy decisions that affect how popular e-scooters could become.

6.2.2 Town Characteristics – The Built Environment

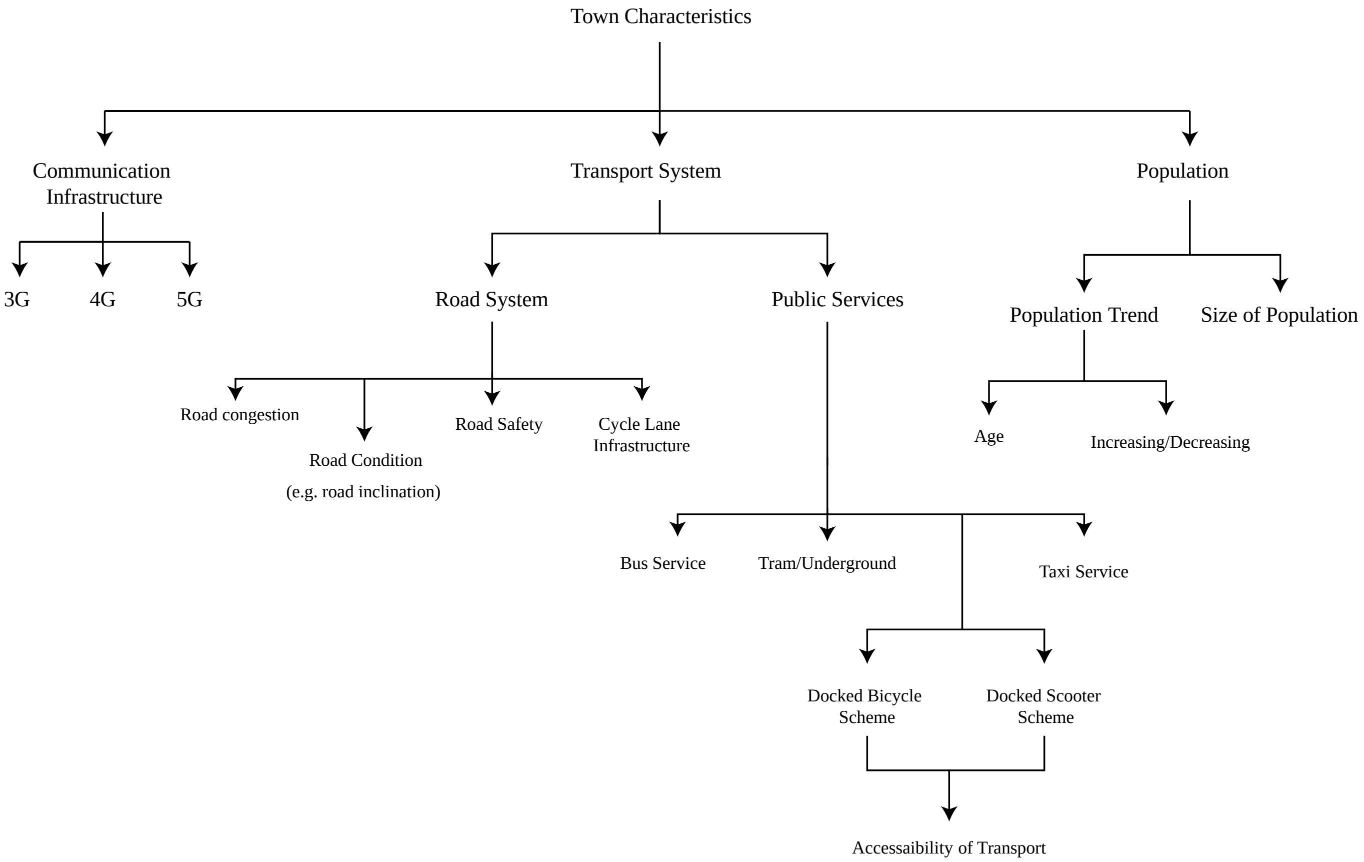


Figure 15: Showing the factors that affect the town characteristics/built environment. Three key elements have been identified for a towns characteristic's that effects e-scooter usage.

The characteristics of a town is one of the key factors that has been identified to determine e-scooter usage in urban environments. Three key elements have been identified and can be seen in Figure 15; communication infrastructure, transport system and population. As many people use shared scooter services, good mobile network infrastructure will be required to allow people to determine where the nearest scooter is. If the network is unable to do this then there is likely to be a reduced demand and therefore a lower electrical load.

The population of a town/city is important to determining the total number of scooters being used on a daily basis. Two aspects are considered in Figure 15, size of population and the trend of that population. How the population is trending is perhaps more important but this overlaps with the demographic factor. It is more likely that the younger a population is the more likely they are to use a e-scooter. Whether or not the population is increasing or decreasing is important for predicting future usage and any future impacts that may arise because of increased/decreased usage of e-scooters.

The transport system in a town or a built environment is by far the most important aspect to be considered for future modelling of e-scooter usage. A review of this factor for this paper has highlighted two issues that affect scooter usage; the road system and the public transport systems available. Considering the road system first, we have already shown that cycle lane infrastructure is important, as is road safety, however road condition (including aspects such as inclination and general wear and tear of the road) is a key element in determining whether or not people are likely to use e-scooters. In addition, as highlighted in section 5.5.2, 70% of people would switch to public transport if it were quicker than car. So, if travelling by a shared e-scooter is quicker than an average car journey due to congestion, then we can expect a higher electrical load demand on the grid. Another aspect that may impact demand is how accessible these methods of transport are. If accessibility is high, then it could be assumed that demand would be higher.

6.2.3 Climate and Weather

Since e-scooters have no way of shielding the user from precipitation and wind it seems very likely that changes to the weather will significantly affect how they are used for transportation. However, the effect that the weather has on an individual when choosing whether or not to travel using e-scooters is stochastic. Different people will have different tolerances to weather. When considering this during modelling of e-scooter usage and electrical demand we can apply an average value to reduce the stochastic nature of this.

Similarly, with predicting the weather, there is a large element of uncertainty. The uncertainty exists due to inaccuracies in the forecasting of weather for more than approximately a week in advance. When considering the climate of a city or town and any changes that may occur over the short-term and long-term future this creates even greater uncertainty.

One key element of weather that effects both scooter usage and the scooter technology is temperature. During periods of lower temperatures, it is unlikely that scooters will be used as transport methods due to fear of ice and users becoming too cold. Additionally, there is the impact that this could have on batteries. This would depend on battery type . As shown in Table 3, temperatures would have to be severely low to affect them significantly. This may be more relevant in countries that are subjected to harsher winters than the UK.

6.2.4 E-Scooter Technology

Although not highlighted by previous research for other transport types, the technology used in e-scooters will play an important role in their aspects such as popularity and performance. It is therefore an important factor to consider. Aspects such as the speed at which a scooter can travel, its ability to climb hills with large inclinations and its overall battery capacity (and therefore range) are important factors which impact people’s thinking when choosing how to travel (as show in section 5.5).

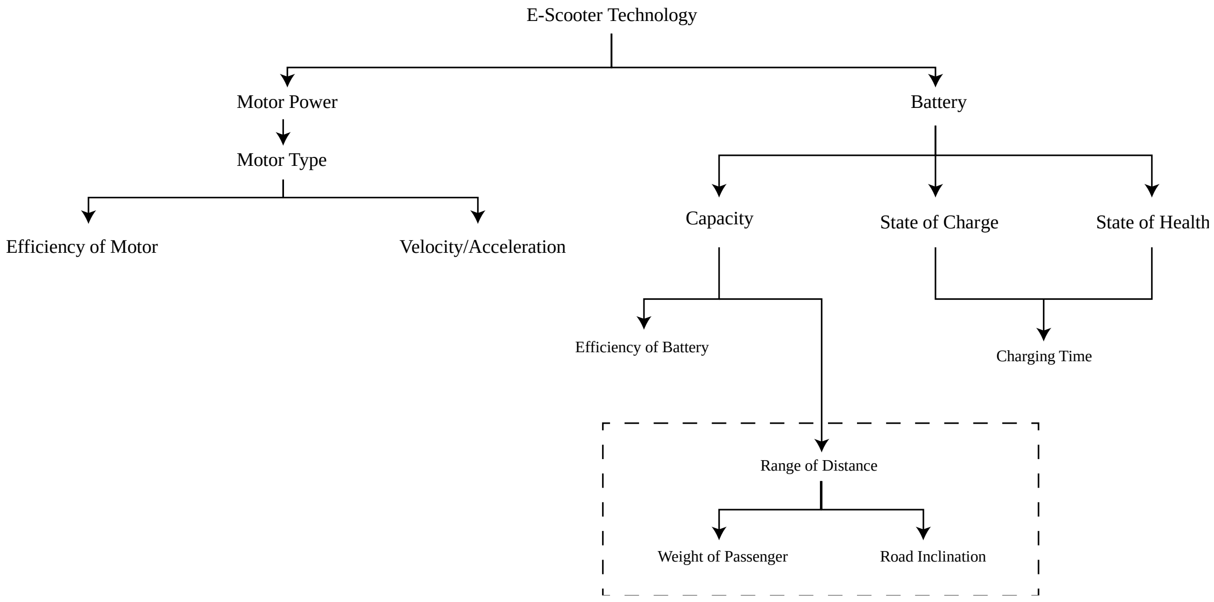


Figure 16: Showing how e-scooter technology impacts scooter usage based on motor power and battery capacity. Dashed line represents elements which are affected by more than one factor.

Motor power and battery size dictate the energy demanded from the grid that is needed to charge the e-scooters so they can be used on a daily basis. Figure 16 highlights the key elements that effect scooter usage. Aspects such as the velocity of a scooter are important to the user. Since we know that people are more likely to switch to public transport if a journey is quicker (section 5.5.2), it is assumed that this extends to e-scooters. Therefore, the velocity of a scooter, and by extension the motor power, are important factors that affect e-scooter usage. To complicate matters further, the energy the motor may demand from the battery could be exacerbated by driver style (e.g. rapid acceleration and breaking) and if a motor/battery uses regenerative breaking this complicates matters even further. These stochastic issues make it almost impossible to accurately evaluate the electrical load that a scooter demands when including these elements within a model.

In addition to the factors outlined above, the capacity of a battery is important as this directly impacts the range of distance an e-scooter can travel. As shown in Figure 16, range of distance can be impacted by other factors such as demographic and the built environment. The weight of a user and the inclination of a road will impact the energy required for the scooter to travel and therefore impact the electrical load demanded on the grid.

6.2.5 Demographic and Economics

The demographics and economics of both an individual and a wider population are important for determining e-scooter usage (as shown in sections 5.5.1 & 5.5.3). How people travel is often based on their circumstances of which economics plays a large role. The complexity of these two factors is increased when you consider how government policy may impact these (Figure 17). For instance, if government policy were to push people to get fitter and healthier, this may decrease the average weight of a population which would in turn have an effect on the energy required to power an e-scooter.

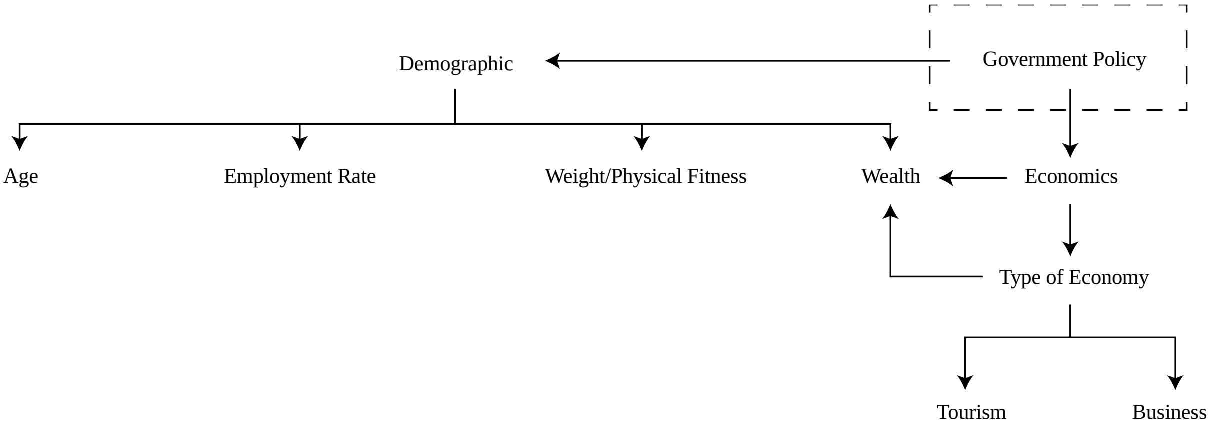


Figure 17: Showing the demographic and economic factors and the key elements that affect them. Government policy would dictate both of these and is shown in the rectangular box.

The type of economy of a built environment is important for predicting scooter usage and charging times. If an economy is mainly business-based, then it could be assumed that the majority of e-scooter users will be travelling to and from work between 8am and 9am and 5pm 6pm respectively. It could then also be inferred that scooters would only need to be charged after this time. Meaning that most scooters will be charged at approximately 7pm. When considering this in a broader context of the UK National Grid, this would be at a time when there is peak demand for electricity on the domestic network. Tourist journey demand would in theory be far more unpredictable and although it would be possible to predict peak times of use this could change based on a number of stochastic factors.

These factors are some of the most complex and stochastic. When considering modelling e-scooter usage and the electrical demand that may be exerted on the grid, these elements are beyond the scope of the model conducted in Chapter 7. Further work would need to be completed to assess these aspects before modelling taking place.

6.2.6 Consumer Behaviour

As shown in Figure 10, each of the factors outlined above (section 6.2.1 to 6.2.5) affect the choice a consumer makes and therefore has a direct impact on the electrical load demanded on the grid. As mentioned in several times through Chapter 5 scooters are becoming popular due to their accessibility through dock-less shared services. However, scooters can also be owned privately. The decisions that individuals go through prior to choosing e-scooters are similar but there are some differences, this is depicted in Figure 18.

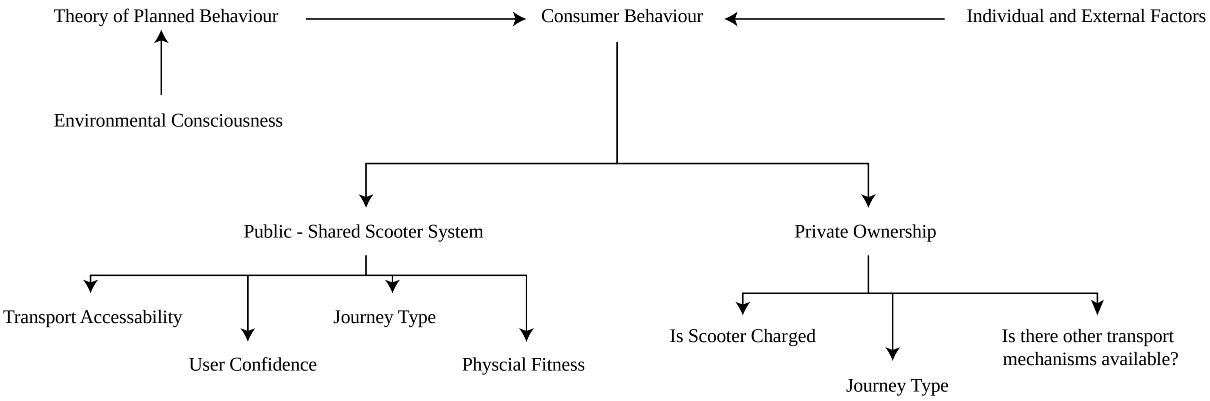


Figure 18: Showing the elements effecting consumer behaviour, the theory of planned behaviour where environmental consciousness is considered along with factors that affect public and private scooter riders - all other individual and external factors considered in the sections directly above feed into the consumer behaviour factor.

Parallels can be drawn between public and private scooter users. The type of journey people use them for is of particular importance. If they are being used for a daily commute to work, it is likely that the load would be consistent, as people would choose that mode of transport nearly every day. For public shared scooter schemes, the accessibility of e-scooters could be a key factor. Questions such as how far an individual has to walk in order to find a scooter and whether or not there is a more accessible option of travel are important. Ultimately, if we use the theory that people are likely to change their transport habits based on how long a journey takes (section 5.5.2) we can determine the likely usage of e-scooters.

Since e-scooter companies market themselves based on their ability to increase air quality and decrease CO_2 emissions in urban environments, it seems likely that if an individual is environmentally cautious this will affect their planned behaviour when travelling. Since those who are environmentally conscious are 11 times more likely to use public transport, we can infer this would be similar for e-scooters. This means the opinion of the environment from either an individual or a wider general public is a key component for determining the electrical load e-scooters could demand in a town.

6.2.7 Impacts from E-Scooters on the National Grid

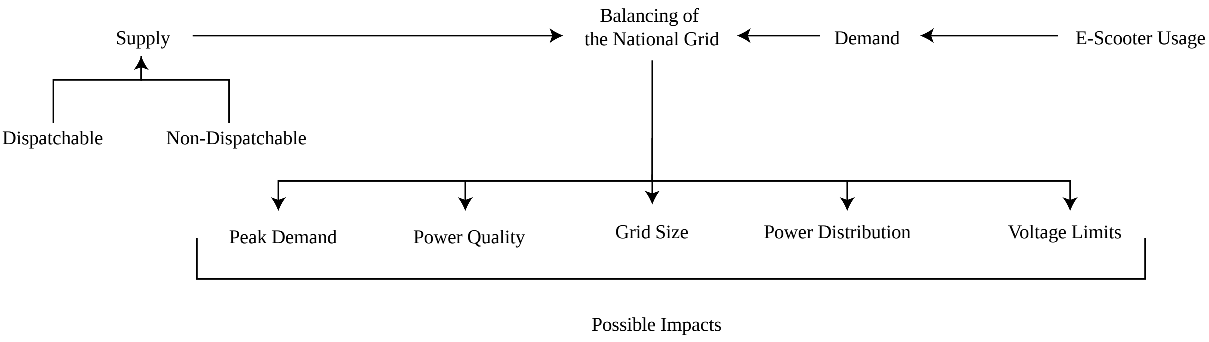


Figure 19: Showing the possible impacts that e-scooter usage could have on the National Grid.

The factors described above that impact e-scooter usage each contribute towards the overall demand they dictate from the UK National Grid. The possible impacts to the National Grid from the new electrical demand are highlighted in Figure 19.

The impacts of a new electrical load demand are complex. These impacts are clearly dependant on the overall usage of e-scooters which is dependent on the many factors discussed above.

The possible impacts discovered as part of the literature review in Chapter 5 are shown in Figure 19. The impacts are dependent on both the supply and demand.

The supply of electricity is crucial to maintaining a balanced grid. As discussed in section 5.7, the UK grid is supplied using both dispatchable and non-dispatchable energy types. The different classifications of supply are crucial when considering impacts on the grid. For instance, if the majority of the grid consists of non-dispatchable energy sources then there may be issues of balancing the grid during periods of peak demand. Aspects such as the journey and economy type (as shown in Figure 17 & Figure 18) of an urban environment will affect this. If the majority of journeys are tourism related, and charging can take place at any time in the day, there could be a large surge of energy demand during an unexpected period. Unexpected demand in a non-dispatchable dominant energy system may cause the grid to become unbalanced and have serious consequences for the security of supply.

As mentioned previously, the impacts such as power quality, voltage limits and power distribution are not considered in this paper. However, the size of grid increase forced from the uptake in e-scooter usage is considered within the modelling. This increase in infrastructure would have a consequence on all three of the impacts not considered.

6.2.8 Charging of E-Scooters

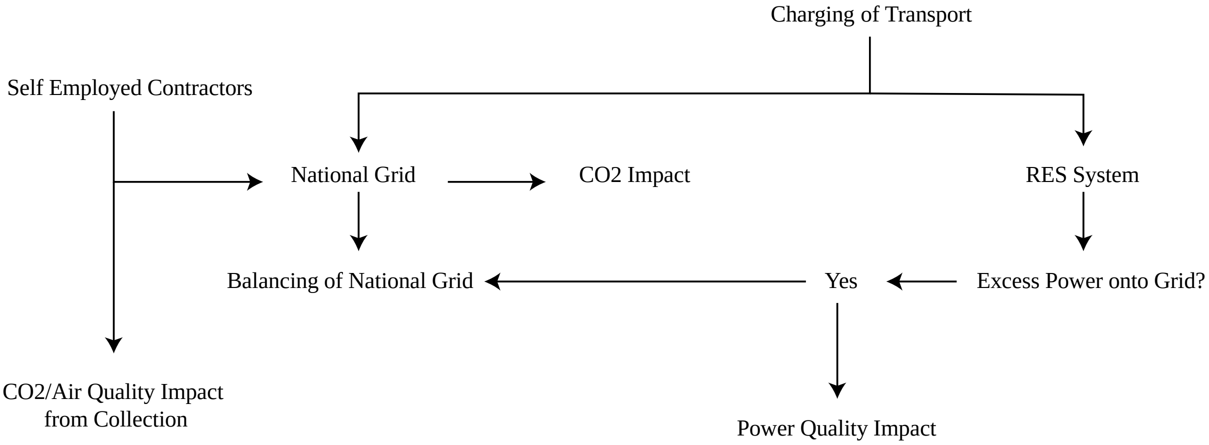


Figure 20: Showing the charging of transport factor and what impacts may be a result of charging e-scooters.

The current e-scooter charging structure used in the US has already been described as inefficient. Self-employed contractors collect the scooters from various random locations. Contractors often use their cars to collect scooters to maximise earning potential. If we first assume that the same charging structure is used in the UK, then there will be a CO_2 and air quality impact on the urban environment during this process. This is difficult to quantify and not included in this paper, however, it is important to recognise that these impacts exist.

The impacts on the National Grid have already been described and depicted in section 6.2.7 and Figure 19 respectively. An alternative charging structure could exist that exploits natural resources such as solar and wind in order to charge the e-scooters. By using a renewable energy system (RES) that is not dependent on the grid the impacts shown in Figure 19 could be eliminated. However, if the RES system is not designed to maximise the resource through DSM, there may be excess non-dispatchable power that is added to the supply of the grid (Figure 20) impacting aspects such as power quality.

The future charging of electric scooters in the UK is purely speculation, there is no data measuring current usage due to their legal status. This allows us to assume that they will be charged in a similar way within the US. However, it is suggested that the future charging of UK scooters could be altered to be more efficient and sustainable from both an economic and environmental standpoint (section 5.4).

6.3 Consideration of Factors

The initial examination of literature and previous research evaluated in Chapter 5 showed how complex it can be to determine the usage of a transport mechanism. The above sections in this chapter have focused on the factors that could affect electric scooter usage in the UK if their legal status changed. In addition to this a review of the impacts that could be felt on the National Grid along with the current US charging system are shown.

One of the key factors identified is the e-scooter technology which has not been considered in previous research of other light electric transport mechanisms. In addition to this, climate/weather and built environment (town characteristics) factors also play a major role in determining the demand for e-scooters as transport methods.

The factors that affect transport are complex stochastic issues. It would be foolish to assume that the factors discussed above are all the possible factors that could affect e-scooter usage. It is likely that there may be factors that have not been considered which could have a minor or major impact to e-scooter usage.

Chapter 7 – Modelling E-Scooter Usage

From the previous chapters, it has been made clear that accurately modelling future e-scooter usage in the UK is complex. The importance of modelling the possible e-scooter usage has been reviewed in section 5.3.1. This review has shown that the modelling of potential e-scooter usage is a key step in the process of attempting to understand the electrical load and impacts that they could have on the UK National Grid. However, the complex stochastic nature of many of the factors that could affect e-scooter usage (highlighted in Chapter 6) make this part of the process exceptionally difficult.

Since e-scooters are currently illegal for use on public roads and pathways in the UK, the future usage is completely hypothetical. With this in mind, it is possible to model the potential usage in a hypothetical manner. This allows us to make assumptions on some of the stochastic factors described in the above sections. In order to complete the analysis, a hypothetical town (E-Village) has been created and the assumptions for this town can be seen in the section below.

A model of the e-scooter usage in E-Village has been created using Microsoft Excel. There are two stages within the modelling phase. The first stage is to calculate the demand for e-scooters in E-Village. The second is to calculate the electrical load the scooters require to be charged. With this in mind, the model created shows the electricity demanded for e-scooters based on the public’s uptake of the transport method.

7.1 Assumptions for Modelling

Assumptions have been made for some of the factors that could affect e-scooter usage in the hypothetical E-Village. As shown in the previous chapter, the integration of all factors within the model is unfeasible. A focus has been emphasised on the characteristics of a town (built environment), the weather and environmental consciousness of a town.

7.1.1 Government Policy, Demographic, Economy and Consumer Behaviour Assumptions

A key assumption made is the national government policy on the usage of e-scooters. It is assumed that the government has first allowed the use of e-scooters on the roads of the E-

Village and secondly will continue to support the Paris Agreement, and therefore a reduction in CO_2 emissions within the country. Assumptions have not been made on a local policy level as the cycle lane infrastructure and the safeness of roads are considered within the town.

Within the hypothetical E-Village there is a population of 100,000. This population is fixed and is not subjected to increases/decreases. The majority age range is 18 – 30. The weight of the population is not considered in the modelling or is their wealth. It is assumed that all residents are employed and commute to work. In addition to this, the E-Village economy is based on business rather than tourism. This means that there are no tourists using e-scooter sharing services during the day and that all journeys are commuter related. It is assumed that the communication infrastructure of a town is not relevant to the overall demand of e-scooters used by the general public.

Some aspects of consumer behaviour have been assumed and others have been included. Private and public users have been split like those seen in Figure 18 and is explained further in sections 7.2.1 & 7.2.2. For private e-scooter users, accessibility of e-scooters and accessibility of other transport types have not been considered. In addition, the charge status of a privately-owned e-scooters has not been considered as an impact to e-scooter usage. For both public and privately users, their confidence in their ability to ride scooters safely is not considered along with their physical fitness.

7.1.2 Technology Assumptions

The technology specifications of an e-scooter have a key impact on whether or not a consumer chooses to use them on a daily basis and the demand they create on the grid. A key technology specification is the distance of which e-scooters can be used before requiring charging. The technology in the battery and the power that is demanded of it from the motor are the key elements that dictate this. As highlighted in section 5.2, the capacity of a battery can be calculated using Equation 1 from section 5.2.3 and the technical specifications of the battery used in the modelling period can be found in Table 4: The technical specifications of a Bosch Battery Powerpack 500 for their e-bike range - adapted from (Riese & Muller , 2016). From these specifications and Equation 1, the capacity of the e-scooter battery can be calculated in the following:

$$Energy\ Content = Voltage \times Rated\ Capacity$$
$$Energy\ Content = 36 \times 13.4$$
$$Energy\ Content = 482.4\ Wh$$

Table 7: Showing the battery efficiency and usability used in the modelling phase of this paper.

Battery Efficiency and Usability	
Battery Efficiency	90%
Battery Usability	70%

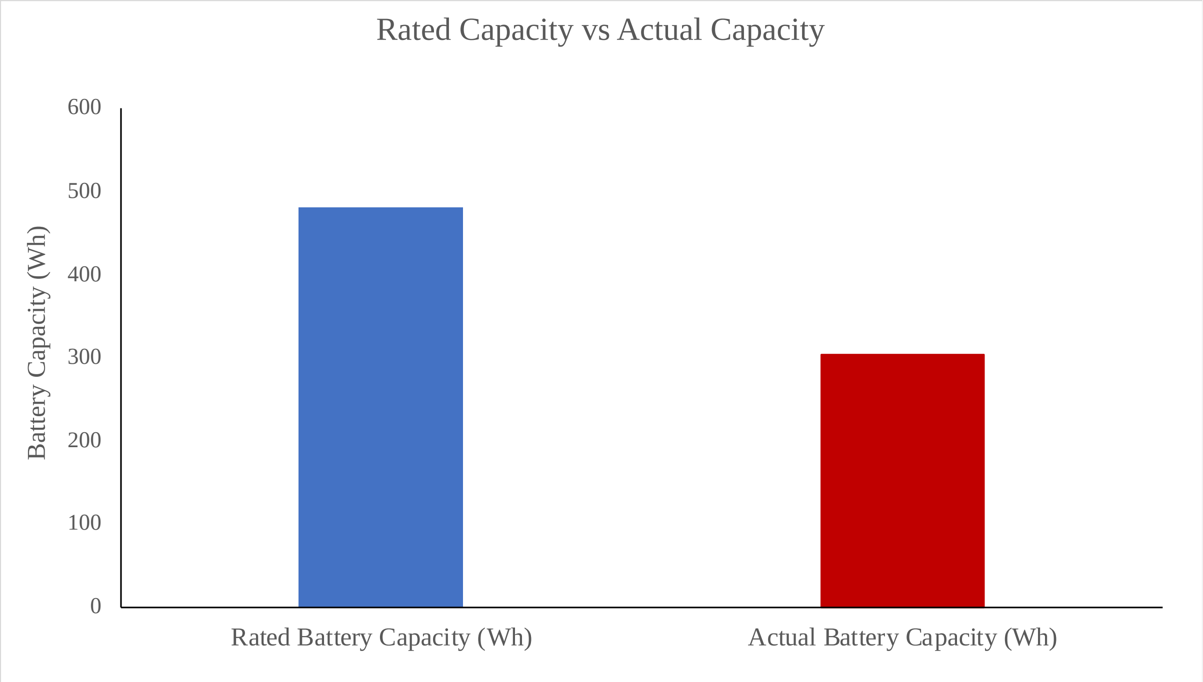


Figure 21: Showing the difference between the rated and actual capacity of the e-scooter battery once efficiency and usability is applied.

The total energy capacity of the battery is shown above as 482 Wh however, this assumes that the battery is 100% efficient and that all 100% of the battery is usable. We know from Table 3 that Li-Ion batteries, like those found in e-scooters, have a 20% – 90% usable range. This means that only 70% of the energy within the battery is available (Table 7). An efficiency of the battery is also applied and in the base case for analysis is 90%, the lower limit for efficiency for Li-Ion batteries (Table 3). As a result, within the base case of analysis, the total energy capacity for the scooter battery is 304 Wh. The difference between the rated and actual capacity is shown in Figure 21. All e-scooters modelled have the same battery. The SoC and SoH of a battery is not considered in the modelling.

7.1.3 Range Calculation of Battery

The range of a scooter is dependent on the battery capacity. The energy demanded from the battery is dependent on many factors for example motor power, user weight and road inclination. When calculating the energy used by the scooter these are not considered. Instead we use the range of distance for which an e-scooters is certified. The particular e-scooter used in this paper is the Boosted Rev shown in Figure 6. The Boosted Rev has a certified range of ~35 km. However, an efficiency has been applied to this range. This range relates to the accuracy of testing where real world conditions are undoubtably not replicated correctly. Applying the efficiency in Table 8, the actual range of scooter in the modelling process is ~28km.

Table 8: The value of efficiency applied to e-scooter range due to the inaccuracy of testing.

Scooter Testing Assumptions	
Range Testing Accuracy	80%

If we apply both the capacity and range, we can determine the Wh/km used by an e-scooter (Equation 2). In the baseline modelling case this is 11Wh/km.

Equation 2: Calculation of the ratio for battery capacity vs electric scooter range

$$Wh/km = \frac{Battery\ Capacity}{electric\ scooter\ range}$$

$$Wh/km = \frac{304}{28}$$

$$11\ Wh/km$$

The resulting Wh/km seen above can be validated by comparing this figure to previous studies (Paffumi, et al., 2015).

7.1.4 Charging E-Scooters

As mentioned briefly above, the SoC and the SoH of a battery is not considered within the Excel model. We assume that e-scooters are charged on a daily basis regardless of their SoC. Equally, the effect the daily charging has on a battery's SoH is not considered. Instead it is assumed that SoH is constantly 100%.

Since e-scooters used in E-Village is purely for the purposes of commuting it is assumed that no charging of scooters takes place during the day. Instead, charging takes place after commuting time and starts from 7pm. Charging takes 3.5 hours.

7.2 Calculating User Demand

As mentioned previously, the demand of e-scooters as transport mechanisms is the key to determining the electrical load and whether or not there will be any impact to the UK National Grid. Within the Microsoft Excel model two types of demands have been determined: private and public. Private demand refers to those who own their own e-scooters. Public demand is those who use shared e-scooter services. The total number of scooters in the E-Village is 10,000 (10% of the population) and is split between the two different types of demand.

7.2.1 Private Demand

It is assumed that 1% of the population of the E-Village own an electric micro-scooter. This means that 1,000 scooters that are privately owned are used on a daily basis to commute to work. The distance of the commute is dependent on the user profiles created (Table 9). This demand is not affected by any factor and remains a constant electrical load that is demanded from the grid.

7.2.2 Public – Shared Scooter Demand

The Microsoft Excel model considers public demand separately from private demand. Within the E-Village, there is a maximum number of scooters that are available for rent through the shared scooter scheme. Within the model, 9% of the population use e-scooters through the shared scheme. This means that 9,000 scooters are available on the streets. Unlike private demand, public demand is determined by the town's characteristics, weather, the resident's environmental consciousness and the accessibility of e-scooters. Each of these factors have a consequence on the demand depending on their relevance to e-scooter usage. This is discussed further in section 7.2.4. If the demand is 100% then 9,000 scooters are used for commuting.

7.2.3 E-Scooter User Profiles

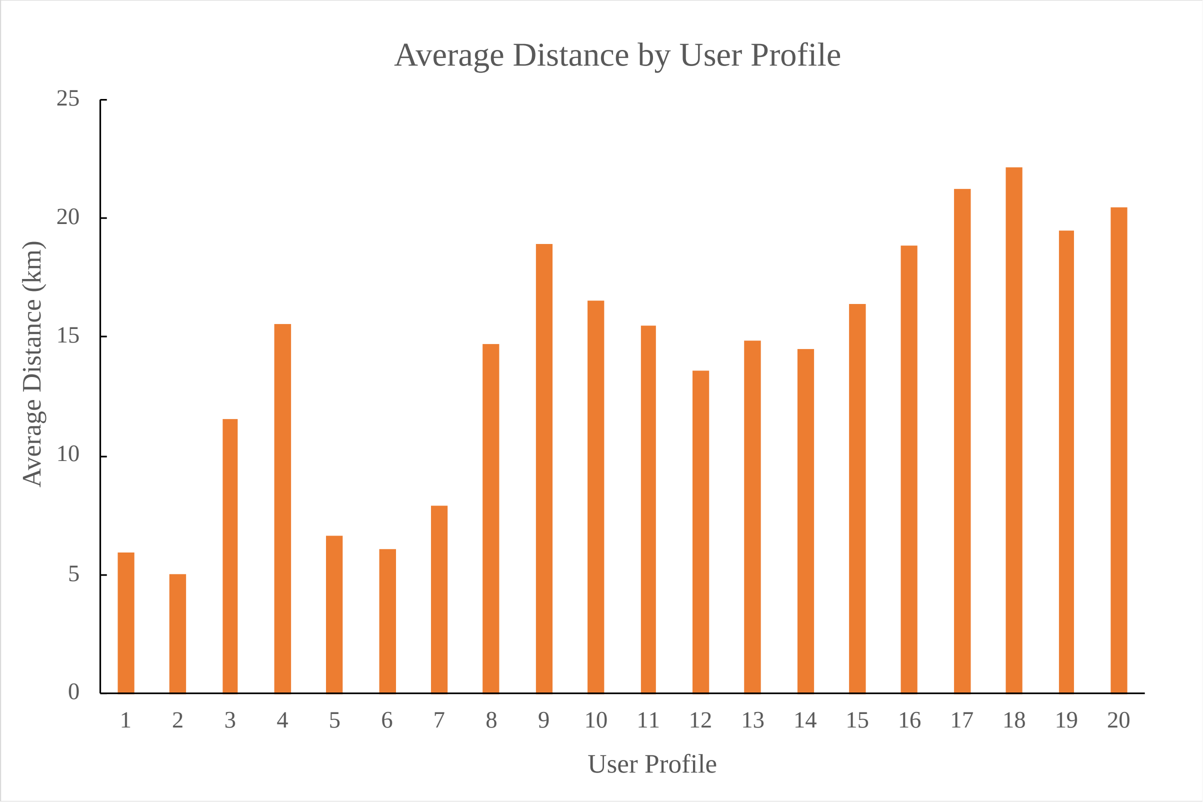


Figure 22:Showing the average distance by each user profile type.

Within the Microsoft Excel model, 20 different user profiles have been constructed. The user profiles are based on different distances that an individual covers on a daily basis. Within each profile, 100 different distances, randomly selected by Excel using Monte Carlo simulation, are used to calculate the average energy demand of each profile.

Each profile has a lower and upper limit of distance that can be randomly generated (Table 3). Across all profiles the minimum distance that an e-scooter can be used is 1km and the maximum is 28 km (the maximum range of the scooter). In addition to this, each profile represents a percentage of the population.

As a baseline, each profile equates to 5% of the population. This means that if the population of the E-Village is 100,000 and 10% of the population use scooters then each profile is multiplied by 500 people. The average distance of each user profile is shown in Figure 22 after a simulation of distances. The average distance within this simulation is 16 km meaning that if a consumer uses them for travelling to and from work each journey is 8 km on average.

7.2.4 Impacts to Shared E-Scooter Demand

Having completed a review of the factors that affect e-scooter usage in Chapter 6, three key aspects have been identified which can be modelled effectively. Each of the factors has been broken down to evaluate different elements and can be seen in the tables below. Each element has a consequence on the overall demand of the shared scooter scheme if true or false. The maximum demand of e-scooter usage is 100%, each of the elements reduce the demand if there is a negative consequence. The total demand is then used to multiply each user profile depending on the percentage they make up of the population.

7.2.4.1 Town Characteristics

Four elements have been used in the modelling step of the process to determine the total demand for shared e-scooters. These can be found in Table 10.

The first element is the congestion of a road, this has a direct impact on the length of time a journey can take. If congestion is an issue within an urban environment (and therefore true) demand is 100%. If congestion is not an issue and journeys are already relatively quick, then the demand is reduced to 40%. Similarly, with road safety, if roads are determined safe, then the demand is 100%, if not then it reduces the demand by 50%. We know from section 5.5.2 and 6.2.2 that cycle lane infrastructure has a large impact on transport type usage. Within the Excel model if there is an extensive cycle infrastructure within the e-village, then the demand remains 100%, if not then demand is reduced to 70%.

Table 9: Showing the upper distance, lower distance and percentage of population each user profile can have in the Excel model.

Scooter User Profile	Lower Distance (km)	Upper Distance (km)	Percentage of Population (%)
1	1	10	5
2	2	9	5
3	3	20	5
4	4	28	5
5	5	8	5
6	6	10	5
7	7	9	5
8	8	23	5
9	9	28	5
10	10	23	5
11	11	20	5
12	12	15	5
13	13	17	5
14	14	15	5
15	15	18	5
16	16	22	5
17	17	25	5
18	18	27	5
19	19	20	5
20	20	21	5

Although not used in the calculation of the energy used by an e-scooter, the inclination of a town is considered when determining e-scooter usage. If the inclination of a town is greater than 11 degrees, then the demand remains 100%, if it is less then demand is reduced to 90%.

Table 10: Showing the elements used in the Excel model for town characteristics. The consequence for demand is also shown where: when values are true demand remains at 100%, when the consequence is false demand is reduced by the relevant percentage.

Elements	**Consequence**	
	True	**False**
Road Congestion	100 %	40 %
Road Safety	100 %	50 %
Cycle Lane Infrastructure	100 %	30 %
Inclination of Town (≥ 11°)	100 %	90 %

7.2.4.2 Weather

Two elements that affect demand have been modelled in Excel for the E-Village: whether or not it is raining and temperature (Table 11). Each of these have been determined to have a significant effect on e-scooter usage. Within the model, rain or no rain can be selected for a day. If raining, the demand is significantly reduced to 30%. Similarly, with temperature, if the temperature is ≥ 11 °C then the demand remains 100%. If the temperature is ≤ 10 °C then the demand is reduced to 30%. It is clear that if either of these indicators are false, then the demand significantly decreases.

Table 11: Showing the elements used in the Excel model for weather. The consequence for demand is also shown where: when values are true demand remains at 100%, when the consequence is false demand is reduced by the relevant percentage.

Elements	**Consequence**	
	True	**False**
No Rain	100 %	30 %
Temperature (≥ 11 °C)	100 %	30 %

7.2.4.3 Consumer Behaviour

Consumer behaviour in the E-Village has the biggest impact on e-scooter demand. This is shown in Table 12 where environmental consciousness and accessibility of e-scooters are highlighted as the elements used in the Excel model. Where environmental consciousness is an important issue in the E-Village then the demand is 100%, where it is not it reduces the demand to 9%. This is based on Donald, et al. (2014) highlighted in section 5.5.6. One of the key attractions of e-scooters is that they are highly accessibile. An assumption has been made that if e-scooters are hihgly accessible then demand is 100%, if e-scooters are not highly accessible then demand reduces to 20%.

Table 12: Showing the element used in the Excel model for consumer behaviour. The consequence for demand is also shown where: when values are true demand remains at 100%, when the consequence is false demand is reduced to the relevant percentage.

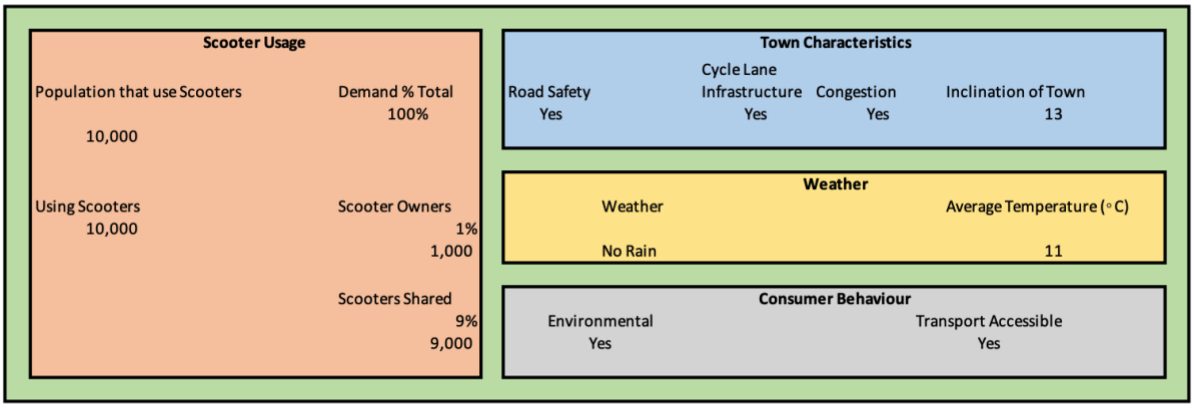
Elements	**Consequence**	
	True	**False**
Environmental Consciousness	100 %	9 %
Accessibility of E-Scooter	100 %	20 %

7.3 Model Example

The steps taken to determine the impact on the grid are shown in this section.

7.3.1 Calculation of Demand for E-Scooters as Transport

The calculation of demand is simple in the Excel model. An "If" function links the consequences of the true or false nature of the elements and the overall demand of e-scooters in the E-Village. Within the model, a user can select either true or false for each of the elements.



Scooter Usage

Population that use Scooters: 10,000
Demand % Total: 100%
Using Scooters: 10,000
Scooter Owners: 1% 1,000
Scooters Shared: 9% 9,000

Town Characteristics

Road Safety: Yes
Cycle Lane Infrastructure: Yes
Congestion: Yes
Inclination of Town: 13

Weather

Weather: No Rain
Average Temperature (◦ C): 11

Consumer Behaviour

Environmental: Yes
Transport Accessible: Yes

Figure 23: Showing a screen capture from the input section of the Excel model where all elements are true and demand for shared e-scooter scheme is 100%.

An example of the Indicator input section can be seen in Figure 23. The “If” statement script from Excel is shown in Chapter 13– Appendix.

Within Figure 23, two values can be seen for the number of scooter users. “Population that use scooters” is the maximum number of scooters than can be used at any one point. This figure is dependent on the percentage of e-scooter users and the shared e-scooter users in comparison to the population of E-Village.

“Using Scooters” shows the total number of scooters that are actively being used for commuting. This is linked to the “Demand % Total”. In this example, since demand is 100%, the total using e-scooters is 10,000. The minimum number this can be is 1,000. This would only occur if demand were 0% for the shared e-scooter schemes. This is due to the assumption that private e-scooter users always use their own e-scooters for commuting, regardless of the factors surrounding them.

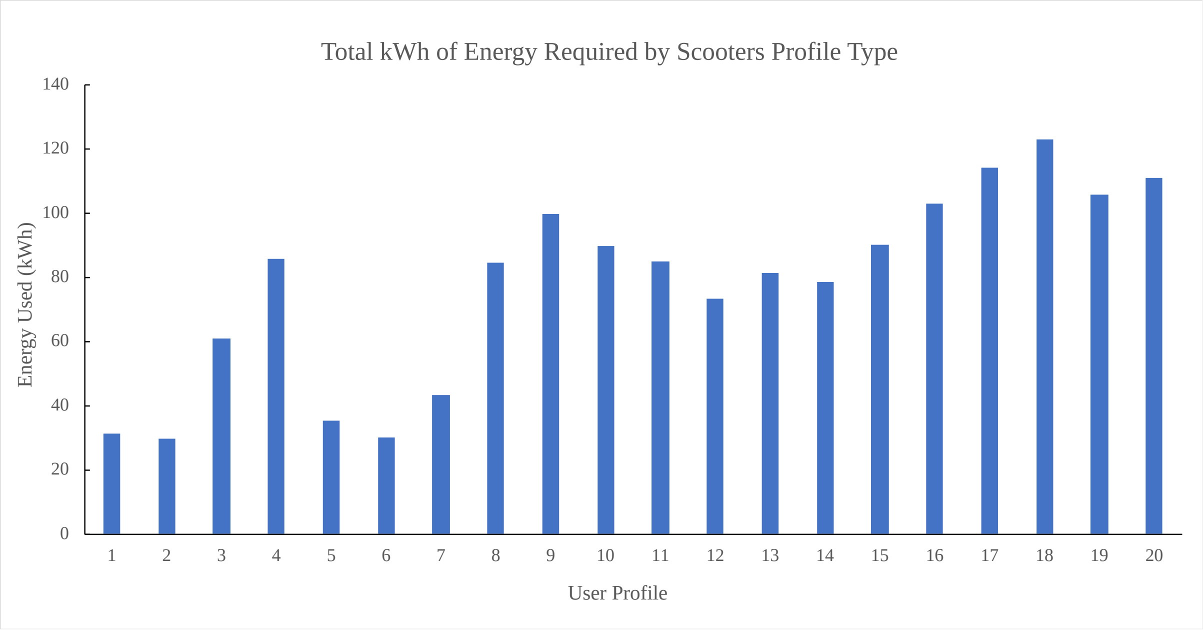


Figure 24: Showing the total energy demand of each user where demand is 100%. The demand is calculated by using Equation 2.

If we consider this case where demand for e-scooters as a transport mechanism is 100%, then we can determine the energy demanded for the commute to and from work for each e-scooter user. As demand is 100%, there are a total of 10,000 e-scooters being used. Since the 20 profiles are split evenly (5% of the population each - Table 9), there are 500 users in each profile. The average distance of each profile is calculated within the model (Figure 22) and using Equation

2 we can calculate the energy demanded of each profile type and then by the total number of e-scooter users. Figure 24 is a graph showing the total energy (kWh) required by each user profile where demand is 100% and 10% of the population use e-scooters. As mentioned above, each profile has 500 different users. This gives a total energy demand of ~1.5 MWh.

7.3.2 Impact to Grid

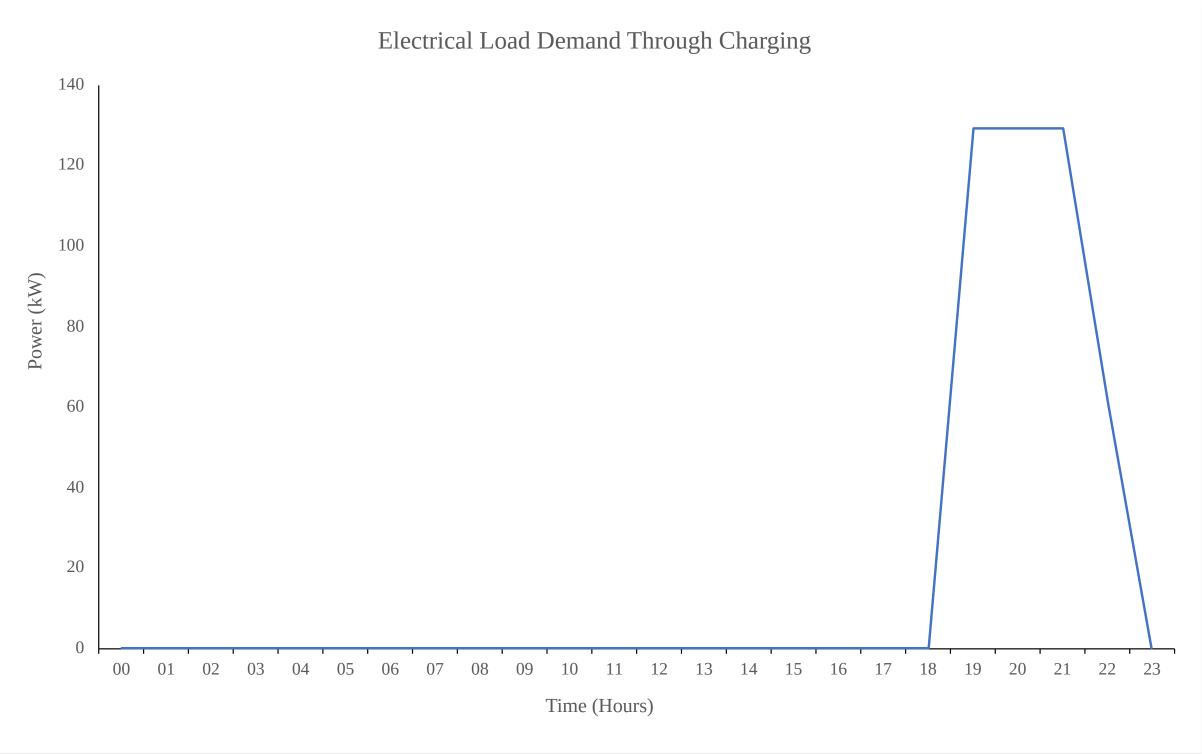
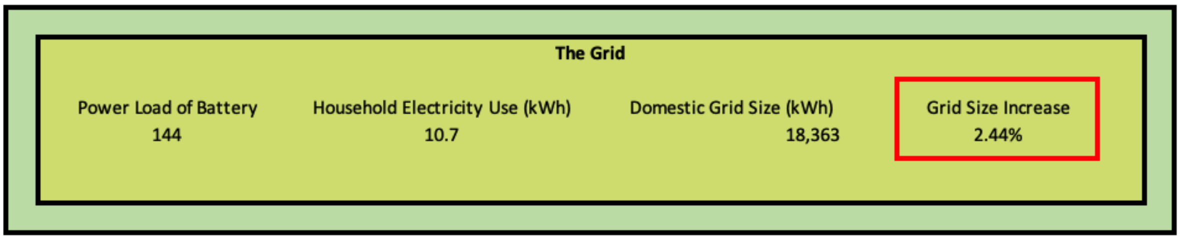


Figure 25: Showing a graph of electrical load demanded by the charging of e-scooters. Where demand is 100% in E-Village and charging begins at 7pm.

The model is designed to determine two impacts to the grid: the electrical load required for charging and the size the grid is required to increase in order to maintain a balanced grid. As mentioned in the assumptions (section 7.1.4) charging of all e-scooters begins from 7pm. The model uses this information and determines the electrical load across the charging time (3.5 hours). In addition to this, as depicted in section 5.7.2, the average household in the UK uses 10.7 kWh of electricity per day. This value has been used in the E-Village model to determine the original size of the domestic electricity demand. In conjunction with this, the ratio of households to people in the UK (Table 6) is used to determine the total number of households



The Grid

Power Load of Battery	Household Electricity Use (kWh)	Domestic Grid Size (kWh)	Grid Size Increase
144	10.7	18,363	2.44%

Figure 26: A screen capture from the Excel model showing the grid size increase.

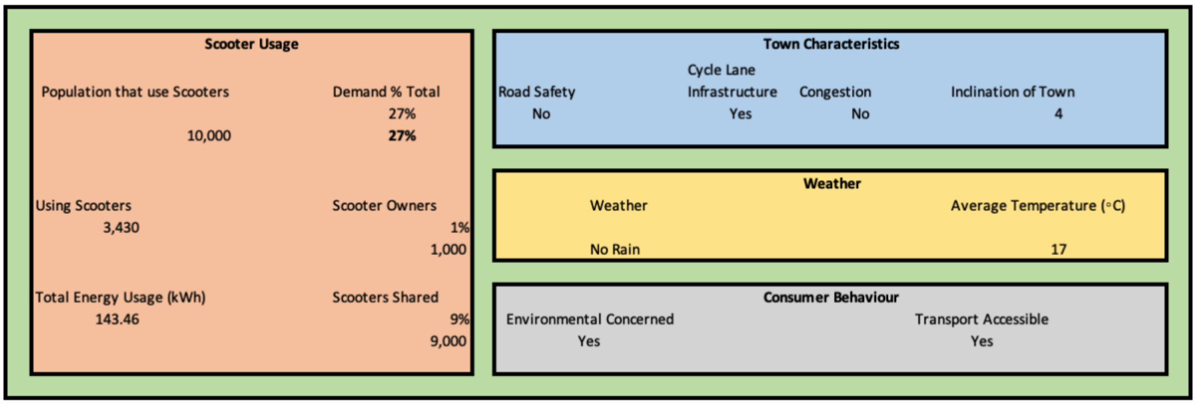
in the E-Village model. In the E-Village the total domestic electrical demand in the baseline model is ~18 MWh for a day.

The total energy demand for the e-scooter users in the 100% demand case discussed above is ~1.5 MWh. This equates to ~450 kW of power demanded from the grid. The charging profile is shown in **Error! Reference source not found.**. As charging begins at 7pm, this coincides with the peak demand of the grid (as displayed in Figure 12). This means that the grid would need to increase by ~2.4% in order to maintain the balanced nature of the grid if 10% of the population used e-scooters (Figure 26). The charging would also add ~135kW of power to the peak demand.

The increase of 2.4% of domestic supply is relatively low. For example, in the UK, the expected growth of EVs could cause the entire UK grid to double (National Grid Eso, 2019). As the model only considers domestic energy demanded from the grid, the percentage increase caused by the uptake in e-scooters could in fact be very insignificant. However, if everyone used e-scooters, and all factors/elements were true, it could be a very significant increase to the grid. The Excel model helps to quantify the demand and is a very important step in the process of ascertaining the effect of e-scooters.

7.3.3 Changes to Indicators

To provide an example of how the model can be altered to determine demand, three out of four elements in the town characteristics have been changed to be false: road safety, congestion and the inclination of a town. By changing these three indicators to false, the demand for e-scooters reduces to 27% resulting in 3,430 people using scooters (Figure 28). The resulting demand reduction from the changing of the indicators reduces the total energy demand to ~140 kWh, peak demand to 12 kW (Figure 27) and results in an increase of ~0.2% to the domestic E-



Scooter Usage

Population that use Scooters: 10,000
Demand % Total: 27% **27%**
Using Scooters: 3,430
Scooter Owners: 1% 1,000
Total Energy Usage (kWh): 143.46
Scooters Shared: 9% 9,000

Town Characteristics

Road Safety: No
Cycle Lane Infrastructure: Yes
Congestion: No
Inclination of Town: 4

Weather

Weather: No Rain
Average Temperature (◦C): 17

Consumer Behaviour

Environmental Concerned: Yes
Transport Accessible: Yes

Village grid. This shows how the demand for e-scooters directly links to the electrical load demanded from the grid.

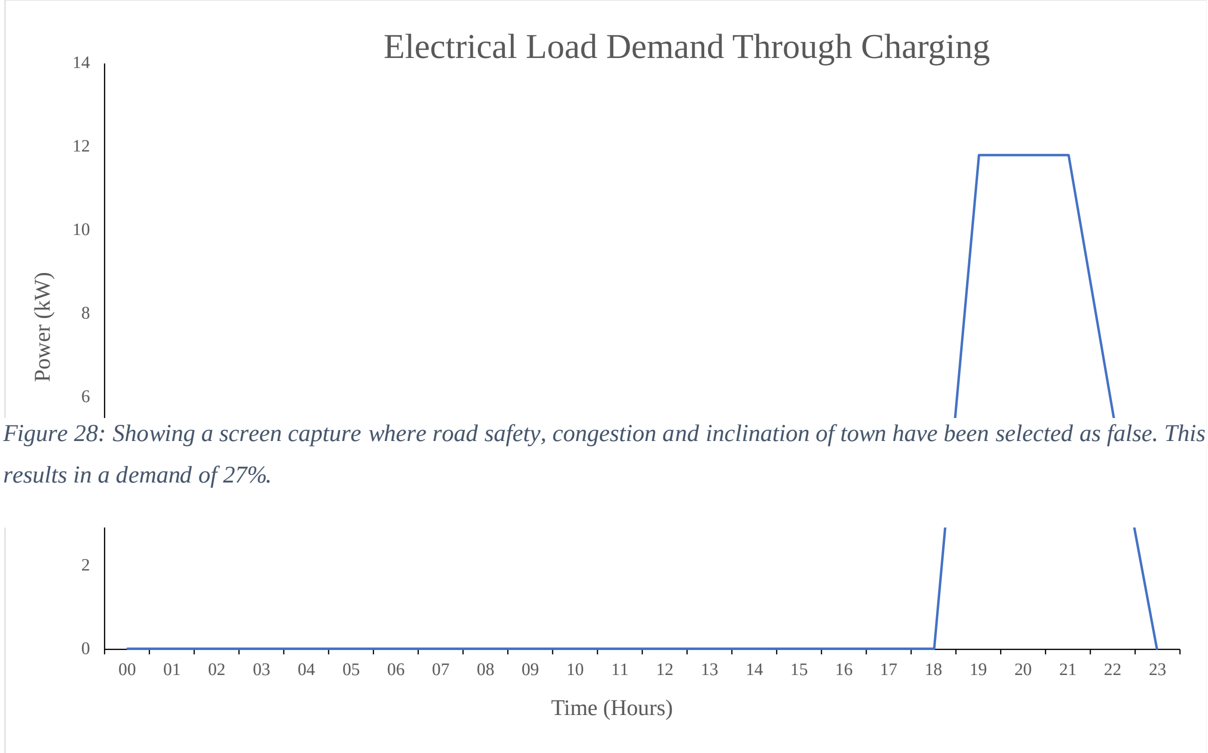


Figure 28: Showing a screen capture where road safety, congestion and inclination of town have been selected as false. This results in a demand of 27%.

Figure 27: Showing a graph of electrical load demanded by the charging of e-scooters. Where demand 27%. In E-Village and charging begins at 7pm.

Chapter 8 – Sensitivity Analysis

Sensitivity analysis has been completed for a various number of different aspects to demonstrate how the model may respond to changes within the E-Village. The analysis has been done when demand of public shared scooter systems is 100% and all elements listed in section 7.2.4. Conducting sensitivity analysis is an important step in the process of determining e-scooter usage. Changes to society and technology occur frequently. Understanding what the possible implications could be for any changes is an important procedure.

8.1 Changes to E-Scooter Users

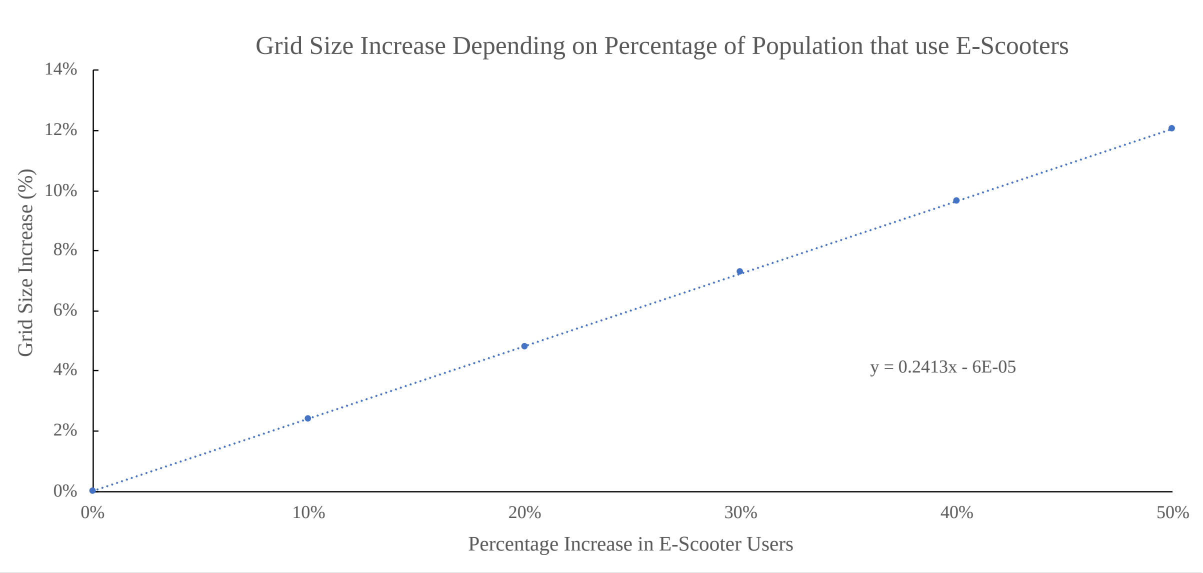


Figure 29: Grid Size increase required for percentage increase in e-scooter users within E-Village when all indicators are true and shared e-scooter demand is 100%.

Sensitivity analysis has been done to show how changes to the number of e-scooter users within the E-Village population affects the grid increase size. Figure 29 shows the relationship between the grid size increase and the percentage increase in e-scooter users within the E-Village. A trend line has been added and the relationship can be described as linear. The results from the sensitivity analysis show that in the E-Village that if 50% of the population used e-scooters the domestic grid would only increase by ~12 %.

8.2 Range of Scooter Battery

The range of which a scooter can travel is a key aspect of the Excel model this is explained through Equation 2. Analysis was conducted to determine the relationship between the tested distance range of an e-scooter and the grid size increase required within the baseline model. In the baseline mode, e-scooter range is 35 km before the testing efficiency is applied. The e-scooter distance range has then been increased by increments of 5 km. The result is a linear reduction in grid size. When e-scooter range is doubled, the grid increase required is reduced by 1%.

8.2.1 Accuracy of Range Testing

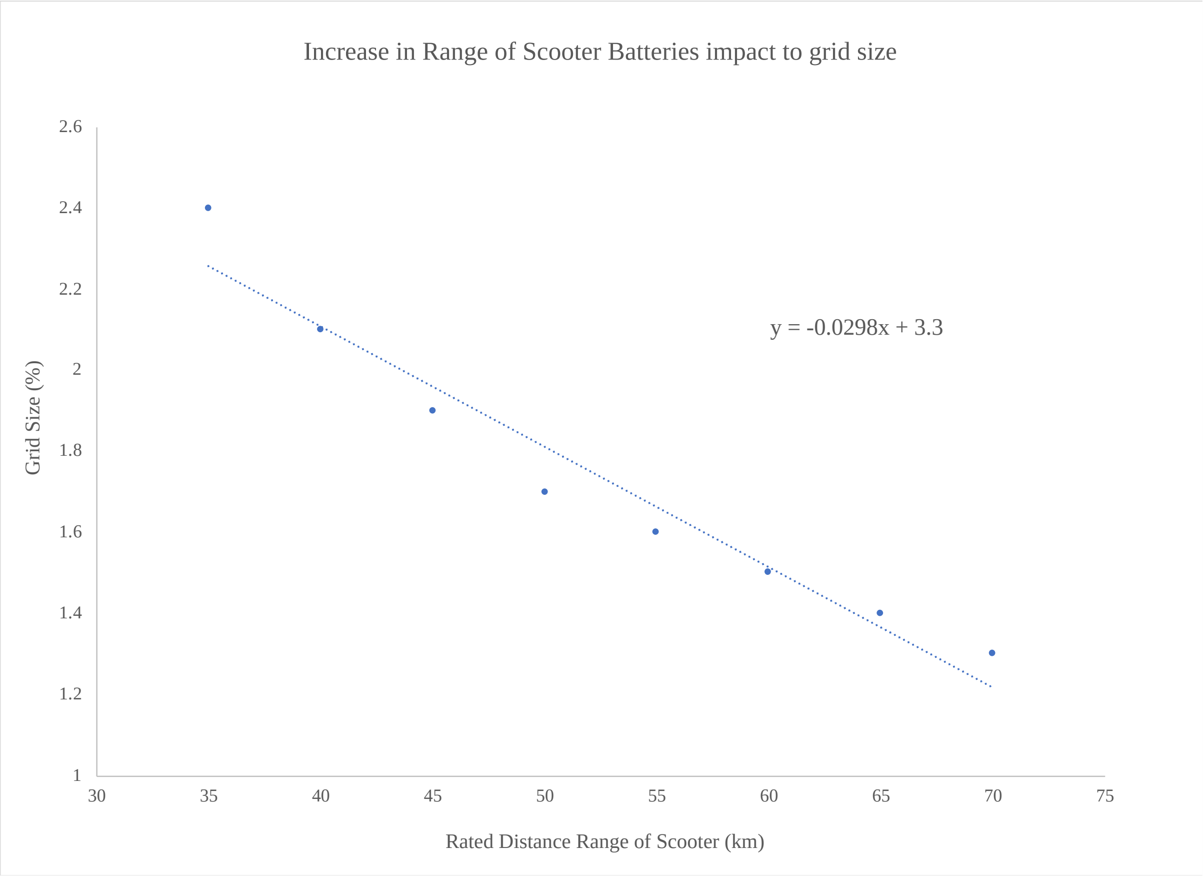


Figure 30: Showing the relationship between the increase in scooter range and grid size increase required to maintain a balanced grid.

One of the aspects included within the model was the ability to alter the range testing efficiency percentage. Within the baseline model this was fixed at 80%. Analysis has taken place to examine the relationship between the range testing efficiency percentage and the grid size

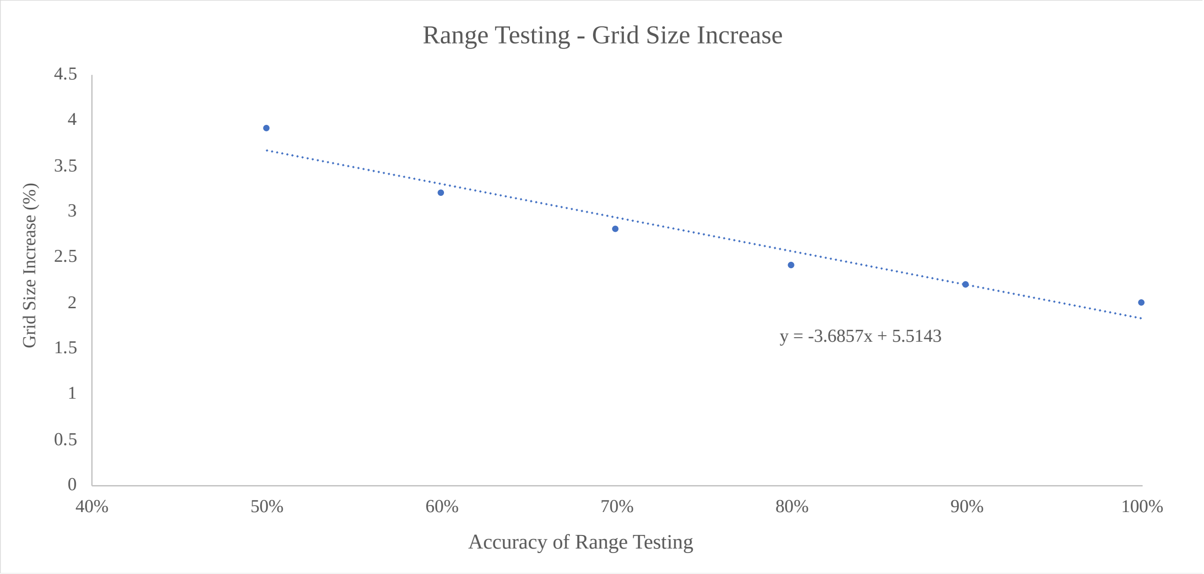


Figure 31: Sensitivity analysis showing how range testing efficiency can influence the grid size increase required to maintain a balance grid.

increase required in order to maintain a balanced grid. When the efficiency is greater than the baseline value, grid size increases. When the efficiency is less than the baseline value, grid size increases.

8.3 Change of Charging Time

Within the original model, charging took place from 7pm after the daily commute cycle had been completed. Analysis has been done to show how shifting of a percentage of the load to overnight could reduce the peak demand at an already demanding time for the grid. Figure 32 shows the original demand with a varying percentage shifting to a 2am charging time. As the percentage of the load shifted is increased, the demand at 7pm decreases. Where 90% of the load is shifted this reduces the load at 7pm (peak demand on the grid) to 13 kW - a reduction of 116 kW.

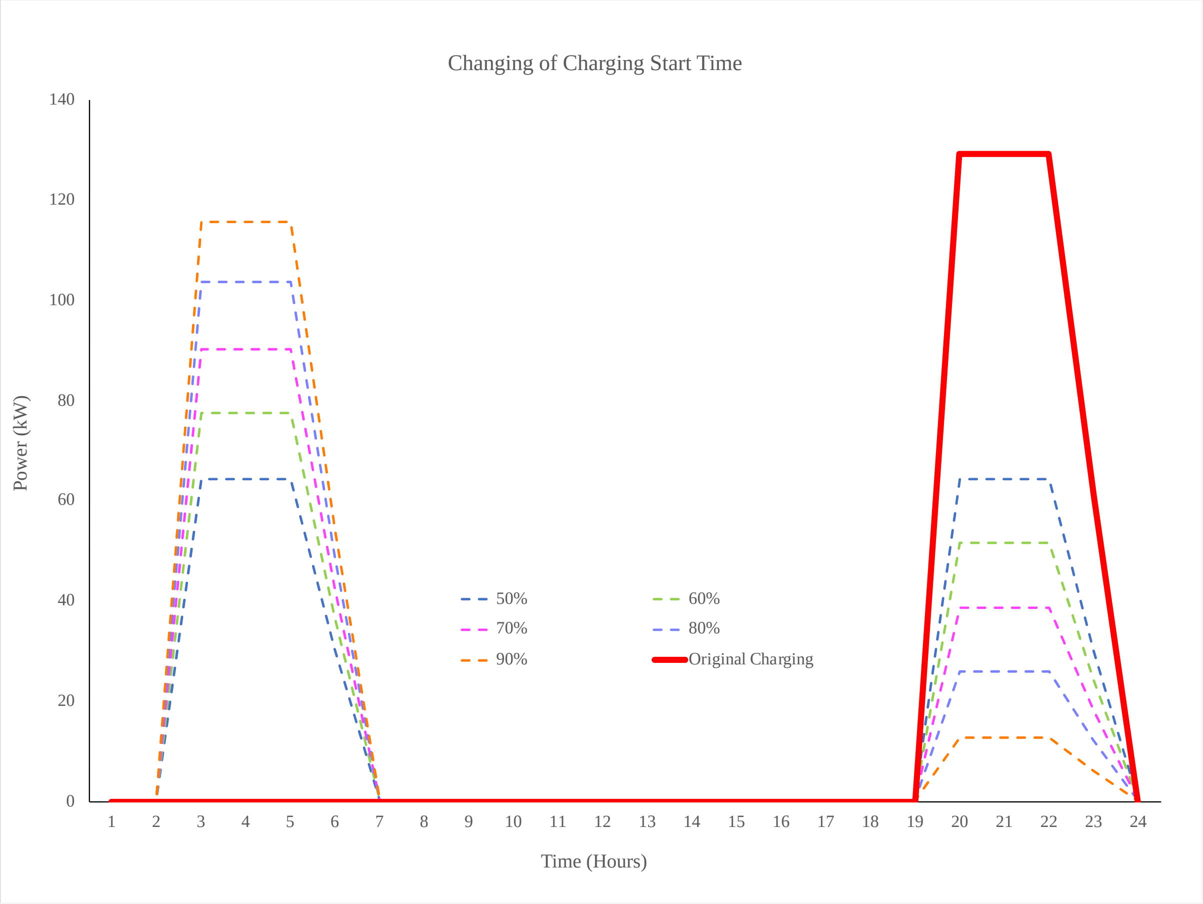


Figure 32: Showing how changing the charging time for a percentage of demand can alter the peak demand. Where 50% to 90% of the demand has been change so charging begins at 2am.

Chapter 9 – Randomised Controlled Trial

This paper has so far looked at literature, how the literature applies to e-scooters and modelling. The analysis completed thus far has been entirely hypothetical. For meaningful data to be collected, an RCT needs to be completed. This section develops the framework of an RCT and makes up part of the process required to determine electrical scooter usage and load on the grid. It is beyond the scope of this paper to conduct such an experiment. However, an attempt has been made to create a trial that could be used to determine: the key factors that affect e-scooter usage demand in the UK, the electrical load demanded from the grid and the impacts that the grid is subjected to.

9.1 Trial Purpose

The purpose of the trial is to ascertain the key factors that affect usage of public shared e-scooter schemes in an urban environment. From the demand it would be possible to develop an understanding of what likely electrical load could be inflicted on the UK National Grid. The trial will be tasked with gathering data on how e-scooters are used by consumers who have a range of demographic and economic factors.

The model developed in Chapter 7 showed how factors could affect demand. The factors included in the model were town characteristics, weather and consumer behaviour. The data gathered from the trial could help to provide more accurate figures for the consequences that lead to a reduction in demand for each individual element. It is also hypothesised that factors that have not been considered or modelled could show to be relevant.

9.2 Trial Design

As a control, the trial should be limited to an 18-30 as a control messure. Future trials could expand this age range. Two evenly split groups should be randomly selected and separated. The participants will not be allowed to self-select which group they are assigned to. Prior to the trial starting, the groups should be monitored before any intervention to manipulate their transport methods. This can be used as baseline data. The pre-trial intervention should last a full year to ascertain if baseline transport demand reflects seasonal weather. Each group should have access to the same e-scooter models.

9.2.1 Group 1

The first group acts as a control group. The group receives no information on e-scooters and continue their journeys without interference. The participants are tasked with logging: how they travelled, why they travelled, where they travelled and the distance, what made them choose that mode of transport and how much the journey cost them. As there is no manipulation of the group, they will openly choose the mode of transport that suits them best for that journey.

9.2.2 Group 2

In contrast to group 1, the second group is manipulated in order to generate a demand in e-scooters. The group receives free access to e-scooters through the shared services. They are free to use any other transport, but like group 1 are tasked with logging the journey and what made them choose that method of transport. If the group uses the e-scooters for transport, they should record the battery status of the e-scooter after every journey.

9.2.3 Length of Trial

The length of trial is key for the validation of data. If the length of trial is too short, then the data may be invalid. Like in the pre-trial intervention, the trial should last a full year to reflect the effects of seasonal weather changes.

9.3 Data Usage

The data collected from the trial should be used to extrapolate the likely e-scooter usage if the scooters were available to the entire general public. As mentioned above, the data gathered from the trial could help to develop the model in Chapter 7. It could also be used to develop a more comprehensive model that uses real world data.

9.4 Development of Trial

The trial should be repeated several times with different randomly selected individuals in different urban environments. This would allow the continual collection and comparison of data and improve validity of results. The trial could be developed to include different types of e-scooter models. This would allow for the testing of different technologies and what impact that they have on 1) the effect of e-scooter usage and 2) the effect that a mix of e-scooter types have on the grid.

Chapter 10 – Discussion

Within this paper, analysis has focused on previous literature on the transport industry, how those factors can be linked to the use of e-scooters in the UK, the development of a model, sensitivity analysis and the designing of an RCT. Each section of this analysis forms a step in the process of determining the effects that e-scooter usage has on the UK National Grid. In this section we discuss the steps taken within this paper and provide an overall process of determining the effect of e-scooters could have on the National Grid. An overarching flow chart can be seen in Figure 33.

10.1 The Application of Literature

The factors that impact transport in the UK has been shown to be a complex stochastic issue. This is clear from the literature review. Applying the literature directly to e-scooters is purely hypothetical. As mentioned, e-scooters are currently illegal for use on public roads in the UK. This means that trying to accurately determine the demand of e-scooters in the UK is complex and theoretical. However, in contrast, it is important to complete this step as it is possible to draw parallels from different transport types. This has been done several times across several factors in Chapter 6.

Although the literature review helps to develop an understanding of transport methods and the factors that affect them, it does not help to accurately show which factors have the biggest affect. In addition, it does not help to resolve the stochastic nature of the factors. Perhaps, from the literature, the affect that consumer behaviour has on the demand is the most important. This is because individual and external factors both affect the choices that consumers make (Figure 10: Taken from Iftekhar & Tapsuwan (2010), showing how individual factors and external factors are intertwined with social and psychological attributes in determining how a person travel. & Figure 13). This then has a direct effect on the demand for e-scooters, which in turn has an effect on the electrical load demanded of the grid to charge the e-scooters. As shown in Figure 13 individual and external factors can also directly affect the electrical load required.

Without completing the step of a literature review and application of a literature review the initial knowledge of e-scooters and transport methods would not be known. By completing this, we have gained an overarching understanding of the transport industry, e-scooters and the factors that affect transport demand. Hypotheses have been made on the factors that affect the e-scooter usage. From this, we can develop a model which attempts to estimate e-scooter demand, the electrical load and the factors which impact the demand.

10.2 Modelling

The modelling conducted in Chapter 7 has two main steps within the overarching process. These are shown in Figure 33 where the development of a model and the simulation phase, to gather results, are the two modelling steps.

10.2.1 Development of a Model

The selection of the software used is the first step within the process. In this paper Excel was chosen for its ability to create a model that can be easily altered by a variety of people. The development of a model was achieved by first determining the factors to include to determine e-scooter demand. In this instance town characteristics, weather and consumer behaviour were chosen. However, the selection of these factors is not based on previous data and the inclusion of these within the model is not a robust assumption. Equally, the assumptions made on their impact to demand (section 7.2.4) is not based on surveys or previous data specific to e-scooter usage.

The input of technological data is difficult due to the current battle between e-scooter technology companies. The data available on batteries used in e-scooters is not readily available and the use of a typical e-bike battery was used instead. The assumption of technology data is key to determining what impact the e-scooters would have on a grid. This is because of Equation 1: Energy Content of a Battery where the energy content of a battery is determined. Equation 2 also plays an important role within the model. Determining the Wh/km of a battery and scooter allows the calculation of energy demand for a journey. The creation of the user profiles ultimately plays the most important role in determining the energy demanded from the grid. In the model these were created and are not based on data. This is because the E-Village that the model is based on is hypothetical; a future model should be backed up by actual data gathered from the RCT.

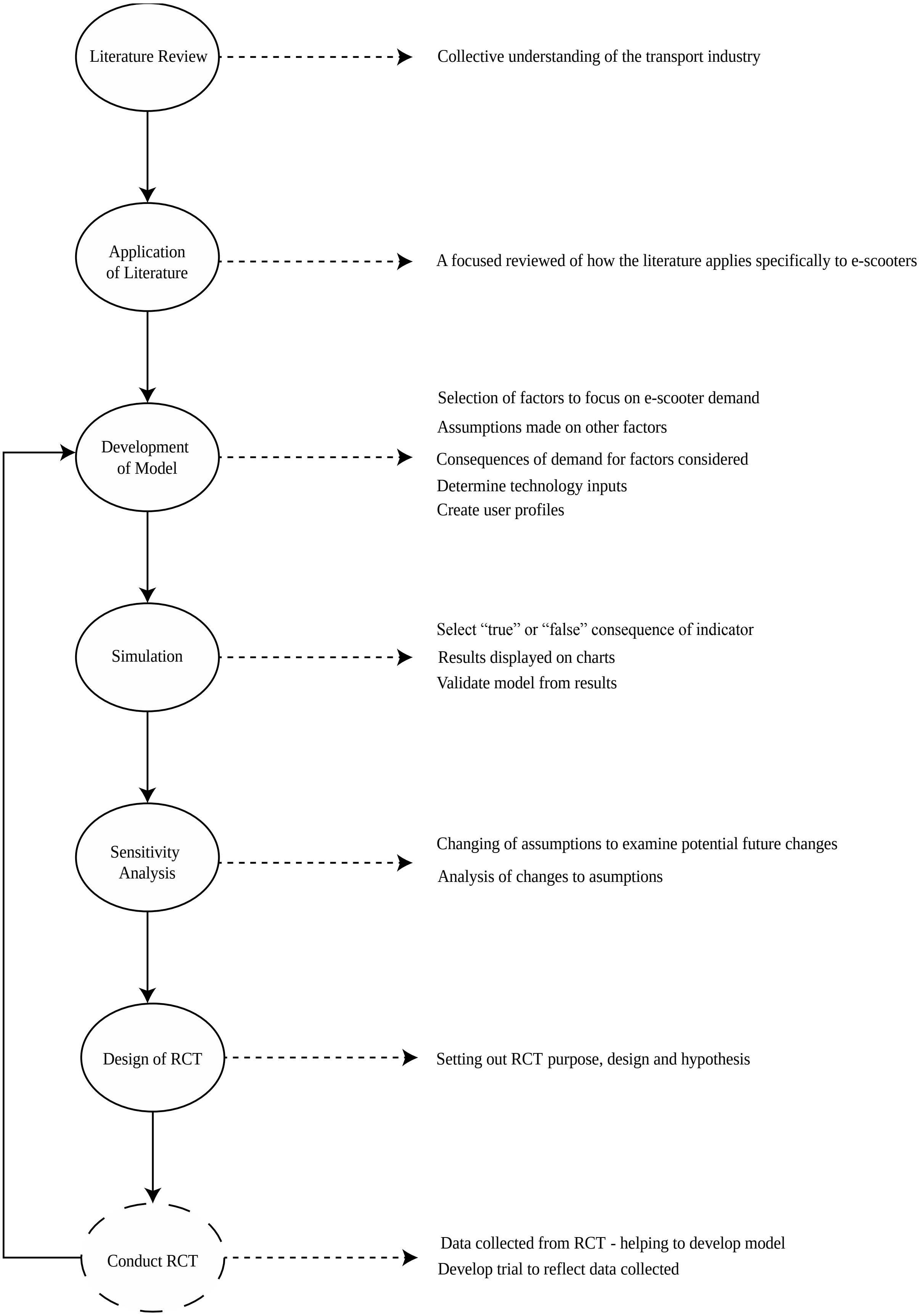


Figure 33: Showing a flow chart of the steps involved in the process of determining e-scooter usage and the electrical load demanded of the grid.

10.2.2 Simulation

The simulation allows the results of the model to be analysed, helping to make informed decisions about e-scooters in the UK. The status of the factors incorporated in the model can be selected as true or false. The nature of the factors dictates the demand for e-scooters. From there, the e-scooter demand calculates the electrical load demanded from the grid.

The results given in section 7.3 for an example where e-scooter demand is 100%, shows that when 10% of a population switches to e-scooters for their daily commute, the grid is required to increase its electricity supply to domestic section by 2.4%. The electrical load demand would fall within a period of peak demand for the grid, since charging begins at 7pm. The charging results in a peak demand of 120 kWs of power for e-scooters. This was determined for the hypothetical E-Village. This does not mean that if the UK did legalise e-scooters the domestic supply would need to increase by 2.4% or that there would always be an additional 120 kW peak of power demanded of the grid. There are several reasons why, however, the most reasoned argument would be that the data and assumptions used in the model are not backed by real world data, since there is none to rely on.

10.3 Sensitivity Analysis

Analysis has been carried out to view how the model responds to changes in the assumptions (e.g. scooter usage increases by population). Completing sensitivity analysis allows the examination of the model and helps to predict how future changes could affect electrical demand. The model developed in this paper responds to these changes linearly. A key piece of analysis took place and is shown in Figure 32. This shows how the shifting of charging times could help to reduce the peak load at an already demanding time for the grid. This could be conducted by using smart grids and may be incorporated in a future RCT.

10.4 Randomised Controlled Trial

The RCT could alleviate the issue of data. It was beyond the scope of this paper to run an RCT. However, an attempt was made to design a trial that could provide insight into what dictates the use of e-scooters in the UK and what electrical load demand were dictated of the grid. The creation of a trial allows the testing of e-scooters in a controlled way, in which data can be collected. The data collected can be analysed, helping to develop the trial and feed data back into a developing model.

10.5 E-Scooters a Sustainable Transport Method?

As discussed in section 5.4 the EU focused on reducing CO_2 emissions and GHGs and increasing air quality in cities. In order to achieve this, governments will be required to think radically about how many parts of society operates and implement policies that achieve the EU's goals without causing serious knock-on effects. E-scooters are a radical change to how we travel. Many of the advantages and disadvantages of e-scooters have been discussed previously in Chapter 4 and Chapter 5. However, the question of whether or not scooters can provide sustainable transport in cities has not been addressed in this paper yet. If we consider the criteria for sustainable transport laid out in Table 5, we know the sustainability of e-scooters could be judged on three indicators: economic, environmental and social.

Addressing the economic argument for/against e-scooters first, we know that from review of news reports that scooter companies are backed by some of the largest hedge funds in the world. However, this does not equate to economic sustainability. Shared scooters are currently being replaced on average every two months and it seems unlikely that the companies responsible for them are managing to turn a profit with this in mind. It is hard to understand how this current business model is sustainable by the criteria laid out in Table 5.

Equally, the replacement of scooters on such a frequent basis could have serious environmental consequences. The impact on the land for mining elements used in the battery and motor as well as the CO_2 emissions involved in the construction of scooters could have significant environmental consequences. However, e-scooters produce no particulates in cities helping to increase air quality and do not produce CO_2 or GHGs emissions.

Determining whether or not the advantages or disadvantages outweigh one another is multifaceted. If the goal is to purely reduce EU CO_2 emissions, then the generation of CO_2 during the manufacturing phase is irrelevant. This is because China is the biggest producer of PLEV technology, and the CO_2 emissions generated during manufacturing will be reported as coming from them. There must be the understanding that government policy seeking to address these current topical environmental issues will have negative consequences. Mitigating these environmental consequences is key for e-scooters to be considered as a sustainable transport method.

The shared nature of dock-less e-scooters means that they are highly accessible for users. They have so far been kept relatively cheap forms of transport. This means that much of society can use them as a mode of transport. There can be associated complications, with many areas where e-scooters are currently in use reporting issues of vandalism and dumping of e-scooters. Whether or not the use of e-scooters would affect future generations is unknown but their current fashionable status in the developed world means that, regardless of their sustainability status, they could become common transport methods.

Chapter 11– Closing Remarks

11.1 Conclusion

E-scooters, when used as a transport method, are a relatively new phenomenon in urban environments. Consequently, there is little research on their impact to society, economics, environment and, importantly, energy systems. The UK government is currently reviewing e-scooters as a method of transport in cities. This paper has attempted to develop a process for determining the impact e-scooters could have on the National Grid in the UK, if their legal status is changed.

Although there is a lack of literature on e-scooters, a review of literature on existing transport methods was conducted. This research highlighted factors that could affect transport usage such as; government policy, demographic economics, social and psychological, technology and climate and weather. The existing literature was applied hypothetically to e-scooter usage. This highlighted the likely factors and the specific elements that could impact the demand for e-scooters when used as a transport mechanism. The analysis showed that individual factors (demographics and economics) in combination with external factors (climate/weather, technology and the built environment) impact consumer behaviour (social and psychological factors). Additionally, these factors can affect the demand for e-scooters separately and can impact one another.

The findings from the application of literature showed that many of the factors that affect e-scooter demand are stochastic and modelling is complex. A model was developed for a hypothetical E-Village, which could reflect demand for e-scooters as a transport method and calculate the electrical load they demanded of the E-Village grid. Each of these steps were taken separately. In the first step, elements within three factors were integrated into the model: town characteristics (built environment) weather and consumer behaviour (psychological). The nature of these elements, either “true” or “false”, contribute to the demand for e-scooters in the E-Village.

By using the energy capacity of the battery and range of a commercially produced e-scooter, the Wh/km was calculated. Twenty user profiles were simulated and based on the distance of

travel each profile does on a daily basis. These combined elements produce the energy demand of the e-scooters.
A simulation was completed where demand for e-scooters was 100%. When 10% of the population used e-scooters for commuting, the energy demanded of the grid was ~1.5MWh and peak demand at 7pm was ~140 kW. Considering the average use of electricity per household in the UK, the electricity required to charge the e-scooters would result in a ~2.4% increase in domestic electricity supply. Sensitivity analysis showed that when 50% of the population used e-scooters for commuting the grid would be required to supply ~12% more electricity. The model also responds linearly to changes in e-scooter range and e-scooter testing efficiency.

Analysis also looked at the development of a randomised controlled trial (RCT). The RCT is a key step within the process of determining the electrical load demanded from the grid. Although the completion of an RCT was not carried out in this paper, it is a key step in the process of understanding the usage and affects e-scooters could have. The data collected from an RCT could feed back into the development of the model and help to produce a greater understanding of their impacts.

The debate on whether e-scooters could be classed as a sustainable mode of transport based on environmental, economic and social indicators is, at present, a matter of opinion. From an economic viewpoint, it is hard to see how the current business model is sustainable. There is no evidence to suggest that they are environmentally sustainable, however they clearly would have a positive impact on air quality if enough people migrated from the use of cars to e-scooters. Socially, e-scooters are a relatively cheap mode of transport, but there are concerns of vandalism and dumping of scooters. Regardless of the sustainable or environmental benefits and consequences, it seems likely that the rise in e-scooters will only continue. It seems exceptionally likely that the UK government will alter the law to allow the use of e-scooters on public roads. However, it is strongly recommended that the potential consequences of widespread e-scooter use are fully understood and attempts are made to mitigate any negative consequences.

11.2 Future Work

11.2.1 Randomised Controlled Trial

The design of a randomised controlled trial (RCT) was set out in Chapter 9. The implementation of an RCT is a key part of future work to determine the effect e-scooters have on energy systems and to refine the process outlined in this paper. The RCT should be conducted and would help feed back into the development of a model. The RCT would also give governments key data which can inform policy.

11.2.2 Renewable Charging System

Several times in this paper the current charging system has been deemed to be inefficient. This is both from a business and an energy system perspective. It could be suggested that a new charging system is introduced which makes use of renewable energy systems, removing the reliance of e-scooters on the grid. There is an environmental case for this since if scooters are charged on the grid there is still an associated CO_2 emission footprint. The business case for this is that contractors who collect scooters would no longer need to be paid. In conjunction with this, there could be a possibility that e-scooters could be used as a supply to the grid while they are not being used (V2G). There may also be an option to include a time of use tariff within an alternative charging model.

11.2.3 Development of Model

The model created within this paper should be continually developed. The data obtained from the RCT should continually by used to develop the model. The model should also be used to determine the feasibility of a renewable energy system and the possibility of V2G.

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Chapter 13 – Appendix

13.1 Calculation of demand If Statement

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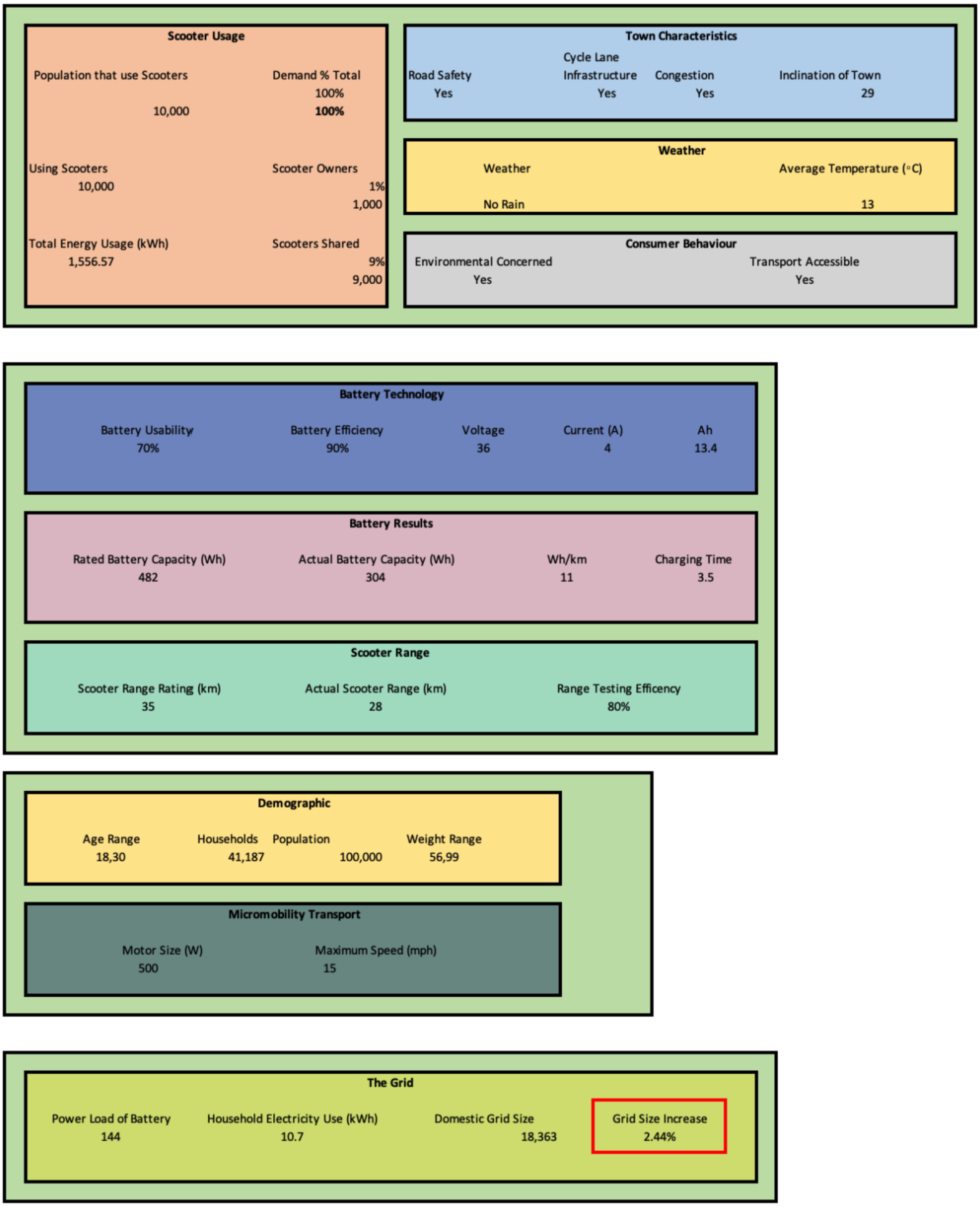
=1*(IF(H5="yes",'TownCharacteristics'!C2,IF(H5="No",'TownCharacteristics'!C3,0)))*(IF(J5="Yes",'TownCharacteristcs’'!E2,IF(J5="No",'TownCharacteristics'!E3,0)))*(IF(K5="Yes",'TownCharacteristics'!G2,IF(K5="No",'TownCharacteristics'!G3,0)))*(IF(I11="NoRain",1,IF(I11="Rain",0.3,0)))*(IF(L11<=10,0.3,IF(L11>=11,1)))*(IF(L5<=10,0.9IF(L5>=11,1)))*(IF(H15="Yes",'TownCharacteristics'!C7,IF(Input!H15="No",'TownCharacteristics'!C8,0)))*(IF(K15="Yes",1,IF(K15="No",0.2,0)))
```

13.2 Screen capture of Model



Scooter Usage

Population that use Scooters	Demand % Total
10,000	100% 100%

Using Scooters	Scooter Owners
10,000	1% 1,000

Total Energy Usage (kWh)	Scooters Shared
1,556.57	9% 9,000

Town Characteristics

Road Safety	Cycle Lane Infrastructure	Congestion	Inclination of Town
Yes	Yes	Yes	29

Weather

Weather	Average Temperature (∘C)
No Rain	13

Consumer Behaviour

Environmental Concerned	Transport Accessible
Yes	Yes

Battery Technology

Battery Usability	Battery Efficiency	Voltage	Current (A)	Ah
70%	90%	36	4	13.4

Battery Results

Rated Battery Capacity (Wh)	Actual Battery Capacity (Wh)	Wh/km	Charging Time
482	304	11	3.5

Scooter Range

Scooter Range Rating (km)	Actual Scooter Range (km)	Range Testing Efficency
35	28	80%

Demographic

Age Range	Households	Population	Weight Range
18,30	41,187	100,000	56,99

Micromobility Transport

Motor Size (W)	Maximum Speed (mph)
500	15

The Grid

Power Load of Battery	Household Electricity Use (kWh)	Domestic Grid Size	Grid Size Increase
144	10.7	18,363	2.44%

Figure 34: A screen capture of the model home selection sheet.