CRITICAL EVALUATION OF THE BATTERY ELECTRIC VEHICLE FOR SUSTAINABLE MOBILITY

By

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Thesis

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Chapter 1 Abstract and the Research Question

1.0 The research question

Can Battery Electric Vehicles replace conventional internal combustion engine vehicles for commuting purposes when exposed to a busy corporate activity within the city of Edinburgh? This thesis investigates the application of Battery Electric Vehicles (BEV) use in a commercial business environment in the city of Edinburgh, Scotland UK. The motivation behind this work is to determine if the Battery Electric Vehicle can replace conventional fossil fuel vehicles under real world drive cycles and the desire by many to combat the causes of climate change.

Due to the nature of this work a significant part of the work will be underpinned by the quantitative methodology approach to the research. As the question indicates the research is supported by real live data coming from the vehicle both in proprietary data logging as well as reading and analysing the data coming from the vehicles own Electronic Control Unit (ECU).

There will be mixed research methodology encompassing quantitative and qualitative research to obtain a complete response in respect to the management of the vehicle these methodologies will be the analysis of the measurable data as well as explorative, to gain the underlying reasons and motivations for choosing a battery electric vehicle as an option to the conventional vehicle for this type of application use.

1.1 Declaration

I hereby declare that the contents of this thesis are original and have been submitted solely to Edinburgh Napier University for consideration in fulfilling the requirements for the degree of Doctor of Philosophy (PhD).

R Milligan

Signed:

Dated:

1.2 Abstract

This thesis deals with the research question of the amount of carbon reduction that is achievable by a societal switch from fossil-fuel to sustainably-charged electric automobiles. This presented research work is focused on analysis of real operational data from the electric vehicle fleet both in proprietary data logging as well as reading and investigating the data coming from the vehicles own electronic control unit. In this work >50 electric vehicles data has been monitored for four years test period. The key characteristics of the electric vehicles operations e.g. journeys, speeds, distances, routes as well as the vehicle energy consumption have been investigated over the evaluation period. It has been noticed that driving cycle patterns have significant impact on vehicle’s energy intensity. Extensive evaluation testing has been reported for different types of batteries for their characteristics. Also, different operational modes e.g. acceleration, deceleration, cruise, ascent, decent have been evaluated and validated using real operational data for determining the regenerative braking efficiency of the electric vehicles fleet. This research has attempted to estimate vehicular driving patterns in the Edinburgh region and to offer an option of battery electric vehicles for sustainable mobility.

Two mainstream electric vehicles were used, the Mitsubishi i-MiEV and the Renault Zoe, both current BEV models and readily available within the UK.

Initial tests with these electric vehicles have shown that when discharging the full capacity of the 16kWh battery in the Mitsubishi i-MiEV energy consumption was calculated at 3.9 miles/kWh. The Renault Zoe has a larger battery capacity of 22kWh and its driven performance has shown an energy intensity of 3.8miles/kWh. It was noted that driving styles had an important bearing on energy intensity. Further drive cycle analysis will determine whether this efficiency can be improved upon.

Evidence to date indicates that that the vehicles are proving to be a cost effective and viable travel option. Energy tariffs considered ranged from £0.07/kWh to £0.15/kWh demonstrating a consumption cost of between £0.016/mile and £0.035/mile respectively compared with an example internal combustion engine fuel cost of £0.13/mile.

Due to rapidly increasing numbers of vehicles, growing traffic congestion and the very limited use of emission control strategies, vehicles are emerging as the largest source of urban air pollution globally. This research aims to offer a control strategy and an alternative to the conventional fossil fuel vehicle the effectiveness of any control strategy depends on accurate data representation to given routes and drive cycles. This study is an attempt to estimate vehicular driving patterns in the Edinburgh and east Lothian area and offer a cost effective option as a transportation means.

The Mitsubishi i-MiEV, Nissan Leaf and Renault Zoe electric vehicles were used as part of a sustainable travel analysis with a view to reducing fuel and carbon emission costs. The

analysis aims to determine whether the battery electric vehicle is a viable alternative to the conventional internal combustion engine vehicle.

The results of this work will be directly useful to the Scottish Government for installing the charging points for the electric vehicles as well as in knowing the power requirements of the charging stations. This work will also benefit and support smart electric vehicle charging management systems for reducing the demand on the electrical network.

1.3 Acknowledgements

First and foremost, I would like to thank my Supervisors Prof Tariq Muneer and Prof Ian Smith at Edinburgh Napier University and Prof Stephen Tinsley formerly at Edinburgh College who made this research work possible. Without your encouragement and support I would definitely never have started this investigation into Battery Electric Vehicle test and critical analysis to characterise and determination of the user and drive cycle.

Throughout the investigation I have had close cooperation with Nissan GB and Mitsubishi cars UK, Ian Murdoch and Zac Tuk in the Scottish Government, (Transport Scotland and Energy Saving Trust, Scotland) and Judith Eadie (Automotive Leasing). I would like to give my thanks and appreciation to Robert Murphy and the Engineering staff at Edinburgh College Scotland, for our countless discussions of test methods and possible mechanisms throughout this research that have been essential to the project. In addition, Shmuel De-Leon (Energy Ltd, Hod-Hasharon, Israel) has contributed with new battery and energy technology systems giving me guidance and his work is a valuable asset to energy storage systems and the electric vehicle market.

I would like dedicate this work to my sons Craig and Scott and to my late aunt K.A. Milligan who always assisted and supported my previous academic activities, writings and contributed with valuable input to various analysis methods throughout my career.

I would also like to thank my wife Rachael Milligan for her full support and the fruitful encouragement accompanied with timeless questions such as “are you getting on with the work” and “is it not finished yet?”

And finally, the financial and continual support from Edinburgh College and Edinburgh Napier University is greatly appreciated their help and support has assisted throughout so as to allow me to complete this work.

Ross Milligan
East Lothian, Scotland, UK
November, 2016

1.4 Aims and objectives

This thesis study analysed and investigates the application of Battery Electric Vehicles (BEV) and the mobility usage and drive cycles when used within a College business environment in Scotland, UK. The motivation behind this work is the increase in mobility requirements and the desire for sustainable transportation and to remove the reliance on Internal Combustion Engine (ICE) vehicles which are recognised as a major contributor of climate change.

Globally speaking, the present day energy scenario does not present an encouraging image as there is an annually increase to the use of ICE vehicles worldwide. Fossil fuel depletion is very evident with the possibility of total exhaustion in a generation's time The evidence suggests that this could be by 2100 (Tang 2013).

This investigation aim will focus primarily on the drive cycle for the user and secondary on its compatibility with the needs of the user and how this is implemented to a large staff base across multiple sites within a busy city.

This study will also discuss the Total Cost of Ownership (TCO) and analyse the power generation methods that exist in the energy supply chain to power the BEV as market penetration increases.

The objective of the study is to determine the possibility of replacing conventional fuel vehicles with battery electric vehicles and still maintain a reliable mobility structure within Edinburgh College.

The battery electric vehicles were sited strategically at each of the College campuses and are used by staff to commute across sites as required.

This study has reported on the life cycle and practicality of battery electric vehicles and a main area of focus was on the drive cycle viability and inoperability when using these vehicles across all campuses in all seasons. The BEV will be required to operate with all staff across all campuses as well as longer distance routes and the focus will be on data capture throughout the charging and the drive cycles.

Key questions were:

- Can the BEV replace a conventional fuel vehicle
- Use and practicality for the staff base involved
- Energy consumption determination for the distance travelled
- Range consideration and efficient route planning for the vehicle type
- What are the CO_2 savings associated with this BEV application
- How effective was the systems implementation and analysis of feedback
- Can the charge infrastructure support this city of Edinburgh application

1.5 The structure of the thesis

The research work that has been undertaken has utilised both quantitative and qualitative research methodologies. This research has critically analysed the implementation of a mobility activity such as staff acceptance, range capabilities, vehicle availability and costs. The charging requirements have been determined in line with the business needs and has developed as the fleet of vehicles have increased.

New battery technology has been investigated coupled with a purpose built battery charger/discharger to analyse the performance of this chemistry and whether this alternative battery type could be a competitor to the current lithium-ion chemistry.

Vehicle monitoring using in-car software and data logging was used to determine and evaluate the systems capabilities and align this to the user needs. This data was recorded and analysed for mobility activities in urban, extra urban, rural and intercity activities.

An area of significant focus was around the actual drive cycle capabilities and economic performance.

Electric vehicles were utilised under rigorous test conditions and their actual performance has been compared with previously published reports and legislative range testing with this information comparison were drawn to the accuracy of fuel economy studies and the current New European Drive Cycle (NEDC) which must be conducted for all new vehicles. The energy, performance, CO_2 and NO_x pollutants were analysed for both urban and intercity journeys as was the effective use of time and consideration in a practical application.

A mix of qualitative and quantitative research was conducted on the process systems management which was investigated within this work. The users were consulted at points during the study to determine effectiveness. User groups were evaluated and adaptations developed as the system developed.

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Chapter 2 Introduction

2.0 Overview

Fuelled by a rapidly rising human global population, an increasing demand for freedom to travel and the affordability made possible by modern manufacturing there has been an exponential rise in the number of automobiles - in the year 2013 there were in excess of a billion automobiles in use worldwide. Three factors that are of serious concern are the consequential energetic, environmental and economic impacts. One solution that is being seen by a number of national governments is the advent (or rather re-introduction) of electric vehicles (EVs). However, one of the key factors that will need to be explored will be the source of the required electricity for the EVs that will define the level of its sustainability with the increase Ultra-low emission vehicle (ULEV) as can be seen in table 1.

Table 1 Ultra-low emission vehicles licenced in the UK

Quarter	Plug-in-Grant Eligible Cars	Plug-in-Non Grant Eligible Cars	Non Plug-in Cars	Quadricycles	All Cars (inc. quadricycles)
2012 Q1	1,527	587	609	224	2,947
2012 Q2	2,001	572	673	371	3,617
2012 Q3	2,629	556	653	443	4,281
2012 Q4	3,321	548	643	494	5,006
2013 Q1	3,909	528	619	535	5,591
2013 Q2	4,804	515	493	563	6,375
2013 Q3	5,802	493	469	581	7,345
2013 Q4	6,747	489	466	591	8,293
2014 Q1	8,429	471	479	584	9,963
2014 Q2	10,655	460	475	569	12,159
2014 Q3	15,336	460	473	582	16,851
2014 Q4	20,522	432	434	555	21,943
2015 Q1	28,363	421	433	581	29,798
2015 Q2	33,716	445	440	620	35,221
2015 Q3	39,668	460	435	618	41,181
2015 Q4	46,105	457	439	598	47,599
2016 Q1	56,768	439	449	623	58,279

(UK Government 2016b)

Table 1 illustrates an increased up-take of ‘plug-in grant eligible cars’ by a factor of approximately 35 when comparing 2012 with 2016 (UK Government 2016b). There has been a steady increase of this band of grant supported vehicle. This is not the case with ‘plug-in-non grant eligible cars’ which indicates that the government support is a major contributor to the volume of vehicles on the road within the UK.

However, this is another misconception of the mechanisms that govern EV usage. Even if a conventional internal combustion vehicle can run more than 300km on one fuel charging, the average daily driving distance is still below 50km (CHAdeMO 2007). Even if the EV’s battery capacity were increased to 300km in the future, it would not significantly alter one’s daily driving distance because the primary determining factors are one’s daily habits and lifestyle not the size of the fuel tank or battery.

In the UK the amount of electricity needed to drive 50km is around 7kWh. Assuming that the EV is charged every night, they can be charged under less than four hours even if a low-capacity 2kW on-board charger is used. Some drivers may worry about the battery running out, but this shouldn’t be a problem if a sufficient quantity of electricity is charged overnight for the next day. If a driver absolutely insists on having a full charge, he or she can always use the nearest rapid charger or workplace/destination charging can be employed.

Table 2 SWOT analysis for electric vehicles

Strengths	Weaknesses
• Eco-friendly • Silent • Low cost of ownership • Cheaper to run • Energy savings – Achievable from regenerative braking system • Simpler Mechanism	• Needs time to recharge • Lack of recharging infrastructure • Changing batteries is expensive
Opportunities	**Threats**
• Government subsidies for ownership • No congestion charge • Lower taxes • Increasing fossil fuel costs	• Competition in form of electric hybrids, alternative fuels, hydrogen-powered cars • Rise in cost of electricity

(M. Knez et al. 2014)

In this thesis an experimental evaluation of an electric vehicle has been undertaken and consideration was given to the previous work conducted by (M. Knez et al. 2014) where a SWOT analysis as illustrated in table 2 was reviewed.

Battery electric vehicles have been used for this task with the 'car chasing' technique employed to measure the College specific driving cycle. 'Car chasing' is the action of following the vehicle in front whilst maintain speed with the traffic flow and conditions. The speed and energy use were recorded for the vehicle that was driven along the principal arteries of the City of Edinburgh, Scotland. In both places urban and suburban routes were covered for different times of the day.

Results are presented to quantify the energetic, environmental and economic performance indices for the driven vehicle. A discussion is also provided on the potential for reduction of carbon emissions from the transport sector by provision of environmentally-friendly means of generating electricity.

Inevitably from a climate change perspective the vehicular release of such large amounts of CO_2 will need to be examined. In this respect the possible link between human population growth, automobile population growth, global CO_2 concentration and temperature is presently (European Association for Battery Electric Vehicles 2009) explored. Furthermore, a critical review of the present road transport needs relating to energy demand for UK needs to be examined. This will determine if alternative sustainable mobility modes could be introduced to reduce current and future vehicular emissions.

2.1 Energy supply and demand situation

An extract from the World Health Organisation (WHO) urban air quality database states that: "Air pollution doesn't just cause respiratory problems in children and adults," explains, a Technical Officer in World Health Organisation's (WHO) European Office in Copenhagen, "It also causes heart attacks, strokes, confuses your metabolic system, has links to diabetes and can even have impacts on a child's health before it's born." (world health organisation 2014).

The United Nations projects that 60% of the world's population will be living in urban areas by 2030. Cities account for 2% of the world's area but 75% of the world's energy consumption (World Health Organisation 2014) . For over a century, the automobile has offered affordable freedom of movement within urban areas. According to Ward's research, global registrations jumped from 980 million units in 2009 to 1.015 billion in 2010.(Sousanis 2014). The world population exceeded 7 billion on March 12, 2012 and every seventh person now owns a vehicle which in all likelihood is powered by an internal combustion engine (ICE). Worldwide, 18 million barrels of oil is consumed each day by the automobile sector. Annually, the vehicles emit 2.7 billion tonnes of CO_2 (IEA 2015).

Inevitably from a climate change perspective the release of such large amounts of CO_2 will need to be examined. In this respect the possible link between human population growth, automobile population growth, global CO_2 concentration and temperature is presently explored and findings have been stated that consumption at the current rate of fossil fuels is not sustainable. (Hawkins et al. 2013) reports that fossil depletion potential (FDP) may be decreased with the application of electric transportation.

2.1.1 Energy and transportation

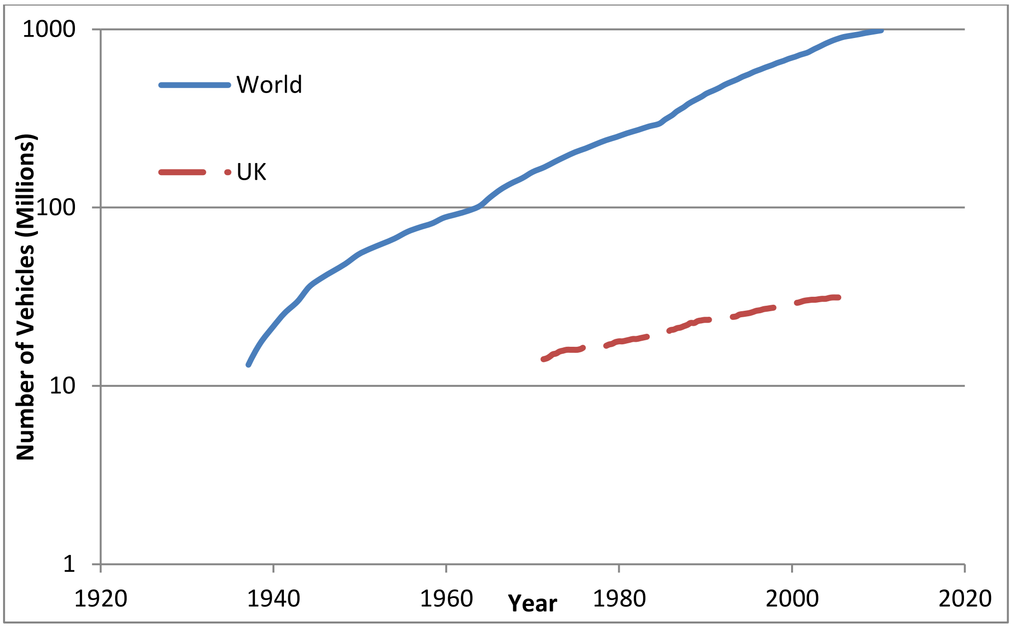
The main advantage of electric vehicles is that they can be recharged using electricity generated from clean, renewable energy sources and at a lower environmental and monetary cost than a petrol or diesel car.

Electric vehicles are not a new idea, many of the first mass-produced cars were electrically driven. The main disadvantage of electric vehicles is that they have limited range and long recharge times compared to fossil-fuelled vehicles, and so cannot match the versatility of conventional internal combustion engine cars.

Electric vehicles have emerged as a promising solution for reducing the oil dependence in transportation systems. Nevertheless, their integration into modern transportation systems is largely limited by the higher cost and the long charging times, on the one hand, and by the low driving range, on the other hand.

It is essential that we fully understand the risks, consequences, and healthcare costs of poor air quality and this could be the single most important issue in realising a significant change in government policies and attitudes around electric vehicles.

Governments and policymakers increased focus on air quality represents a shift in emphasis for low emission vehicle programmes, which have traditionally been motivated by carbon reduction, energy security or economic development. These will remain highly important in a national and global context.



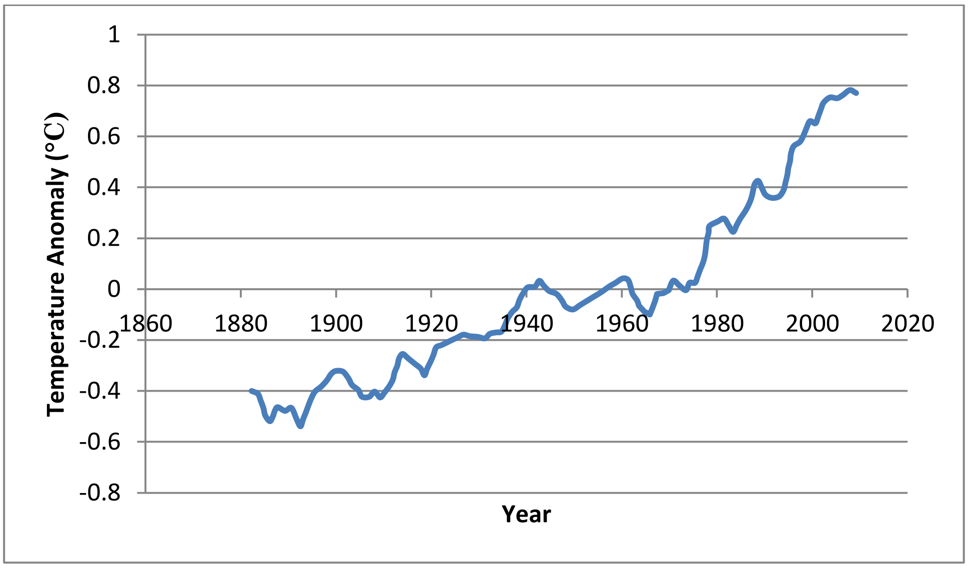
(Muneer et al. 2015)

Figure 1 Chronology of automobile population

However, to an individual motorist there is a certain psychological distance that limits the perceived significance of these issues in their own life, or indeed their ability to have any positive influence on such massive global challenges. Breathing polluted air into our lungs is an altogether more local and tangible issue. Studies over recent years have led us to understand that the risks from road transport emissions are now far greater than previously thought or understood and this reflects in the incentives given by manufacturers to buy vehicles with low tail pipe emissions. Figure 1 illustrates the increased use of automobiles over time. This increase in vehicle use is a serious risk as it will give an increase in air pollutants created by the road vehicles. Improving motor vehicle technology and providing a better assessment of the levels of human exposure around the world is required.

The effects of air pollution have been repeatedly communicated by multiple authors however the most significant landmarks in developing understanding of the health impacts of air quality was the 2012 communication by the World Health Organisation International Agency for Research on Cancer. This classified diesel exhaust emissions as a definite cause of cancer, placing it in the highest category hazard alongside smoking and asbestos. In this document it explains that “When something is classified as carcinogenic (causing cancer) it means that there is no safe exposure threshold below which no adverse health effects will occur.” In other words, incremental efficiency improvements in respect to new internal combustion engines technologies do not solve this problem and an alternative must be sought. (world health organisation 2012).

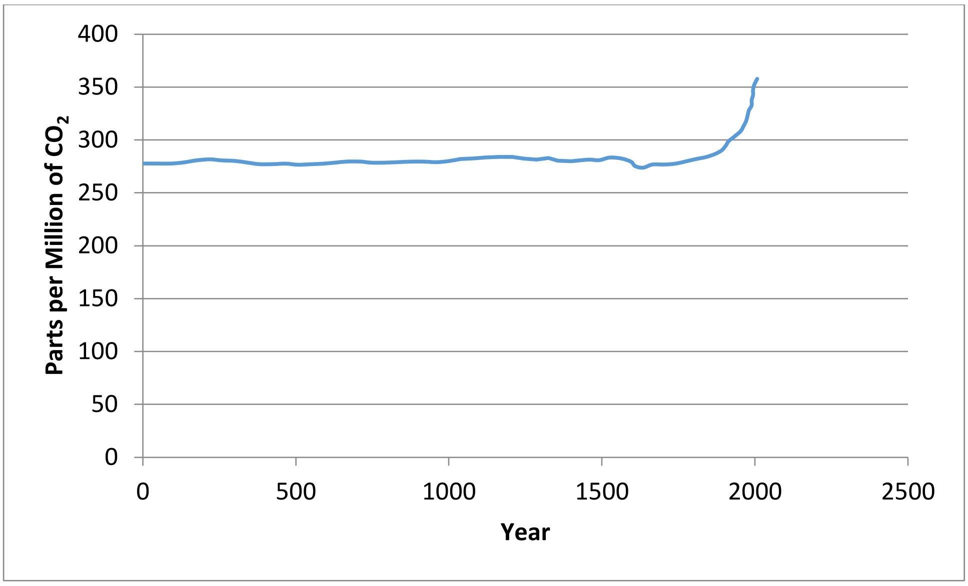
2.1.2 Climate change



(Muneer et al. 2015)

Figure 2 Chronology of Global Temperature Change

Figure 2 shows the anomalous behaviour of global temperature change since the latter part of the industrial revolution when significant carbon loading of the planet had ensued.



(Muneer et al. 2015)

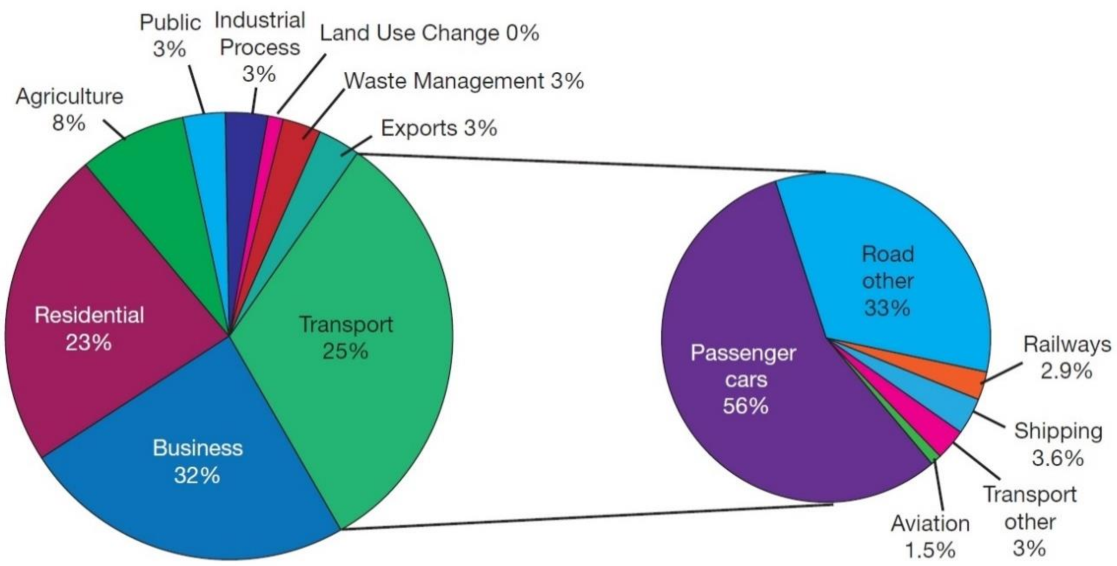
Figure 3 Chronology of Global Atmospheric CO_2 Concentration

Figure 3 shows an exponential rise of atmospheric CO_2 concentration. This behaviour is in line with (figure 1 and 2) the effect of a sharp rise in the number of automobiles on the road and an increase in global temperature. This will increase the use of fossil fuels that is consumed to drive the vehicles.

2.1.3 The United Kingdom and power generation methods

In the UK, a quarter of all CO_2 emissions come from transport and approx. 90% of this comes from road vehicles. According to the UK Government at the end of 2013 there were 35 million vehicles licenced for use on the roads of UK and during 2013, over 4300 new ultra-low emission vehicles (ULEV – vehicles with emissions of CO_2 below 75 g/km, or fully electric) were registered for the first time, this is 25% up on 2012. This included over 3600 automobiles and vans eligible for UK government 'plug-in grants' this too is up, nearly 50% more than in 2012. The largest increase for individual models were the Renault Zoe and the Nissan LEAF being the most popular.

It is evident from the dataset from (Lytton 2012) which has indicated that in the UK there is evidence that transportation is responsible for 25% of all CO_2 greenhouse gas emissions and of this percentage passenger vehicles make up 56% of the emissions alone. It is essential that future road transportation using conventional fuels is reduced and that is the volume of traffic on the roads and not how efficient vehicles become in the short term. Some of these conventional cars can be directly replaced with battery electric vehicles (BEV) which will have sufficient range and car carrying capacity. As can be seen in figure 4, automobiles make up 56% of the transportation CO_2 pollutants.



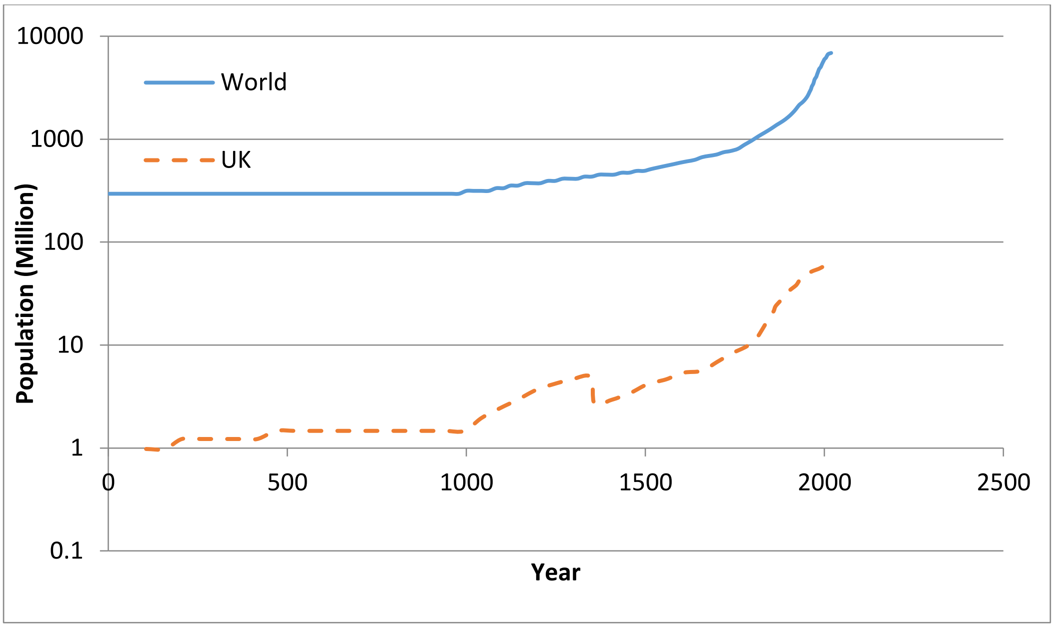
(Lytton 2012)

Figure 4 UK GHG emissions 2008 measured in CO_2 equivalents

2.1.4 Impacts of climate change

The impact of climate change has been discussed in areas such as within the scientific community as well as national government to such an extent that it has become an significant area for discussions related to sustainable use of energy.

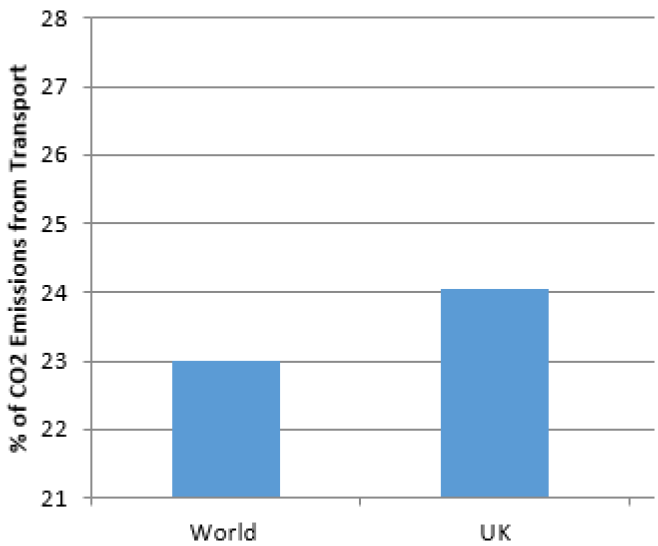
Since the latter part of the industrial revolution and with the introduction of the automobile significant carbon loading of the planet has ensued and there has been an exponential rise of atmospheric CO_2 concentration. This has also been coupled with the sharp increase of human population as indicated in figure 5 and a rise in the number of automobiles on the road and the increased use of fossil fuels that is consumed to drive the vehicles.



(National Records of Scotland 2013)

Figure 5 Human Population Increase

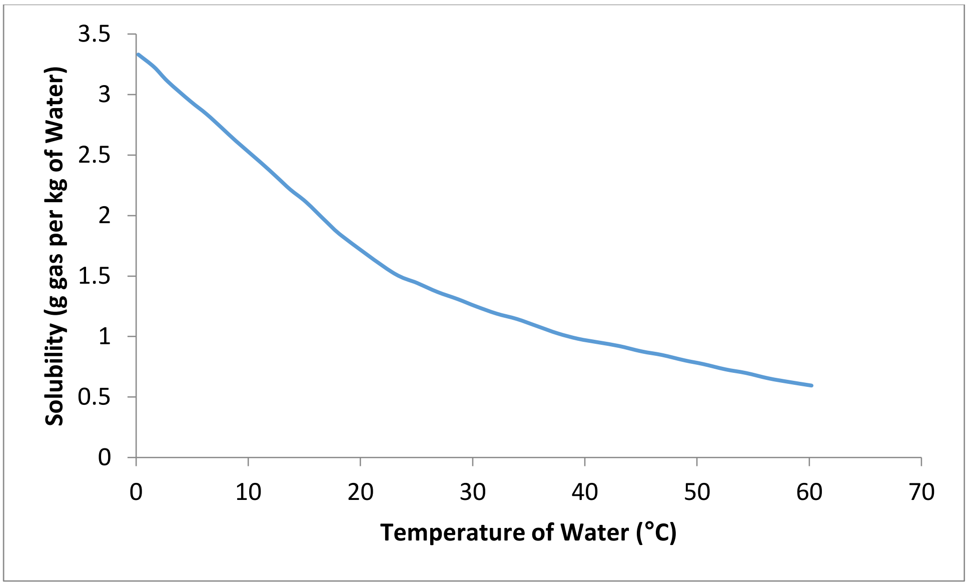
As shown in Figure 6 the present proportion of 23% share of CO_2 emissions for global transport is set to rise.



(Muneer et al. 2015)

Figure 6 Percent of CO_2 emissions from transport sector 2010

Figure 6 shows that in the UK there a much greater pollutant release than the rest of the world due. This coupled with the greenhouse gas emission from the fossil fuelled power stations to support the population increase is a major contributing factor to the change in climate conditions.



(Engineering toolbox 2014)

Figure 7 Solubility plot for CO_2 in water

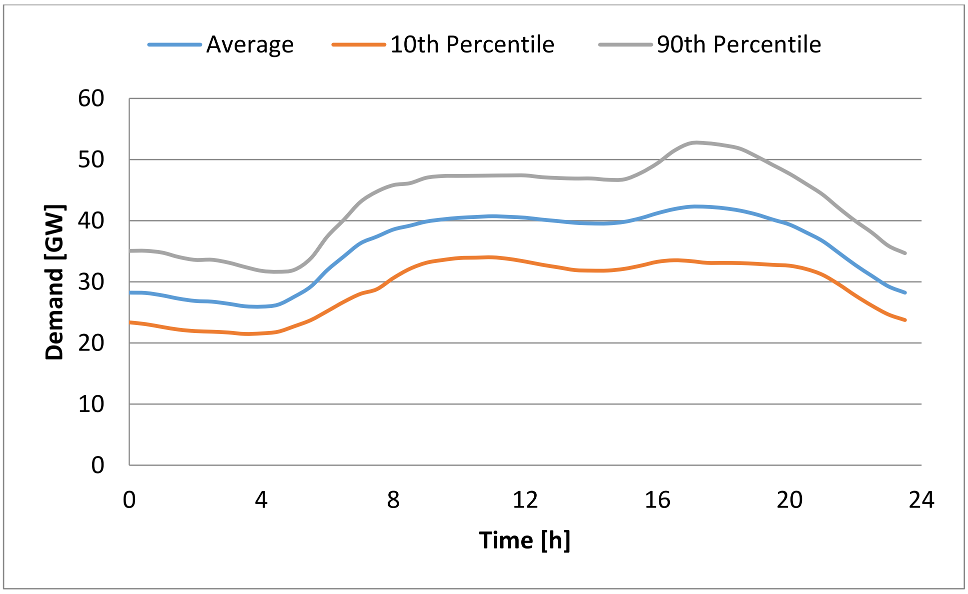
There has been significant thermal loading of sea waters as demonstrated in Figure 2 and in conjunction with Figure 7 there is a sharp decline of solubility of CO_2 in sea water. The seas of planet Earth hold 40 atmospheres of CO_2 by mass. Therefore, any slight sea temperature elevation would release an abundance of CO_2. Note that the annual average temperature of North Atlantic Sea which surrounds the major economies is 6° Celsius during winter months and 17° Celsius in summer. This argument is particularly consequential to power plants including those that are nuclear-fuelled which would typically dump twice the amount of their useful energy output to their cooling systems. To address the issue of climate change the European Union has set itself a challenging task of a serious overall reduction of greenhouse gas (GHG) emissions.

The resident population of England and Wales in 2011 was 56.1 million. The number of cars and vans available to households in England and Wales increased from 23.9 million in 2001 to 27.3 million in 2011. In 2001 there were on average 11 cars per 10 households whereas in 2011 there were 12 cars per 10 households. Scotland's population on census day 2011 was estimated to be 5,295,403 (Office for National Statistics 2012). In 2011, 69 per cent of households had at least one car or van available, compared with 66 per cent of households in 2001. The total number of cars and vans available to households in Scotland in 2011 was 2.5 million, compared with 2 million in 2001.

Transport emissions make up just over a quarter of Scotland's total emissions, with more than two thirds of these emissions coming from road transport (Scotland 2011). For England and Wales a similar statistic is reported. Furthermore, poor air quality reduces the UK life expectancy by an average of 7-8 months and up to 50,000 people a year die prematurely because of it.

2.1.5 Hydrocarbon - impact and grid alternatives

Data collected by IEA for the OECD countries indicates that currently 60% of the electricity is generated by burning fossil fuel (International energy agency 2015; National Grid 2014). Therefore, when one compares the energetic and environmental impact of electrical propelled vehicles against the fossil-fuelled ones it is important to audit the CO_2 emissions associated with electricity generation. In this respect the data presented in Figures 16-18 is relevant. Note that in the period from January 2010 and December 2012 the maximum electricity demand in UK was 44.4 GW, the latter event occurring at 17:00 on December 31st, 2012. Figure 8 presents the average 10th and 90th percentile data for UK demand. This information shall be of use in ascertaining the design of charging networks for electric vehicles across the UK to ensure that the supply can match the demand under all conditions. (International energy agency 2015; National Grid 2014).



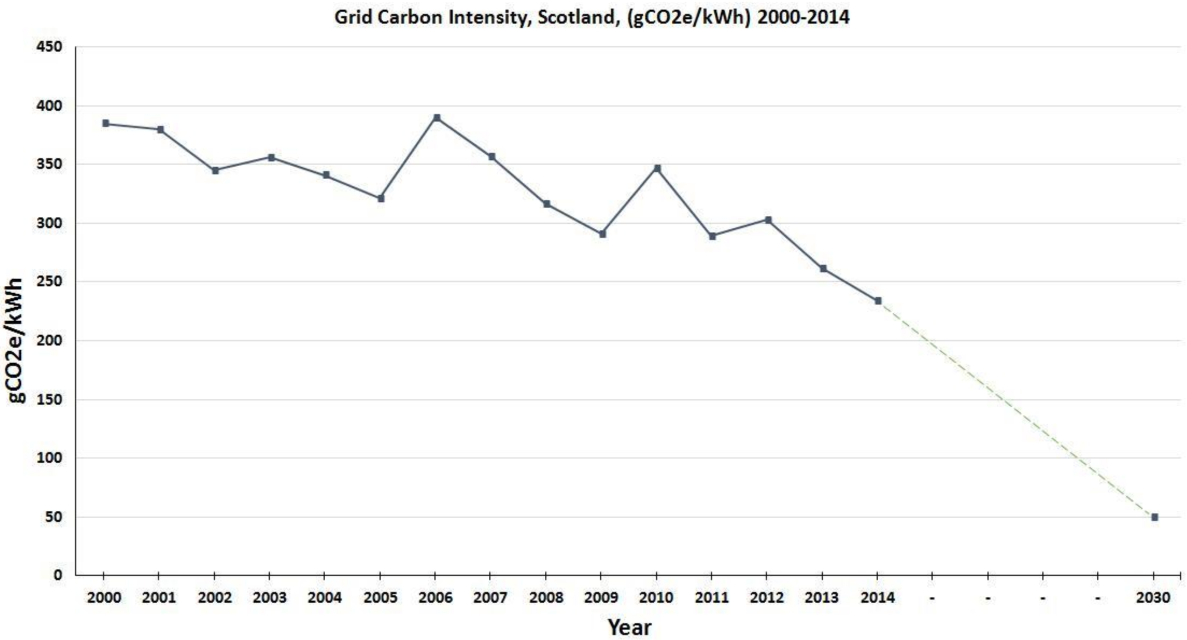
(International energy agency 2015; National Grid 2014)

Figure 8 UK electricity demand profile

While two-thirds electrical energy generation for the world as a whole is from fossil-fuels, for Scotland that fraction drops to 40%. Of particular note is the considerable increase of 'Other Renewables' which is mainly the contribution of wind farms. Scotland has a very ambitious target of 100% carbon-free electricity by 2020.
There is a sharp contrast between fossil-fuel and renewable sources when comparing the CO_2 emission release per kWh. Even with a weak solar energy resource a nine-year, Edinburgh based solar PV monitoring project has indicated an emission intensity of 44g of CO_2. With onshore wind and hydro power that figure drops to 11g and 5g of CO_2. (Irshad, Wahid., Girard, Aymeric., Muneer 2013)

2.1.3 Environmental impact and objectives

Although scepticism and uncertainty remain, it is now widely accepted that human activities are contributing to and accelerating the pace of climate change through the release of greenhouse gases (GHGs), carbon dioxide (CO_2) in particular, into the atmosphere. In order to avoid adverse impacts for future generations, global warming must be limited to no more than 2° Centigrade, which according to modelling analysis by the International Panel on Climate Change (IPCC) would require GHG emissions reductions of at least 80% by 2050 relative to 1990 levels (Metz 2013).



(Committee on Climate Change 2015)

Figure 9 Grid carbon intensity

With legislation and changing government policy, figure 9 indicates the actual reduction and proposed further reduction of grid carbon intensity to the 2030 level of $50gCO_2e/kWh$ this reduction will play a vital role in the commitment to air quality issues and will necessitate renewable energies to support the grid demand.

The Scottish government has committed to almost complete decarbonisation of the road transport sector by 2050. As such a major element of this transformation will be a shift towards the electrification of road transport. A sustainable fleet of electric vehicles aligns with Scottish investment in a renewable energy sector. After all, a quarter of Europe's tidal and offshore wind potential lies in Scotland (Scotland 2011) . Scotland has set itself a most ambitious target to acquire 'the equivalent of all of Scotland's electricity needs to come from renewable sources by 2020 (Committee on Climate Change 2015). A resolution has therefore been approved for the deployment of rapid charge points at intervals of at least 50 miles on Scotland's primary road network to enable extended all-electric journeys (Alba n.d.). Furthermore, there is a 100% funding for the installation of home charging points.

Likewise, the UK Committee on Climate Change suggested in 2010 that 16% of new car sales by 2020 would need to be plug-in vehicles. On a broader scale the European Commission, in its 2011 Transport White Paper set out to:

- Halve the use of 'conventionally-fuelled' cars in urban transport by 2030
- Phase them out in cities by 2050
- Achieve essentially CO_2-free city logistics in major urban centres by 2030

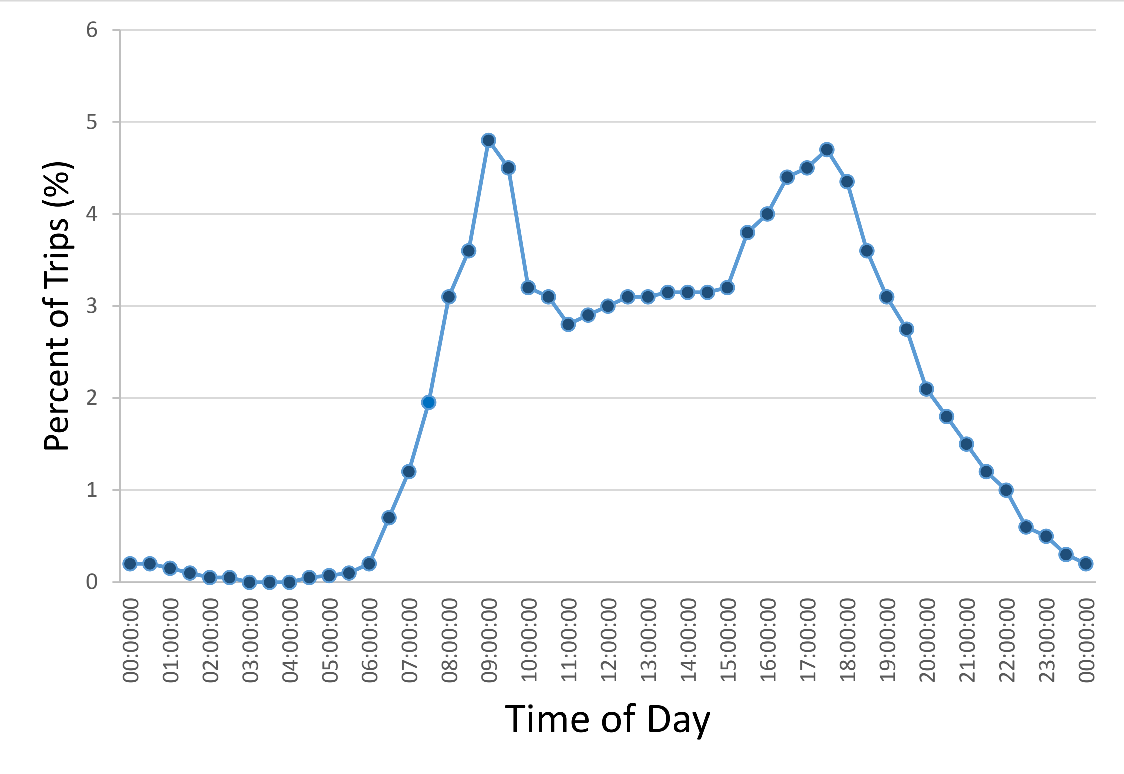
The main drivers for the above actions have been identified as:

- Climate change
- Energy security through exploitation of renewable energy resource
- Air quality and noise pollution
- Public health
- Economic opportunities and job creation

2.1.4 Commitment to air quality issues

Figure 12 presents a relationship between population density and automobile ownership, the data being collated from Scottish cities and towns. There seems to be a definite relationship between the above two parameters. Local and Central governments across the world are trying to wean people off personal transport with appropriate policies such as high automobile parking charges, parking permits for local residents and inducements for the use of public transport which seem to pay the dividends. For example, within the past two decades Scotland’s drivers have realised the on-street vehicle parking charges increased by a factor of 10 (Energy Savings Trust 2015).

Figure 10 presents the usage pattern for automobiles in Scotland and this pattern has similar characteristics to the Edinburgh College usage.



(Office for National Statistics 2012)

Figure 10 UK vehicle travel profile in an urban area

This information will be of use when we visit the problem of gradually replacing fossil-fuelled vehicles with electrically propelled units and the charging related issue. The fossil-fuelled automobile has served mankind for over a hundred years but its energy audit shown in Figure 11 indicates an efficiency of only 13% to move the vehicle mass clearly not an efficient method of mobility (Mitchell et al. 2010).

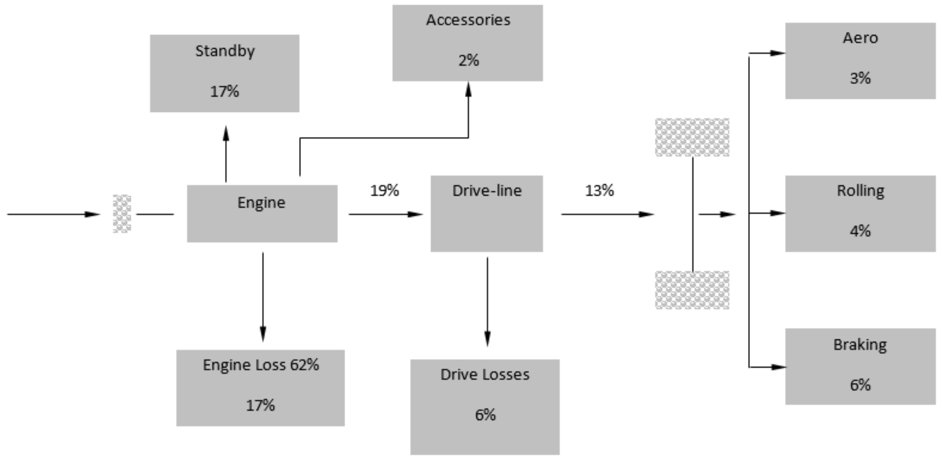
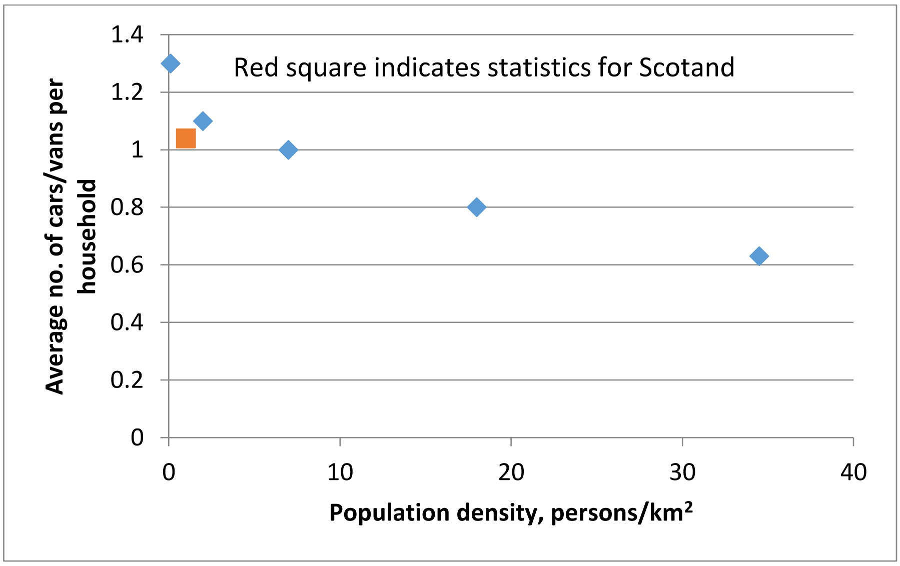


Figure 11 Energy losses in an automobile

(Mitchell et al. 2010)

This study has indicated that in terms of overall efficiency of the useful energy contribution to transport the driver within this mobility exercise has a value of less than 13%. If the energy contribution is in the region of 13% to propel the vehicle, there is potential to improve on this figure with new and emerging technologies such as the battery electric vehicle.



(Office for National Statistics 2012; Muneer et al. 2015)

Figure 12 Link between population density and vehicle ownership

Figure 12 indicates from a previous study that the average household in Scotland has vehicle ownership at a ratio of at least one vehicle per household when compared with 5 other EU27 countries.

In decending order Figure 12 depicts vehicle ownership indicated in the EU countries as:

1.3 Luxembourg
1.1 Italy
1.0 Lithuania
0.8 Poland
0.6 Germany

2.2 Renewable energy – barriers and deliverables

The major global energy challenges are securing energy supply to meet growing demand, providing everybody with access to energy services and curbing energy's contribution to climate change. For developing countries, especially the poorest, energy is needed to stimulate production, income generation and social development, and to reduce the serious health problems caused by the use of fuel wood, charcoal, dung and agricultural waste. For industrialised countries, the primary reasons to encourage renewable energy include emission reductions to mitigate climate change, secure energy supply concerns and employment creation. Renewable energy can open opportunities for addressing these multiple environmental, social and economic development dimensions, including adaptation to climate change. Some form of renewable resource is available everywhere in the world, for example, solar radiation, wind, falling water, waves, tides and stored ocean heat or heat from the Earth. Furthermore, technologies exist that can harness these forms of energy. While the opportunities seem great, there are barriers and issues that slow the introduction of the deliverable renewable energy systems into modern economies.

2.2.1 Solar energy

Solar energy technologies is a diverse source of energy. It responds and adapts to the various ways that we use energy—such as heating and electricity. This solar energy can be summarised as:

- Solar thermal, which includes both active and passive heating of buildings, domestic and commercial solar water heating, swimming pool heating and process heat for industry.
- Photovoltaic (PV) electricity generation via direct conversion of sunlight to electricity by photovoltaic cells.
- Concentrating solar power (CSP) electricity generation by optical concentration of solar energy to obtain high-temperature fluids or materials such as steam to drive heat engines and electrical generators.
- Solar fuels production methods, which use solar energy to produce useful fuels. The term 'direct' solar energy refers to the energy base for those RE technologies that draw on the Sun's energy directly.

Estimates for solar energy's technical potential range from 1,500 to 50,000 EJ/year. The Exajoule is a factor of 10^{18}.

2.2.2 Wind energy

Wind energy has significant potential to further reduce GHG emissions. The use of wind energy to generate electricity on a commercial scale, however, became viable alternative to energy production as late as the 1970's as a result of technical advances and government support. A number of different wind energy technologies are available across a range of applications, but the primary use of wind energy of relevance to climate change mitigation is to generate electricity from larger, grid-connected wind turbines, deployed either on land ('onshore') or in sea ('offshore'). Wind energy offers significant potential for near-term (2020) and long-term (2050) GHG emissions reductions. Estimates of the technical potential for offshore wind energy alone range from 15 EJ/year to 180 EJ/year (Wiser et al. 2011).

2.2.3 Wave energy

Ocean energy offers the potential for long-term carbon emissions reduction but is unlikely to make a significant short-term contribution before 2020 due to its nascent stage of development. The theoretical potential of 7,400 EJ/year contained in the world's oceans easily exceeds present human energy requirements. Government policies are contributing to accelerate the deployment of ocean energy technologies, heightening expectations that rapid progress may be possible. The five main classes of ocean renewable energy technology are as follows:

- Wave energy
- Tidal range (rise and fall)
- Tidal currents (coastal regions)
- Ocean currents (ocean circulation i.e. 'Gulf stream')
- Ocean thermal energy conversion (OTEC)

They offer a diversity of potential development pathways, and most offer potentially low environmental impacts as currently understood.

There are encouraging signs that the investment cost of ocean energy technologies and the cost of electricity generated will decline from their present non-competitive levels as R&D and demonstrations proceed, and as deployment occurs. Whether these cost reductions are sufficient to enable broad-scale deployment of ocean energy is the most critical uncertainty in assessing the future role of ocean energy in mitigating climate change (Charlier & Finkl 2009).

2.2.4 Hydro energy

Hydropower is a renewable energy source where power is derived from the energy of water moving from higher to lower elevations. It is a proven, mature, predictable and cost-competitive technology.

The mechanical power of falling water is an age old technology used for various services from the time of the Greeks more than 2,000 years ago. The world's first hydroelectric station of 12.5 kW was commissioned on 30th September 1882 on Fox River at the Vulcan Street Plant in Appleton, Wisconsin, USA. Though the primary role of hydropower in global energy supply today is in providing centralised electricity generation, hydropower plants also operate in isolation and supply independent systems, often in rural and remote areas of the world.

The annual global technical potential for hydropower generation is
14,576 TWh (52.47 EJ/year) (Edenhofer et al. 2011).

2.3 Battery Electric Vehicles

The author as the fleet manager had significant focus on key areas around BEV usage within the Edinburgh College fleet and the information was generated expressively for this work.

Purchase – The initial purchase cost will be significantly greater than a comparative petrol or diesel vehicle. The cost of the Nissan Leaf for example is £25500 this is £5000 to £10000 greater than a conventional similar sized vehicle with similar specification on-the-road. The used electric vehicle market is something that is currently an unknown. As we cannot look back at historical data and sales, this second-hand market will be slow to buy into, making the depreciation value far greater than conventional similar vehicles. There are not any modern technology electric vehicles to compare with that are more than 4 years old making this a very recent newcomer to an existing and established market.

Insurance - The Group Rating Panel is comprised from members of the Association of British Insurers (ABI) and Lloyds Market Association (LMA). The members meet monthly to set advisory motor insurance group ratings for new passenger cars in the UK. Thatcham Research are experts in vehicle safety technology and they plays an integral role in the Group Rating Process, carrying out the administration of the group rating scheme for private cars. Thatcham hosts the list of group ratings on their website on behalf of the ABI. In 2009, the number of insurance groups was expanded from a 1-20 system to a 1-50 system. This move to 50 groups means that each model of car can be more accurately banded with cars of similar characteristics and therefore create a more precise Group Rating System.
The cost to the electric vehicle owner for car insurance will be greater than a similar internal combustion engine vehicle, for example the Nissan Leaf has been given the insurance grouping 22 whereas the Mitsubishi i-MiEV has been given the grouping of 27. These groupings are 50% higher than an equivalent conventional vehicle this is due to the BEV complexity and the higher replacement costs. Higher technological expertise from the repairers will also become a controlling factor of the insurance costs (Association of British Insurers 2016).

Range – The approximate usable range for an electric vehicle is 80 to 100 miles on a full charge. This makes it unviable transportation for certain types of journey and may make it the ‘second car’ in a family. This range is dependent on the load in the vehicle (number of passengers and luggage), the planned route taking into account inclines and the weather conditions. As the electric vehicle ultimately only has one power source, heater and wiper loads plus all in car comforts will reduce the state-of-charge of the main traction battery.

Charge infrastructure & future work – Currently (2012 - 2016), the electric vehicle manufacturers have not decided on one standardised plug/socket for vehicle charging. This cause's user uncertainty as the car may not plug into the street charge point.
Without this standardisation in place, currently vehicle manufacturers all believe that their chosen method is the correct one and expect the other manufacturers to adopt it. To date this technology is fraught with compatibility issues.
The plug-in electric vehicle will require a cable from the post to the vehicle, so correct socket location, the charge post and the vehicle charge bay (street?) all have to be compatible with the process of using a cable. Cable security and unauthorised un-plugging are factors that will play a major role if the vehicle is to be fully charged for maximum distance. Another issue is that the Battery Electric Vehicle (BEV) cannot be refuelled as easily as a conventional vehicle owing to the long charge times and the network availability of charging stations.

Battery electric vehicle fuel economy

The time frame of this study is nominally limited to the year 2020. The working assumption about BEVs might be regarded as pessimistic by some. Plug-in Hybrid Electric Vehicles (PHEVs) have be introduced into the market in 2010 and they may become one preferred option as they can have the flexibility with regard to range that the BEV cannot asserts (Dallinger & Kohrs 2015).
If the degree of success of PHEVs were to be similar to BEVs in the U.S., this would mean that only one to two per cent of new vehicle sales would be PHEVs in 2020. The share of PHEVs in the total on-road fleet would be far lower. I do not anticipate that PHEVs will have a significant effect on the nation power grid and power plants in this time frame as their current market penetration is not significant.
With the current expectation of carbon reduction by 2020, the electricity providers have had to supply sufficient energy to power a potential significant increase of BEV and Plug-in Hybrids. In 2011 the 'source London' project began to install 1300 charge points across the city with a further 150 car park charge points, the cost for a full-charge in these car parks can vary between free and £3.00 per car per visit. The 'Source London' project primary aim is to replace conventional cars with electric powered ones and the Mayor of London has stated that he wants 'every Londoner to be within 1 mile of a charge point' in a press statement from The Guardian newspaper in 2011 (London & Charging 2010).
Plug-in cars are getting significant attention, for a variety of reasons: they are virtually oil-free, can cut emissions responsible for global warming, and have a high-technology appeal. In 2013 the Nissan LEAF and the LEAF's battery are to be manufactured in Sunderland in the North of England, UK, this is good for the economy and will employ hundreds of workers

to satisfy the demand-safeguarding jobs and developing skills in the Electric Vehicles technology (Nissan UK 2011).

An all-electric vehicle like the Nissan LEAF is driven entirely on electricity and recharged from the electric grid. Its “fuel economy” can be compared to that of a petrol-powered vehicle using an energy-based conversion factor of 33.71 kilowatt-hour (kWh) per gallon to translate miles per kilowatt-hour to miles per gallon. For the LEAF, which gets 3.14 miles per kWh in the city and 2.73 miles per kWh on the highway according to the Environmental Protection Agency (EPA), that’s equivalent to 106 miles per gallon (mpg) city and 92 mpg highway, or 98 mpg combined. That makes the LEAF nearly twice as energy-efficient as the Toyota Prius hybrid, at 50 mpg, for example. High efficiency is reported by (Holland et al. 2015) as it translates into sizable savings at the “pump” – while the Prius costs $720 per year for fuel at $3 a gallon and 12,000 miles, the LEAF costs $400 a year to power, for the same distance travelled and at 10 cents per kilowatt hour .

The generation and distribution of the electricity used to charge the battery – and the resultant emissions of greenhouse gases and other pollutants – are not reflected in the above “in-use” energy efficiency comparison. Taking those losses into account, as well as the corresponding refining and distribution losses associated with gasoline, the electric vehicle’s energy and emissions advantage over the hybrid vehicle is reduced, but not eliminated. When charged on the average United States electricity generation mix, the LEAF generates 20% less greenhouse gas than the Prius does on a “full-fuel-cycle” basis.

The conventional engine light vehicle sector is the second biggest emitter of greenhouse gas and has increased its carbon dioxide emissions steadily over the last 20 years with the increase in transportation demands and the increase in traffic volumes. Government figures indicate a 3% rise year since 1990, this is a significant increase when compared to the energy sector which has dropped by 23%, with business emissions dropping by 31% and household emissions dropping by approximately 5% as reported in the Guardian newspaper 12/03/2011.

Plug-In hybrid fuel economy

Energy consumption of a plug-in hybrid like the Mitsubishi Outlander PHEV or Chevrolet Volt - officially both “extended range electric vehicles” – involves both electricity and petroleum consumption from two modes of operation. The percentage of distance the vehicle would be driven in electric mode by a typical driver is termed the “utility factor” of the vehicle. A 0.6 utility factor indicates that the plug-in vehicle is expected to operate in electric mode 60 per cent of its miles travelled; for the remaining 40 per cent, it is driven on gasoline. A plug-in’s utility factor is computed in turn from its “all-electric range”, i.e. the distance it can travel on battery alone, together with data on the driving behaviour of the user.

Complicating matters is that the range and the utility factor of a vehicle can vary according to the type of driving. The Volt's electric performance is similar in city and highway driving, however – it has an all-electric range of about 35 miles and a utility factor of roughly 0.64 in both cases. The overall fuel economy for the Volt can be calculated from its city and highway fuel economies and utilities factors when running on electricity, together with its gasoline fuel economies. In all-electric operation, the Chevrolet Volt has fuel economy values of 2.81 miles per kWh city and 2.76 miles per kWh highway. Its gasoline fuel economy is 35 mpg city and 40 mpg highway. The final result is an overall fuel economy of 60 mpg-equivalent for the Volt (Loveday 2012).

Battery and charge time evaluation:

(Liu 2010) investigated battery capacity and cost and determined that these are key factors to whether electric vehicle would be used as a contender to the ICE vehicle. The lead acid battery costs less and has a lower energy density of that of a Lithium-ion battery. The Lithium-ion battery has the capabilities of improving the mileage range of the electric vehicle due to the significantly higher energy density and features an excellent discharge characteristic whereas the lead acid battery capacity is limited especially when put under load. Liu identifies that the electric vehicle usage is severely restricted by the batteries ability and having a high density battery can improve the mileage range of electric vehicles albeit with a high battery cost. The voltage of a single battery at 3.6v is too low to have a practical application for the electric vehicle, connecting multiple batteries (x100) in series will be required to supply power for load voltage demand. Increasing battery efficiency in-line with reducing battery cost and Liu's research states that this should be the focus of future studies.

To complement this (Liu 2010) investigation, (Lu et al. 2010) analysed ways to increase battery energy efficiency whilst improving battery performance. As previously stated the electric vehicles initial high cost is a function of the battery technology. The energy efficiency is the significant feature of the electric vehicle battery and the whole of the vehicle's running and service costs are reliant on the battery performance. (Lu et al. 2010) stated that there are several methods to determine the battery efficiency. Coulombic efficiency and energy efficiency; these respectively are 'Coulombic efficiency as a ratio of the discharged capacity to the capacity needed to be charged to the initial state before discharge'.

The Coulombic efficiency equation is defined as:

Equation 1 Coulombic efficiency

$$\eta_C = \frac{Q_{discharge}}{Q_{charge}} \cdot 100\%$$

And, 'energy efficiency is defined as the ratio of the discharged energy to the energy needed to be charged to the initial state before discharge'.

The energy efficiency equation is defined as:

Equation 2 Energy equation

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{total energy input}}$$

The real-world performance and impact of electric vehicles are dependent on the conditions of use of the vehicle.

(Aguirre et al. 2012) examines various studies into the differing current and projected costs of advanced batteries for electric and hybrid vehicles in the determination of life cycle. He investigates the reasons that reported battery costs vary widely for both current and projected production levels and identifies a range of potential causes. A comprehensive life cycle inventory for the vehicle system would require a large amount of up-to-date primary data and much detailed information required to be analysed with respect to battery technology (Ma et al. 2012). Linked to this the percentage capacity achieved affects the number of cells needed in a pack leading to varied production cost projections. Furthermore the author recognises that the type of thermal management used is important when analysing battery costs with air cooling currently believed to be the cheaper option. However, he admits that further studies are required for a more exact estimate.

Improved production capabilities and increased scale of production will result in reduced battery costs and has identified studies where such projected cost reductions vary between 30- 50%.

Vehicle end-of-life (VEOL) – this phase is also very dependent on the actual practice in real life and only a limited amount of data with large variability exist in the open literature; furthermore, it is unclear what the state-of-the-art disposal and recycling technologies will be for 2015 vehicles and beyond, the VEOL treatment of which will not likely be carried out until 2030. There is an assumption the vehicle and battery expected life span is in the region of 150,000km and this is reported by (Erikson 2014) although life spans have been reported as between 150,000 and 300,000km's (Hawkins et al. 2012). End of life treatment will consist of common procedures as applicable to ICE vehicles but will have the added treatment impact associated with dismantling and material disposal process of the battery pack. VEOL can open further studies for future discussion.

2.3.1 Batteries and storage

The current technology and modern battery chemistry of the BEV utilises Li-ion technology as the preferred chemistry for the high voltage traction battery this has a high density to weight ratio and is able to be discharged and recharges (cycled) well in excess of 2000 times giving it excellent properties as an energy source for the vehicle.

The industry currently utilises Li-ion for the traction battery and this is accompanied with a lead acid (Pb) battery the same as in the conventional vehicle as a power source for all of the auxiliary components, heating the interior etc as well as systems such as wipers and in-car entertainment. The BEV is not equipped with an alternator in the battery charging circuit so in this case the energy is transferred from the HV (high voltage) traction battery to recharge this LV (low voltage) battery, ensuring that it must maintain 13.2 - 13.8VDC supporting the auxiliary systems which are similar to a conventional vehicle in design. This energy transfer will have a detrimental effect on the overall traction battery energy and will result in a reduction of predicted range.

2.3.2 Technical and practical application

While there are concerns about changes in driver's behaviour which depict a significant role in the acceptance of the BEV, the main challenges to the deployment of BEVs are currently linked to advances in battery technology and overall improvements in crucial aspects such as specific energy, specific power, lifetime and safety. Battery lifetime is more accurately explained in cycles rather than time. Automotive batteries usually reach the 'end of life' when their capacity falls to 80% of its initial value. Under high temperature conditions (55°C) the life cycle will be in the region of 1200 cycles, indicating that battery temperature must be carefully controlled to maximise the pack life (Han et al. 2014).

Technical bottlenecks directly translate into high battery systems production costs and make BEVs marginal when competing with internal combustion engine alternatives.

It is evident from the work of (Matthey 2015) that while improvements to the lithium-ion cell chemistry will help reduce the weight of battery packs for electric vehicle applications the largest weight gains will come from the pack design, technological developments in energy density per unit will be possible in the future.

2.4 Edinburgh College BEV - early adopters

The College has twelve electric vehicles, two located at each campus with the exception of the Midlothian Campus, where there are three vehicles. There is also an electric mini-bus available for staff use. There are a total of twelve charging points, three located at each campus. The electric vehicles are for staff use only and for College business and figure 13 indicates the user plots captured over a five year period. The College has leased the electric vehicles since 2011 with the first year operating as a trial period, following full roll out of vehicles to the four main campuses. Trials are still frequently undertaken to understand the efficiency of the vehicles in serving the operational needs of the staff at the College to maximise the integration to the changing business requirements.

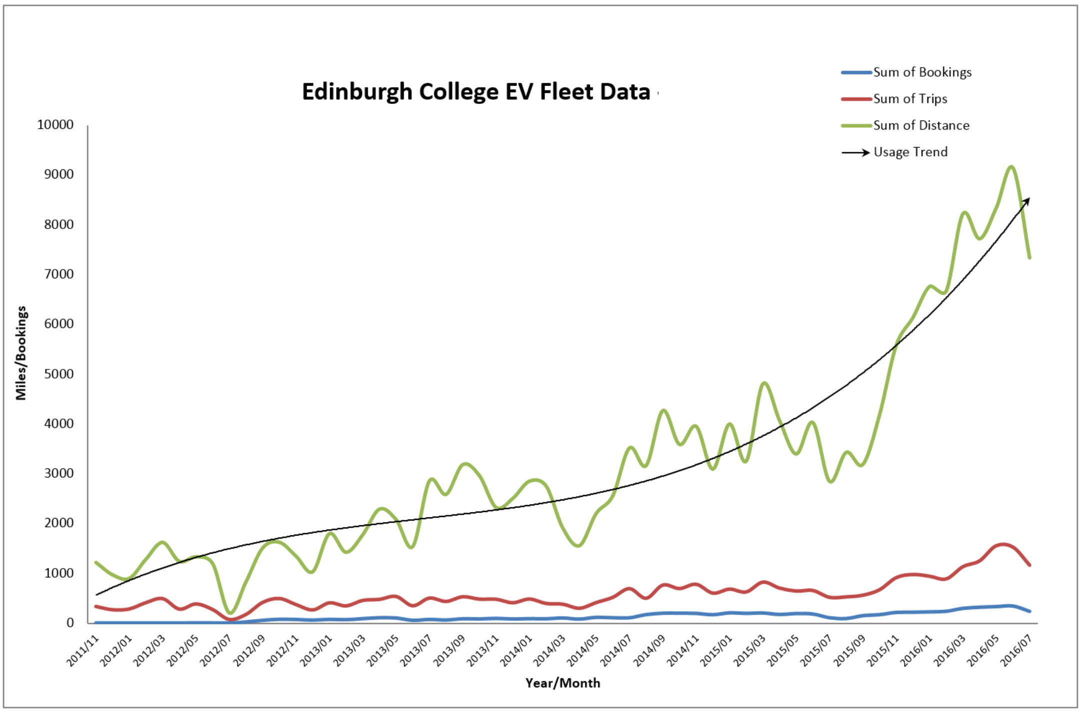


Figure 13 Battery electric vehicle usage 2011-2016

As an alternative option to purchasing Edinburgh College opted to design and manufacture our own model of electric vehicle (EV) charging post designed with on-charge/off-charge illumination for the user, these will be strategically positioned on routes and at businesses that will have the maximum impact to the BEV user without the attached high cost from a proprietary version.

2.4.1 Edinburgh College travel

A research study at Edinburgh College conducted analysis to determine the most suitable method of vehicle procurement. It was decided that due to the nature of the business the lease option was most applicable.

The <u>advantages</u> of leasing a fleet vehicle may include:

- reduced capital costs
- operation of a more fuel efficient fleet
- reduced fuel costs in the longer term
- removing maintenance and servicing issues
- flexibility to choose the vehicle that meets the College's requirements
- ability to select low carbon vehicles with the latest technology
- easy disposal of used vehicles

The <u>disadvantages</u> of leasing a fleet vehicle may include:

- restrictions within the terms and conditions of the lease
- vehicle is not owned
- repayments may be higher than financing the purchase
- vehicle cannot be modified
- high penalty costs can be incurred at end of lease period
- potential limitations to vehicle use and mileage restrictions

2.4.2 College commuting requirements

Post merge and consolidation of the three Edinburgh Colleges a decision was taken to develop an innovative idea to the inter-campus travel initiative using electric vehicles. Introducing the battery electric vehicle into Edinburgh College brings important societal benefits as it improves energy efficiency, air quality and urban noise, and reduces CO_2 emissions when conducting the inter-campus commute. As part of the corporate travel plan all mobility activity should be subject to the required analysis as reported by (Baddeley 2008), initially determining whether the journey is absolutely necessary.

2.4.3 Mobility methods

The College is implementing a car sharing system 'Lift Share' which is used by other organisations throughout Scotland. Lift Share is a social enterprise which helps individuals to travel more sustainably by sharing their journey. It provides the largest online car-sharing network in Scotland and matches people with similar journeys so they can travel better together – save money, cut their carbon footprint.

With support from SEStran and other partners the College now operates a fleet of fourteen electric vehicles on full maintenance contracts, plus a wholly owned electric minibus, and three Mitsubishi i-MiEV's kindly donated by Automotive Leasing, UK. The cars have covered

over 200,000 miles to date and saved around 33 t/CO_2e of GHG emissions which would have come from equivalent medium-sized petrol vehicles such as a Ford Focus.
Savings to the business pre 2015 are in the region of £68,000 based on a fuel expenses claim rate of £0.45 per mile for the same mileage.
Edinburgh College pool vehicles are fully integrated with the curriculum, offering students within Engineering, Automotive, Science and Electrical courses hands-on experience which benefits their understanding of environmentally friendly transport technologies plus associated infrastructure requirements and management processes to support the mobility aspect.

2.4.4 Economic and environmental consideration

The deployment of electric vehicles for inter-campus travel was a strategic forward thinking decision which will utilise the electric power system grid with a sector carbon intensity of 330g CO_2/kWh in 2010, a typical electric car would result in emissions of around 66g CO_2/km, compared to an average of 126g CO_2/km for new internal combustion engine cars in 2013. Electricity as a mode of transportation is thus an extremely effective way of solving the European Union's transport emissions challenge while lowering the annual cost of importing oil into the EU.

Electric Vehicle Disadvantages:

It's what industry players call the "premium for being green." This upfront cost is largely attributed to an EV's most critical component: its battery.
The main disadvantage of electric vehicles is that they have limited range and long recharge times compared to conventional vehicles, and so cannot match the versatility of conventional cars. With this limited achievable range there are higher range anxiety levels present as the study by (Rauh et al. 2015) report. This range anxiety is a potential barrier for the widespread adoption of BEV's. However, recent advances in lithium ion battery technologies, as well as concerns about emissions from conventional vehicles, indicate that electric vehicles are becoming viable, particularly for the short commutes that make up a large part of the trips made by conventional cars.
The author agrees viability must recognise the power production chain or else the BEV will aggregate emissions at a few power point sources as identified by (Nauclér & Enkvist 2009).
Battery-powered electric cars (BEVs) play a key role in future mobility scenarios. However, little is known about the environmental impacts of the production, use and disposal of the lithium ion (Li-ion) battery. This makes it difficult to compare the environmental impacts of

BEVs with those of internal combustion engine cars (ICE). Consequently, a detailed lifecycle inventory of a Li-ion battery and a rough low carbon analysis (LCA) of BEV based mobility were compiled (Notter et al. 2010).

The study shows that the environmental burdens of mobility predominated by the operation phase regardless of whether a gasoline-fuelled ICE or a European electricity fuelled BEV is used.

Electric Vehicle Advantages:

The main advantage of electric vehicles is that they can be recharged using electricity generated from clean, renewable energy sources and at a lower environmental and monetary cost than a petrol or diesel car.

Table 3 Most efficient passenger car energy pathways for alternative fuel sources

(Gaines et al. n.d.)

Lifecycle greenhouse gas emissions rate (gCO_2e/km)	Energy pathway
40	Wind and solar electricity generation, plug-in hybrid
40	Combined cycle electricity generation from farmed trees, plug-in hybrid
142	Natural gas combined cycle electricity generation, plug-in hybrid
180	Oil, petrol-electric hybrid car
218	Integrated gasified coal combined cycle electricity generation, plug-in hybrid
258	Coal-fired power station, plug-in hybrid
257	Oil, conventional petrol, spark ignition

(Gaines et al. n.d.) concluded that plug-in hybrids can sharply reduce oil use and greenhouse gas emissions per kilometre if the electric energy used to recharge them comes from renewable sources as indicated in table 3.

They did not consider pure electric vehicles in their analysis. The emissions from pure electric vehicles should be significantly lower than plug-in hybrids.

Based on previous work conducted by (Wong et al. 2010) investigate a life cycle cost analysis of different vehicle technologies in the city of Singapore. They argue that the setting and typical daily driving range indicate that EV's would be a viable solution to the congestion issues and energy efficiency problem in Singapore however there are barriers to their adoption. This previous evidence developed a life cycle cost model to compare different vehicle technologies including electric vehicles and more traditional internal combustion engines.

The study by (Yun et al. 2011) distinguishes three types of costs: upfront, operation and external costs and their analysis shows that upfront costs are high with electric vehicles but that operational and maintenance costs are typically lower.

(Wong et al. 2010) identified that the main contribution to upfront costs is the open market value of the vehicle and that current government subsidy schemes can help lower this but they are not enough.

The open market value at resale or at the end of lease is a significant contributor to the consumer uptake, this will be a major factor when making a decision between BEV and ICE. However, others (McCarthy & Yang 2010; Olsson & Carlson 2013) argue that, when deciding on a policy aimed at promoting electric mobility to reduce GHG emissions, a marginal electricity principle should be applied, this is the change in electricity use which is assumed to affect the production unit in the system which has the highest operational cost i.e. the marginal unit.

2.5 Charging infrastructure

Electricity as a mode of transportation is thus an extremely effective way of solving the European Union's transport emissions challenge while lowering the annual cost of importing oil into the EU.

The uptake of electric mobility will ultimately necessitate improved control over 'dumb charging' that is to control when the electricity is supplied to the vehicle. This 'smart charging' as discussed by (Lopes et al. 2010) is expected to establish a positive loop with renewables integration, given that electric vehicles are a moveable, mobile and controllable load which could allow energy flow back into the grid as well as taking power from it. This vehicle to grid concept will require a bi-directional communicational link between the car and the grid.

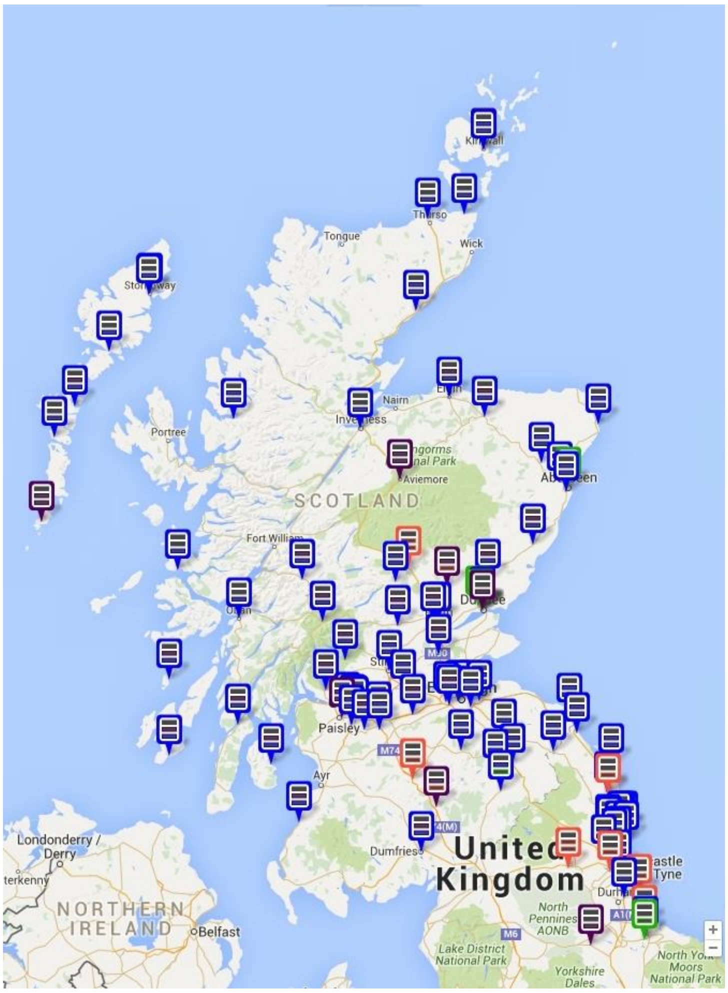
Smart charging could lead to almost decarbonisation of electric transport as less emitting power plants outside peak hours are used and more renewable capacity is utilised - achieving in addition annual savings of 1,863 million EUR as a result of avoided costs on CO_2 emissions in 2050 (Eurelectric 2015).

2.5.1 Campus requirements

All four of the main campuses have slow chargers and fast chargers and one of the campuses has all three types installed. All of these charge points are also publically accessible so one of the main concerns of the College BEV user is the charger availability when moving from campus to campus.

2.5.2 National requirements

One of the main concerns of the national BEV user is charging availability and will the BEV infrastructure remain robust enough to support it. The infrastructure network as at August 2016 was becoming far reaching across Scotland, the map below indicated the state and locations of the rapid charger network in Scotland, UK.



(Zap-Map 2016)

Figure 14 Rapid chargers – Scotland 2016

As of August 2016 in Scotland there are currently 164 rapid chargers see figure 14 and these are not including Tesla Supercharger network. A further 3 are awaiting replacement/re-siting in Moffat, Hawick, and Brodick, and there are another 11 awaiting installation and grid connection.

Due to the high cost of these charge facilities their location must be strategic, publically accessible and continually under review to the changing requirements of the BEV.

All charge points will be commissioned with 'back office' data capture and are continually monitored to ensure functionality, this 'live' data is transmitted to administration for control and update of location map systems.

2.6 System control management and monitoring

A method of embedding the vehicles into the business infrastructure was determined. It was decided that the Battery Electric Vehicles (BEV's) should be correctly controlled so as to allow maximum staff usage evenly distributed across the four Campuses. The newly combined Colleges did not have any existing pool cars to allow staff to travel between sites so the system had to be designed from the ground up.

It is important for businesses to have a successful induction of new products and to realise the key factors to maintain their existence and their future success as indicated by (Bayus et al. 2003) they state, and it is agreed that a fundamental important part is that the key factors are realised and the initial period of existence is given the support from the staff that will experience the BEV and its acceptance as a means of corporate transport.

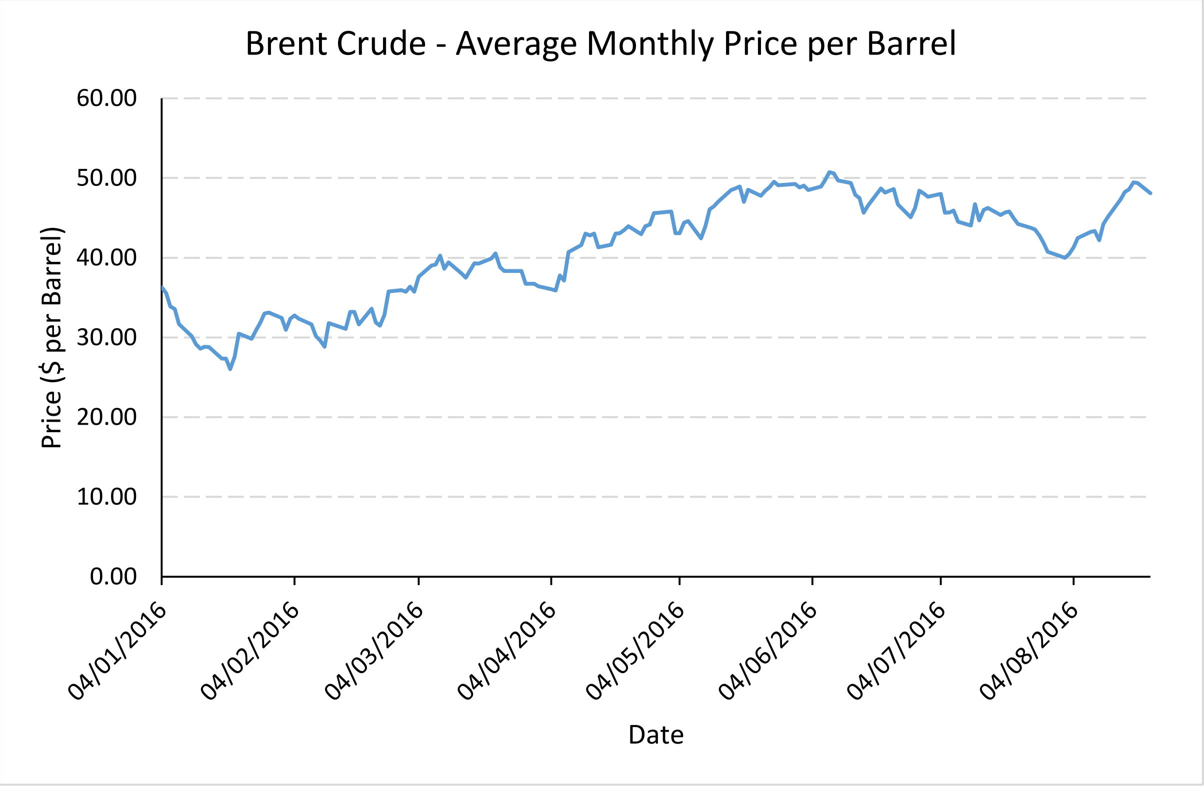
2.7 Conclusion

Since merger in 2012, Edinburgh College has operated a fleet of electric pool vehicles to provide staff with a sustainable, low-carbon transport option for inter-campus and other corporate travel. This innovative and exciting project indicates that significant impact has been made in reducing the number of trips once normally carried out in staff members' own cars - the so called 'Grey Fleet' - with quantifiable and corresponding reductions in CO_2 emissions and fuel expenses. Reducing the grey fleet component is also in line with corporate responsibility and removes any uncertainty around own vehicle roadworthiness and legislative concerns. This chapter scope has provided overview of increasing up-takes of ultra-low emission vehicles in the UK. Energy supply and demand situation have been reported considering CO_2 emission. Also briefly renewable energy sources and their barriers have been presented. Various issues (e.g. purchase, insurance, electric vehicle range, charging infrastructure, economy etc) related to the battery electric vehicles have been presented. Edinburgh College's fleet of electric vehicle operation has been reported for understanding the low-carbon transport option for inter-campus / corporate travel. This is a good example for showing the corporate responsibility of reducing CO_2 emission through sustainable mobility.

Chapter 3 Transportation Analysis Research

3.0 Overview

It has been considered by (Lytton 2012) that if electricity generation is decarbonised and with the introduction of BEV long term road transport emissions can be significantly reduced. From examining the findings on climate change, and the availability cost and environmental credentials of energy, there are issues of vital importance to the road using public. The price of fossil fuels for vehicles may rise substantially over the coming years as global demand for oil begins to exceed economical supply, and the possible introduction of new carbon taxes might push the price higher.



(Nasdaq 2016)

Figure 15 Brent oil prices - 2016

Figure 15 indicates the volatile cost of oil and clearly indicates a steady cost increase in the last six months.

A shift away from a reliance on petrol and diesel will not only be good for the planet but will also help to retain the personal mobility so many of us rely on. It is for these reasons that this study has a close interest in the development, delivery and mass market availability of practical low carbon vehicles.

Conventional fuelled vehicles have 100 years plus of history with respect to costs and new car sale value, however the BEV has 4 or 5 years at the most and this creates a significant unknown with many key questions that cannot be answered. The used BEV car market is completely unknown territory and this data is not known therefore it gives an unsure picture to the potential BEV buyer – as in 'what it will be worth in 10 years'? And how reliable will it be? Most are sceptical of the residual value (RV) at the end of term or ownership are all potential future areas of study.

The 2015 insurance quotes are high which is a direct reflection of the previous statements, as the insurers are not at all certain how or where to position this type of vehicle so typically it has to carry a high insurance premium (Lytton 2012).

3.1 Introduction

Within this area of research, the need to measure driving cycles for a particular area of study rather than using standard cycles that will not accurately represent the reality and the works of (Giakoumis & Lioutas 2010) and (Brady & O'Mahony 2016) is of great importance. A driving cycle of any vibrant city environment is a 'dynamic' entity, which is continuously changing and evolving. Knowledge of the driving cycle, which describes the exact patterns of the city in question, is of paramount importance with reference to its understanding and the role it will play in accurately forecasting vehicular emissions. It is also important to ascertain the simple requirements of the vehicle and how it has made a significant change to human behaviour in the last 100 years (see table 4) and to consider the advantages and disadvantages that is being realised.

Table 4 Merits and demerits of Automobiles

Advantages	Disadvantages
Freedom of movement	Air pollution. Major contributor towards climate change
Personal (driver/passenger) security	Road congestion
Large employment sector	Fossil fuel exhaustion
Personal or work space	Loss of building material
Ability to travel long distances	Space consumption on roads
Increased speed	Society stratification
Enjoining of communities	Accidents

(Matjaz Knez et al. 2014)

Preceding 2011 the Further Education sector within the Edinburgh and Lothian area encompassed three Colleges, Jewel and Esk, Edinburgh's Telford College and Stevenson College of Edinburgh. At point of merge in 2012 all individual entities became Edinburgh College. This was a large College within the sector encompassing in the region of 22,000 students.

The project began with Jewel and Esk College (JEC) from September 2011 through to August 2012 utilising four Mitsubishi i-MiEV's Battery Electric Vehicles which were being used for corporate business use. These were used by all staff for work related activity with a strategic aim to reduce the College carbon footprint. The College initially designed and manufactured six 13amp charge posts (ground mount) to enable our own effective use of the BEV's. The College designed and introduced an effective car management system to control the driver activity of these cars this system would enable the user to 'book' the car for their use from their desk top PC.

With all of the cars fitted with GPS tracking systems the useful data could be gathered – where they went, how they got there, how it was driven and by who and at what time. It was uncertain within the early stages of implementation whether the initiative would be a model that could be taken forward and how this would be perceived by personnel and what approach should be taken with respect to acceptance. This understanding was recognised by (Franke, Bühler, et al. 2012) paper.

Credibility can be further evidenced by embedding the project within the curriculum and offering student scholarships; these are funded from partners that are currently involved with this e-Car project and are designed to give our students a greater depth of knowledge in the emerging new technology of the electric vehicle.

3.2 Scotland and its economy

Scotland is a relatively small country that covers 78,772 square kilometres, about half the size of England and is the northern part of Great Britain. Scotland comprises of a two tier system of 9 regions further divided into 32 Council districts. Scotland's population reached its highest ever total in 2014. Statistics published by the National Records of Scotland (NRS) showed that the estimated population of Scotland was 5,347,600 in mid-2014. The figures showed a rise of 19,900 (0.4%) people since mid-2013 (National Records of Scotland 2015b). Almost 70% inhabiting lowland Scotland alone as shown in figure 16. The lowlands contain six of the country's seven cities, Edinburgh is the Scottish capital on the south east coast, Glasgow which has the highest population of around 575,000 is 75km to the west of the capital and there is Stirling and Perth in the northern central lowlands. The last three cities are Dundee and Aberdeen on the northern east coast of the lowlands and Inverness in the highlands, situated where the River Ness meets the Moray Firth, on the geological fault between the north-western Highlands and the Cairngorms. Scotland also has some 40 large towns which make up about 25% of the population.

Scotland is 440km from South to North has 154 variances in breadth between 40 and 248 kilometres from east to west. The total length of coastline is estimated at 10,000km. The country consists of a mainland area, almost two-thirds of which is mountain and moor land, and 787 islands, of which 93 are inhabited contributing 2% of the population and only 62 are larger than $8km^2$. They are mostly contained in several island groups, including Shetland, Orkney, and the Hebrides, which are divided into the Inner Hebrides and Outer Hebrides. The mainland is geographically divided into three regions: the Highlands in the north, the Central Lowlands, and the Southern Uplands.

3.2.1 Scottish economy growth

The Scottish economy is closely linked with that of the rest of the United Kingdom yet GDP per capita is 18.3% higher in Scotland than the rest of the UK when offshore revenue is inclusive. Scotland has a higher GDP in nominal terms including the share of geographic North Sea oil revenue at £145 billion in 2012. The current economy is recovering from recession that dropped GDP by -5.6% in Scotland and -7.3% for the UK over the period of 2008 and 2009 but has seen sustained growth over the last 3 years. According to (Beverages et al. n.d.) the average household domestic spend in Scotland using Classification Of Individual Consumption according to Purpose (COICOP) is £406.30 with one of the higher individual spends being transport at approximately 17% Figure 17.

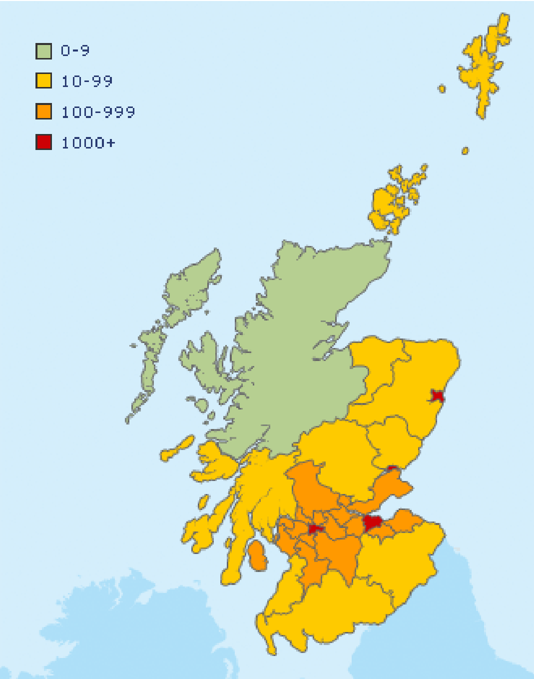


Table 5 Breakdown of Scottish cities and towns by population.

	Number of cities/towns
Over 400,000	2
Between 400,000 and 100,000	2
Between 100,000 and 50,000	5
Between 50,000 and 25,000	20
Between 25,000 and 15,000	23

Figure 16 Breakdown of Scottish population.

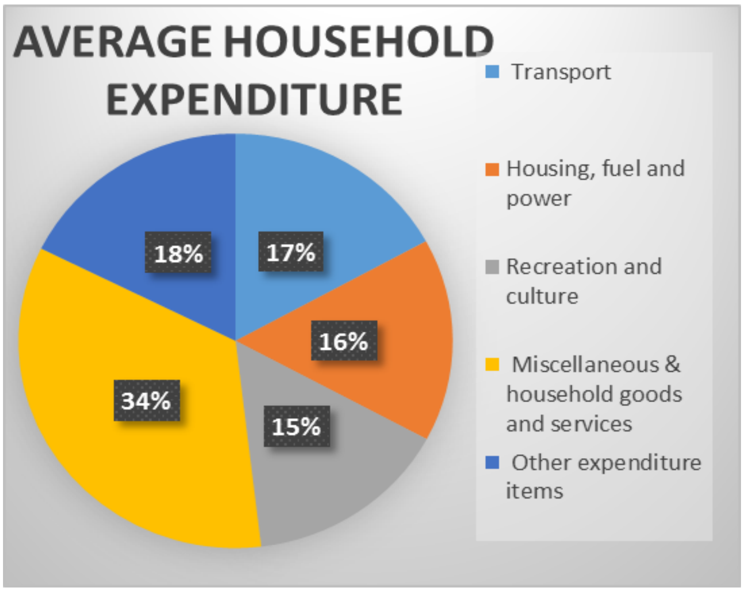


Figure 17 Average household expenditure.

Energy use in Scotland is higher per capita than the rest of the UK due to many factors such as industrial processes and colder climate. However, the Scottish government has recognised this and have set many targets to largely reduce emissions and decarbonise the electricity generation and heat sector by 2030. Also Scotland aims to have 100% of energy consumption in Scotland to be produced by renewables by 2020.

This does not however mean that all energy produced will be renewable as Scotland exports around 25% of energy to England and Northern Ireland and requires balance within the power distribution network. Scotland typically produces 50,000GWh per annum and consumes around 57% of this, around 10% is lost or consumed by transmission, distribution losses and by auto generators. Scotland consumes 3000 tonnes of fuel in transport with 66% of the total being in used for personal use as shown in figure 18. The total energy used is inclusive of all fuel types transport is one of the largest energy consumers with petroleum products accounting for 65,000GWh equivalent of the nation's total final consumption. The Scottish government have many campaigns to introduce a lower carbon trend and reduce energy usage and the latest figures show a drop in energy consumption per capita although it is likely that this trend arises from poor economy and high fuel duties.

(Dept of Energy and Climate Change 2016)

Figure 18 Road transport energy consumption

3.2.2 Oil and the automobile

The stockpiles of crude oil which are used and refined to produce petrol and diesel fuel and which are the life blood of the transport system within the UK as well as the world are diminishing quickly. Change is needed to decrease the global dependence on oil and to tackle the environmental problems of greenhouse gases that are produced as a result of the usage of fossil fuels. (David & Mackay 2009) state that automobiles are quite inefficient with approximately 75% of the energy going into producing heat. With the global number of automobiles in use coming close to 1 billion the demand for fossil fuels for transport is high and ever increasing (Barkenbus 2009).

3.3 Background of the electric automobile

Electric vehicles have been on the roads in the UK for more than 150 years. In the 1830's a Scot, Robert Anderson developed an early electrically powered cart. In America circa 1897, the Electric Carriage and Wagon Company of Philadelphia had built fleet of New York City taxis.

Figure 19 illustrates an early 1900's electric vehicle, this had many advantages over their competitors as they did not have vibration, noise or smell that was associated with petrol vehicles and was significantly easier to drive as there was not a gearbox or a starting handle.

(Kris De Decker 2010a)

Figure 19 Early electric car and charger - circa 1900

The history of the car is inextricably linked with industrialisation and our modern society. Transport represents around 25% of total energy demand and global CO_2 emissions. Many of the lessons to be learned from the history automotive power can be applied to the wider energy industry, in particular that decarbonisation will require a combination of energy efficiency and finding clean sources of power (Consult EV 2014).

3.3.1 Automobile registrations within the UK

The fuel for Internal Combustion Engine (ICE) vehicle is still being market led by petrol engine vehicles, and the UK market is predominantly controlled by petrol and diesel fuel ICE vehicles. This has taken a dip in 2011 with a higher percentage of sales for diesel vehicles but overall, across the years the new vehicles powered by pure electric as in the Battery Electric Vehicle (BEV) is only 0.2% in 2013 (Cookson n.d.) and as figure 20 indicates this has risen to approximately 1% in September 2015.

Very low volumes of BEV indicated giving marginal market penetration as stated by the Society of Motor Manufacturers and Traders (SMMT) and the Office for Low Emission Vehicles (Office for Low Emission Vehicles 2015).

(Office for Low Emission Vehicles 2015)

Figure 20 BEV registrations (UK) 2014-2016

3.4 Review of performance, vehicular energy models and driving cycles

This review presentation encompasses the most relevant work on both vehicular energy models and driving cycles. The drive cycle is analysed regarding its characteristic parameters, such as, data collection techniques, methodology, statistical analysis air quality and pollutants covered, when appropriate. Other parameters were taken into account such as transportation as a national problem, objective results and relevance regarding the wider spectrum of the road traffic situation was considered.

The United Kingdom (UK) road transport emitted 33 million tonnes of CO_2, accounting for approximately 22% of the total UK CO_2 emissions. Following the Kyoto Protocol agreement of December 1997, the UK voluntarily agreed to reduce the 1990 level of total "greenhouse gas" emissions by 12.5% by the year 2010. Within this context the UK government is therefore committed to a 20% reduction in CO_2 emissions over the same time period. One of the means by which the government aims to achieve this target is by reducing emissions from road traffic (Dept of the Environment 2000).

Traffic reduction policies although necessary, can be highly controversial, since it is an aspect which affects either directly or indirectly the whole population. Reducing the volume of traffic, and therefore pollution, in congested areas, such as city centres, is not by itself an optimum solution. According to (Matjaz Knez et al. 2014) public transport journeys take, on average, three times as long as equivalent car journeys. This means that either policies necessarily tackle public and private transport simultaneously, or else face the consequent congestion caused by, for example, closing some main arteries of city centres, which, will inevitably result in additional levels of pollution.

In addition, modelling inaccuracies also result from a lack of data on emission measurements for different vehicle types, vehicle operational modes (idle, acceleration, deceleration and cruise) and difficulties inherent in accurately predicting vehicle usage under real driving conditions (DEFRA 2015).

This and the high costs attached align the needs for modelling predicting emissions, though potentially expensive to develop, can represent a cost-effective alternative to direct measurement and be used for multiple use situations. Attention will also be given to work developed in relation to the measurement of driving cycles. The reasons for this inclusion are that, for an emissions model to be accurate, its method and empirical formula ought to be based on traffic data that accurately represent real driving behaviour. There is therefore an increasing need to measure and define driving cycles for a specific area, such as Edinburgh, Scotland, as opposed to using standard cycles that will not accurately represent the real situation.

Knowledge of the driving cycle, which accurately describes the exact patterns of vehicle movement within a specific city is of paramount importance if vehicular energy usage are to be accurately forecast.

3.4.1 European standards

The NEDC test is a standard European measurement of emissions and consumption based on a rolling road test. It is the same standard for petrol and diesel engines as it is for Battery Electric Vehicle. It is a recognised and objective way to measure the performance gaps between competition models and changes in specification. The car is on a rolling road dynamometer, undertaking the same urban cycle (ECE-15 cycle) three times, then the extra-urban cycle once. The average of these 4 cycles decides the NEDC range (Barlow et al. 2009).

This range is a comparative indication of range measured under very specific driving and temperature conditions. Exactly as with petrol and diesel cars, this study is a comparison of values when the BEV is driven under real conditions and comparing the NEDC range with the predicted dashboard indicated range, this range will vary according to speed, driving style, the terrain of the road and the use of air conditioning and heating. If the vehicle is driven in temperate conditions, then the range could more realistically be approximated to a 30% reduced distance for an average suburban trip.

If the vehicle is driven in extreme winter conditions, then the range could more realistically be reduced by 50% for an average suburban trip when compared with the NEDC figures. This study will address the ‘range anxiety’ discussion that is often voiced when offering the BEV as an alternative to the conventional fuel vehicle.

3.4.2 NEDC laboratory requirements and conditions

This test is conducted within a laboratory at 20-30° C on a simulated, flat rolling road where no pre-warming is allowed and all air conditioning and electrical equipment is switched off. An electrical machine simulates wind resistance and vehicle inertia. This drive cycle, it is a very specific drive cycle (figure 21) with periods of acceleration and constant deceleration and speed in effect bears little comparison to the real world drive cycle (figure 22) that has been conducted within our tests routes. Driver behaviour, historical driver techniques, road works or closures, wind and weather have little or no bearing on this type approval testing as the procedure is conducted within laboratory conditions. The Department for Transport agree that this drive cycle has little relation to a real driving patterns on the road.

Figure 22 shows a greater comparison to the test drive cycle that is being evaluated this is collected from real world data directly from the vehicle as it is being driven. This real world data is much more transient than stylised as with the NEDC data (Barlow et al. 2009).

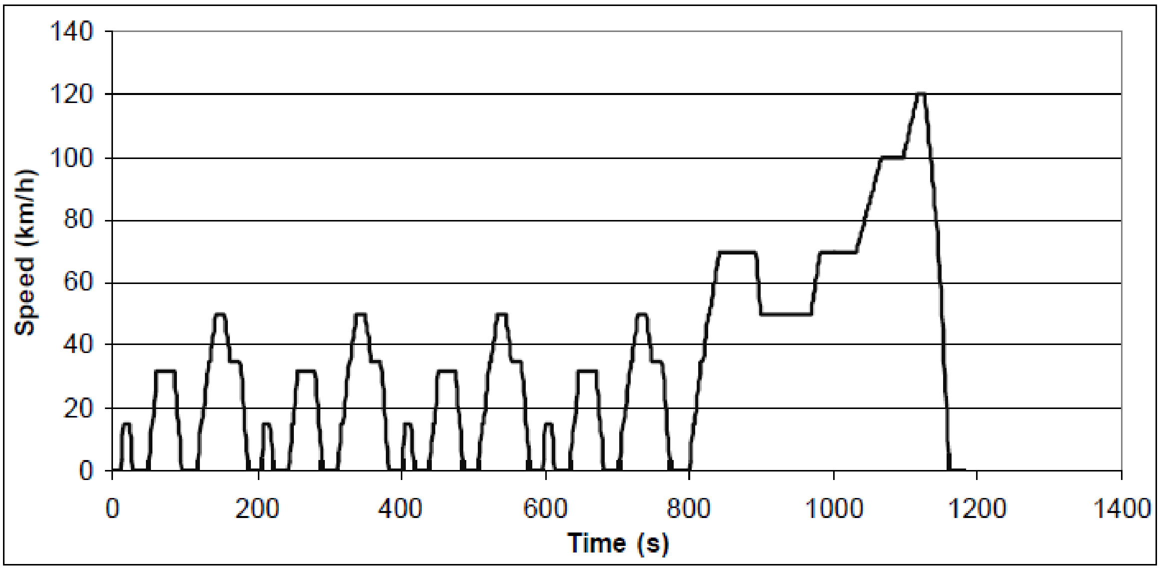
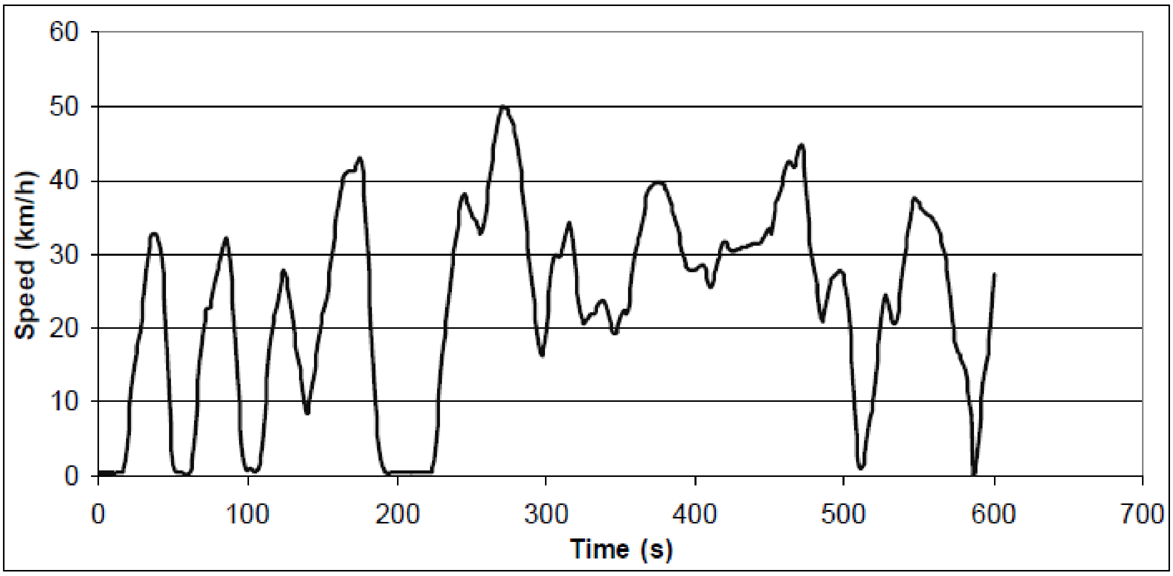


Figure 21 New European Drive Cycle – typical (2009)



(Barlow et al. 2009)

Figure 22 Real World Drive Cycle – typical (2009)

Table 6 EU emissions standards for passenger cars (in g/km)

Euro Standard	Implementation date*	CO (g/km)	HC (g/km)	NMHC (g/km)	NOx (g/km)	HC+NOx (g/km)	PM (g/km)
	Diesel						
Euro I	July 1993	2.72	-	-	-	0.97	0.14
Euro II	January 1997	1.00	-	-	-	0.70	0.08
Euro III	January 2001	0.64	-	-	0.50	0.56	0.05
Euro IV	January 2006	0.50	-	-	0.25	0.30	0.025
Euro V	September 2010	0.500	-	-	0.180	0.230	0.005
Euro VI	September 2015	0.500	-	-	0.080	0.170	0.005
	Petrol						
Euro I	July 1993	2.72	-	-	-	0.97	-
Euro II	January 1997	2.20	-	-	-	0.50	-
Euro III	January 2001	2.30	0.20	-	0.15	-	-
Euro IV	January 2006	1.00	0.10	-	0.08	-	-
Euro V	September 2010	1.000	0.100	0.068	0.060	-	0.005**
Euro VI	September 2015	0.100	0.100	0.068	0.060	-	0.005**
	* Market placement (or first registration) dates, after which all new engines placed on the market must meet the standard. EU emission standards also specify Type Approval dates (usually one year before the respective market placement dates) after which all newly type approved models must meet the standard. ** Applies only to vehicles with direct injection engines.						

(Miller 2016)

CO	Carbon monoxide
THC	Total Hydrocarbons
NMHC	Non-methane hydrocarbons
NO_x	Nitrogen oxide
PM	Particulate matter

Since January 2015 Euro 6 emissions standards have been in force, but most cars don't meet Euro 5 or even Euro 4 standards in real world use, a study has shown.
Imperial College London and the vehicle analysts at Emissions Analytics teamed up to look at harmful NO_x emissions in the exhaust emissions of a sample light-duty diesel vehicles which meet the Euro 4 and Euro 5 standards as indicated in table 6 (Transport for London 2015).

Of the ten cars in the sample group, all failed to meet Euro 4 and Euro 5 emissions limits, while only one was in line with the Euro 3 standard which came into force in January 2000. Average NO_x emissions across the group were almost four times higher than Euro 5 requirements, while Euro 6 will set an 80% reduction in NO_x emissions for all type approvals after September 2014, and new registrations from January 2015.

Produced primarily by diesel engines, NO_x emissions can cause breathing problems and premature death, the reasons behind the EU's recent legal proceedings against the UK. Emissions of NO_x were above January 2010 limits in 16 areas of the UK, with studies showing London would be unable to meet these targets until 2025.

In a statement published with the report, Emissions Analytics said: 'NO_x and miles per gallon standards are calculated using the New European Drive Cycle, the shortcomings of which have been widely reported and are supported by Emissions Analytics' large volume of real-world data.

'Others have voiced concerns regarding the number of monitoring stations and the use of modelled data in EU Air Quality Directive compliance assessments. What it is clear is that real-world data has an important part to play in policy making.'

In 2015 a breach to the emission standards was realised which involved multiple different engine manufacturers. NO_x emissions were reported as seven times higher than the Euro 6 limit. In 2017, the European Union will introduce testing in a 'real-world' situation, this will be called Real Driving Emissions (RDE) which will use portable emission measuring equipment in the addition to laboratory testing.

At the end of this comprehensive study the International Council on Clean Transportation (ICCT) are expecting a 100% conformity factor to close this fraudulent loophole (Poliscanova 2015).

It is this real world data that will be critically analysed within this research work as it will be a 'true' measure of the capabilities of the automobile to be effective for the Colleges' application.

3.5 Pollutants – Industrialisation, urbanisation and fuel use

The long range drive cycle studies within this research paper has a focus on whether the BEV can replace an ICE vehicle to improve on the air quality of intercity mobility this drive must explore and review the effect to the environment as well as the practicalities of the vehicle under this condition.

The (Parliamentary Office of Science and Technology 2002) indicated that the main pollutants of concern are nitrogen oxides (NO_x), volatile organic compounds (VOCs), particles (especially PM10, which are particles with a diameter of less than one hundredths of a millimetre, i.e. 10μm), carbon dioxide (CO_2) and carbon monoxide (CO).

All of these are mainly emitted by road transport, but also arise from fossil fuel power generation and domestic and industrial sources.

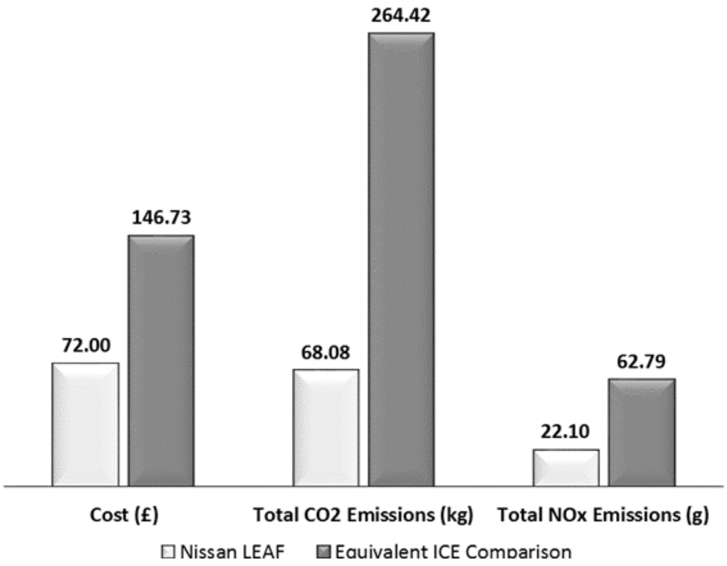
Within this research paper levels of NO_x pollutants were considered and accounted for as studies have shown that NO_x can cause lung irritation as well as lowering people's resistance to pneumonia, bronchitis and other respiratory infections. In the presence of sunlight, NO_x can react to produce a photochemical smog.

If hydrocarbons are also present ozone and VOC can be produced, which has a similar health effect to NO_x. All harmful pollutants in their own right.

Although higher concentrations of NO_x are found in city areas, the NO_x emissions must be accounted for when undertaking this study as it is detrimental to health, toxin whether emitted locally from the vehicle or from the power generation source will have the same end effect.

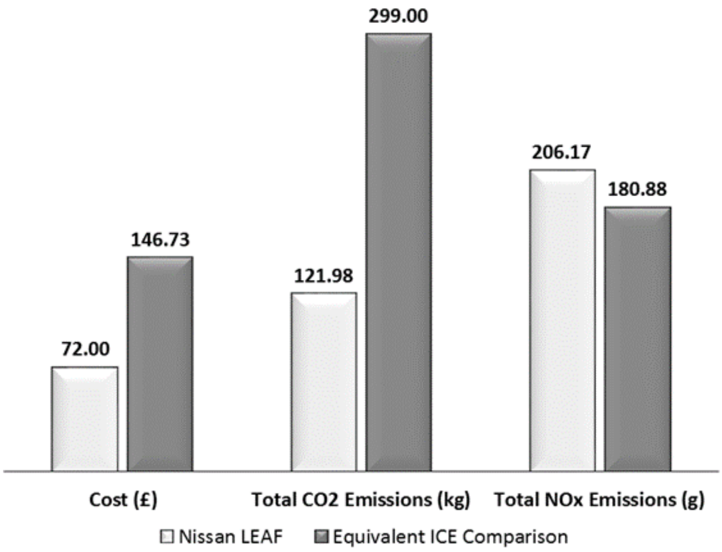
Figures 23 and 24 indicate the concentrations levels are higher in England. The greenhouse gas effect of nitrous oxide itself is hundreds of times greater than carbon dioxide – it is the fourth largest contributor to greenhouse gas global warming (RAC 2012).

This higher level of NO_x must be addressed by both the correct utilisation of ‘clean’ emission vehicles and supporting legislation to generation companies in an attempt to ‘clean-up’ the generation process as the mobility relies on clean energy generation to support the new BEV technology as there is a significant difference between Scottish and UK figures.



(Milligan & Muneer 2015)

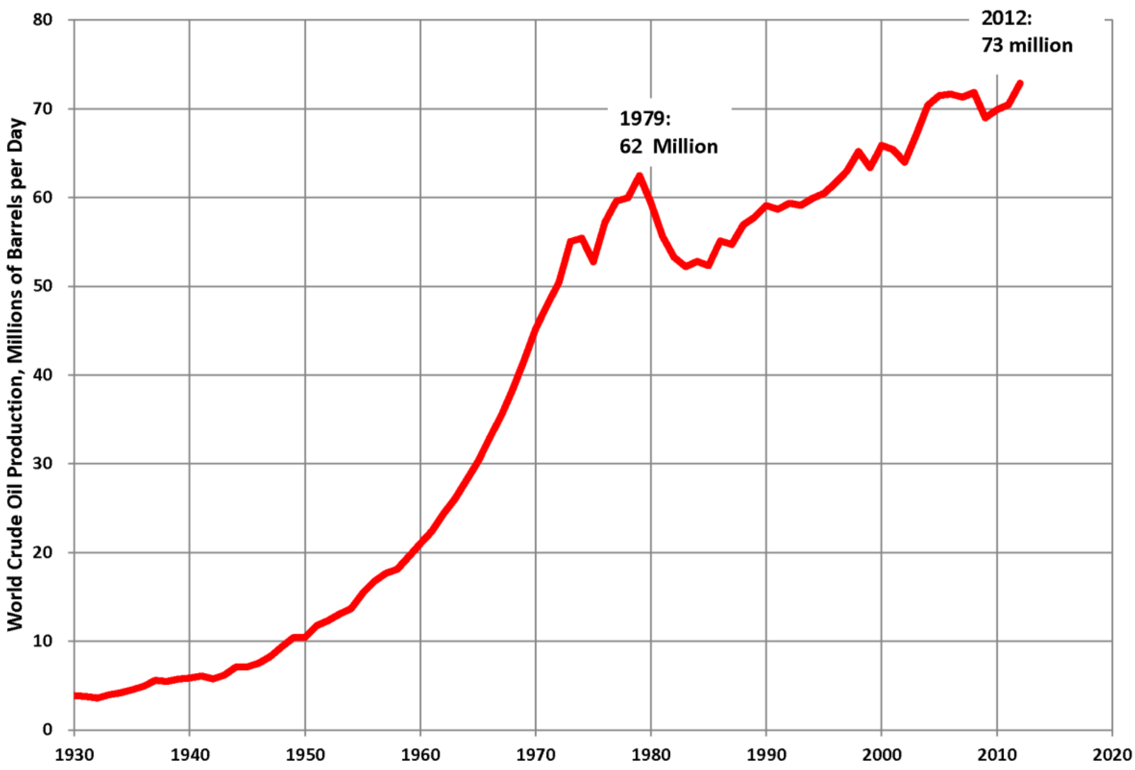
Figure 23 Pollutant comparison Scottish Figures – generated by the author



(Milligan & Muneer 2015)

Figure 24 Pollutant comparison English Figures – generated by the author

Figure 24 indicate the calculated results from an experimental journey from central Scotland to southern England and indicates the differences in pollutants dependant on the energy mix at source in the electricity generation process.



(US Energy Administration 2012)

Figure 25 Production volume of barrels

The trade of oil worldwide has from 1866 been sold and transported in barrels. Figure 25 illustrates the steady and unsustainable increase of production volume. Both the 42 US-gallon barrels, based on the old English wine measure, the tierce (159 litres), and the 40 US-gallon (151.4 litre) whiskey barrels were used. Also, 45 gallon barrels were in common use. The 40 gallon whiskey barrel was the most common size used by early oil producers, since they were readily available at the time.

1 Barrel of oil equivalent = approximately 1628 to 1700 kWh

The barrel of oil equivalent (BOE) is a unit of energy based on the approximate energy released by burning one barrel (42 U.S. gallons or 158.9873 litres) of crude oil (Pees 2004).

3.5.1 Greenhouse gas emissions and effects

Local and national governments have been heavily influencing the market to switch to electric passenger cars in order to reduce air pollution. However, a review by (Timmers & Achten 2016) suggests that electric vehicles may not reduce levels of PM as much as expected because of their relatively high weight.

This review found that there is a positive relationship between weight and non-exhaust PM emission factors. In addition, BEV were found to be 24% heavier than equivalent conventional fuel vehicle.

As a result, total PM_{10} emissions from EVs were found to be equal to those of conventional modern vehicles. Therefore, it could be concluded that the increased popularity of electric vehicles will likely not have a great effect on PM_{10} levels.

Terrestrial eco-toxicity potential (TETP) from tyre wear and brake wear according to (Hawkins et al. 2013) was comparable with conventional vehicles and (Huijbregts et al. 2000) indicated that there was uncertainty and no clear difference.

Carbon Dioxide (CO_2)

While carbon dioxide is non-toxic, its main environmental effect is as a greenhouse gas. Each year an estimated 30 billion tonnes of carbon dioxide are emitted due to human activity, 2% of which originates from the United Kingdom.

To illustrate the scale of the impact of these emissions as a result of human activities, the atmospheric concentration of carbon dioxide (from all sources) has increased by 31% since 1750. The present concentration has not been exceeded during the past 420,000 years and likely not during the past 20 million years. The current rate of increase is unprecedented during at least the past 20,000 years. Over the last two decades, about three-quarters of the anthropogenic emissions of carbon dioxide have been a result of burning of fossil fuels, the rest being predominantly due to land-use change deforestation and development.

By enhancing the greenhouse effect, greenhouse gas emissions are leading to increases of the Earth's atmospheric, land and sea temperatures. During the 20th century the global average surface temperature (the average of near surface air temperature over land and sea surface temperature) increased by 0.6 (+/-0.2) °C (IPCC 2016). This temperature is predicted to increase by 1.4-5.8°C by 2100 (1990 baseline). Based on palaeo-climate data, the projected rate of warming is very likely to be without precedent during at least the last 10,000 years. The concomitant rises in sea levels and resulting climatic change will be of great (and as yet unknown) significance to all patterns of life on Earth.

Carbon Monoxide (CO)

Produced during the incomplete combustion of carbon compounds such as fossil fuels, this gas is known to be deleterious to human health. During respiration it readily combines with haemoglobin in the blood thus hindering the body's ability to take up oxygen. It is thought therefore to aggravate respiratory and heart disease.

Carbon monoxide also contributes to global warming to a small degree. This it does indirectly after first taking part in chemical reactions within the atmosphere. One such reaction would be with oxygen, forming carbon dioxide and thus contributing to the enhanced greenhouse effect.

Nitrogen Oxides (NO_x)

As a result of the high temperatures occurring during combustion, nitrogen combines with oxygen from the air forming oxides of nitrogen (NO, NO_2, N_2O etc.). These gases are known to be responsible for acid deposition via the formation of nitric acid. As stated by (Zandaryaa n.d.) Nitrogen dioxide (NO_2) is toxic even in small concentrations and is known to cause and aggravate human respiratory diseases. Nitrous oxide (N_2O) also contributes directly to global warming and is responsible for around 7% of the enhanced greenhouse effect.

Particulates (PMs)

Particulates, commonly known as 'black smoke', are fine particles produced by incomplete combustion, the burning of lubrication oil and by the presence of impurities within the fuel. Typically, with a dimension of the order of 10 microns or less (known as 'PM_{10}'), they are known to cause and aggravate human respiratory diseases and are thought to be carcinogenic. The World Health Organisation (world health organisation 2012) has issued a report stating that there are no concentrations of airborne micro-sized particulate matter that are not hazardous to human health.

In response to these studies, (Timmers & Achten 2016) stated that BEV's total PM_{10} (particulate matter with a diameter less than 10µm) emissions from BEV's tyres, brakes, resuspension of road dust and road wear were found to be equal to those of conventional vehicles.

Volatile Organic Compounds (VOCs)

From a study conducted by (Gray 2016) volatile organic compounds consist of a number of different chemicals including hydrocarbons (eg methane), which are released during the production, refining, storage and combustion of fossil fuels. The largest environmental risks of VOCs are due to the presence of benzene and 1,3-butadiene, which are both carcinogens and are easily inhaled due to their volatile nature. Other chemicals in this category are responsible for the production of tropospheric ozone, which is toxic even in low concentrations.

Methane is a significant greenhouse gas and is released during the drilling for oil and gas and during the combustion of petroleum products. Around 5% of methane emissions are due to the production and use of fuels used for road transport.

Tropospheric Ozone (O_3)

In the stratosphere, ozone absorbs ultraviolet light, therefore reducing the number of harmful rays reaching living organisms at the Earth's surface. However, at ground level (the troposphere), ozone is toxic to animals and plants. Ozone is thought to be responsible for aggravating human respiratory disease and is known to reduce crop yields.

While the concentration of stratospheric ozone is being depleted by the action of chlorofluorocarbons and other chemicals, exhaust emissions from road vehicles are increasing the concentration of ozone at ground level. As stated by (Ab 2009) although there are a number of sources of man-made tropospheric ozone, transport is known to be a major contributor of emissions through the action of sunlight on emitted VOCs.

Lead (Pb)

Lead is known to affect the mental development of young children and is known to be toxic. It was originally introduced into petroleum products as an 'anti-knock' additive to improve combustion in a spark-ignition (petrol) engine. At its peak, road transport was responsible for three quarters of airborne lead in the UK. However, due to the introduction of unleaded petrol and the elimination of leaded fuels in Europe in 2000 (Holgate 1998), the amount of lead emitted has fallen by over 80%.

3.5.2 Global climate change

United Nations Convention on Climate Change known as the “Montreal Protocol” means the Montreal Protocol on Substances that Deplete the Ozone Layer, adopted in Montreal on 16 September 1987 and as subsequently adjusted and amended (Nations 1998). This protocol considers all ozone depleting gasses and has far reaching actions for all areas of energy and subsidiaries.

- Enhancement of energy efficiency in relevant sectors of the national economy
- Research on, and promotion, development and increased use of, new and renewable forms of energy, of carbon dioxide sequestration technologies and of advanced and innovative environmentally sound technologies
- Encouragement of appropriate reforms in relevant sectors aimed at promoting policies and measures which limit or reduce emissions of greenhouse gases not controlled by the Montreal Protocol
- Measures to limit and/or reduce emissions of greenhouse gases not controlled by the Montreal Protocol in the transport sector

Within the scope of this research, reference was made with the Kyoto Protocol to the United Nations framework convention on climate change, Kyoto 1998, where it states that individual or joint parties to this protocol, ensure that their aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gas CO_2 do not exceed their assigned amounts where it is stated that the sectors under study are energy, industrial processes and transportation.

Calculated pursuant to their quantified emission limitation and reduction commitments for the United Kingdom has been set at 92% of the base year inscribed within this protocol, with a view to reducing their overall emissions of such gases by at least 5 per cent below 1990 levels in the commitment period 2008 to 2012.

It is evident from the data from (Sakurai & Suzuki 2010) the background pertaining to the electric vehicle, the social demand of the emission reduction of CO_2 for the prevention of global warming. The importance of the research and development of alternative energy has increased due to the depletion of fossil fuels. Therefore, reduction of CO_2 for the well-being and mobility at Edinburgh College encouraged development and popularisation of low emission vehicles is an important issue for the prosperity of the earth (Vilchez & Jonathan 2013). From an environmental standpoint, we hope to see more electric vehicles in consideration of the circumstances. Electric vehicles will operate in urban areas as a commuter car and its characteristics will be recognised.

In development, electric vehicles are modified from an existing vehicle standpoint therefore it is important for the electric vehicle to portray a standardisation regarding the user operations as there is distinct commonality required irrespective of the fuel source.

The transport industry is a major contributor to greenhouse gas and emissions of pollutant. While BEV will reduce the vehicle emission, the produced energy required to recharge will be generated at power station sites and the emission levels at this point will increase if the electricity is produced by convention generation methods.

3.5.3 Air quality – UK analysis

In the UK, air pollution is a serious problem that has only recently come to the centre of policy concerns. The social and economic costs of air pollution in the UK are likely to be large. The UK is dependent on expensive and unsustainable energy resources that exist from first generation power plants which are inherently inefficient and requiring high demand on natural resources placing a big burden on the welfare and economy, air pollution is becoming a great environmental concern in the country. In this regard, renewable energy resources appear to be one of the most efficient and effective solutions for clean and sustainable energy development in the UK.

One of the general main aims at national and local authority level is to improve on the air quality. Measures are being put in place initially in the areas of poor air quality such as congestion points within cities to act on this and offer a solution that will give a measurable difference.
In the UK, a quarter of all CO_2 emissions come from transport and approx. 90% of this comes from road vehicles. According to the UK Government at the end of 2013 there were 35 million vehicles licenced for use on the roads of UK and during 2013, over 4300 new ultra-low emission vehicles (ULEV – vehicles with emissions of CO_2 below 75 g/km, or fully electric) were registered for the first time, this is 25% up on 2012.
This included over 3600 cars and vans eligible for UK government ‘plug-in grants’ this too is up, nearly 50% more than in 2012. The largest increase for individual models were the Renault Zoe and the Nissan Leaf being the most popular.
Electric vehicles have emerged as a promising solution for reducing the oil dependence in transportation systems. Nevertheless, their integration into modern transportation systems is largely limited by the higher cost and the long charging times, on the one hand, and by the low driving range, on the other hand. The limited driving range has been considered as one of the major factors that affect the acceptance of electric vehicles.
I agree with the works of (Rauh et al. 2015) as it has been shown that reliable information regarding the remaining driving range (RDR) may help to overcome the range anxiety, i.e., the fear that the range of the vehicle is insufficient to reach the desired destination.
The city of London, UK has enforced a restriction to the use of carbon emitting vehicles. It has introduced the ‘congestion charge’ and is planning to introduce 100,000 electric vehicles by 2020 and the council authorities are planning legislation supporting supply and charge points for public and commercial use.

Scotland’s 2020 Renewable Electricity Target

One of the leading bodies in Scotland that is at the forefront of shaping the current energy supply and demand is Scottish Renewables, Glasgow (Palo 2015). They are the representative body for the renewable energy industry in Scotland, providing a united voice for more than 320 member organisations working across the full range of technologies delivering a low-carbon energy system integrating renewable electricity, heat and transport. Work conducted by Scottish Renewables in conjunction with the renewable energy target estimates potential progress towards the Scottish Government’s target for the renewable energy sector to generate the equivalent of 100% of the country’s annual demand for power by 2020.

The Scottish Renewable's vision is for a Scotland that harnesses the full economic, social and environmental potential of all forms of renewable energy in order to provide consumers with secure, low-carbon supplies of energy at the lowest possible cost (WWF Scotland 2015).

Cost

Cost is often viewed to be a key barrier to the deployment of energy generation and storage. There is a growing expectation that the capital costs of storage technologies will fall (Ernst & Young China 2015) while a number of projects taken forward under the Low Carbon Networks Fund have shown that it is possible to significantly improve commercial viability by realising the additional value that such technologies can add to the system (Networks 2015) making them a viable investment contribution to the networks. An energy generation system that can provide energy as the demand grows and in addition is cost effective, secure with lower CO_2 emissions.

Demand

Scottish Renewable's have assumed electricity demand remains at 2013 levels, given recent years have shown small fluctuations and that over the next five years we predict energy efficiency measures may lower demand but economic recovery may increase demand and offset those measures. Electricity demand in Scotland in 2013 was equal to 38,256GWh (Palo 2015).

Table 7 Forecast Renewable Electricity Capacity and Output 2020

	Installed Capacity in June 2015	Forecast Installed Capacity in 2020	Assumed Load Factors	Forecast Annual Output in 2020 (GWh)
Onshore Wind	5,182	8,171	0.28	19,900
Offshore Wind (Operational)	197	197	0.40	690
Offshore Wind (New)	-	1,142	0.47	4,702
Shoreline wave / tidal	8	38	0.26	87
Solar photovoltaics	177	328	0.11	316
Small scale Hydro	191	266	0.35	804
Large scale Hydro	1,339	1,348	0.35	4,074
Landfill gas	116	126	0.55	610
Sewage sludge digestion	6	6	0.55	29
Energy from Waste	18	58	0.53	269
Animal Biomass (non-AD)	13	13	0.53	60
Anaerobic Digestion	24	41	0.87	314
Plant Biomass	174	211	0.69	1,267
Total	**7,444**	**11,945**	-	**33,122**

(Scottish Renewables 2015)

Progress against Target

From their data it can be seen that on current projections, Scotland will fall short of its 2020 renewable electricity target, with predicted capacity only sufficient to generate 87% of the equivalent annual demand for power.

However, there is significant capacity on onshore wind, offshore wind and solar with planning consent which could proceed if offered appropriate support in the necessary timescales. This includes 2,830MW of offshore wind across three projects in the North Sea, and some 700MW of onshore wind projects on the Scottish islands (Scottish Renewables 2015). These projects cannot meet the deadline for the closure of the Renewables Obligation and have not yet secured a Contract for Difference, but could deliver the capacity required to take us up to and beyond the 100% target.

3.5.4 Air quality – within experimental regions

Air quality analysis, and the reduction of toxic gases is a significant area of study, and another main objectives of the study is to analyse the impact of the market share increase of different vehicle technologies in terms of energy consumption and CO_2 emissions in a main route into Edinburgh from East Lothian. An extensive characterisation of how road vehicle technologies energy consumption and CO_2 emissions compare in a full life cycle perspective for comparison.

The principle theory is conservation of energy and several analytical and experimental data such as rolling resistance, aerodynamic drag, and mechanical efficiency of power transmission for the general driving performance of the BEV on this route which will be conducted by a professional driver. Regenerative charging of the BEV will be monitored with respect to the change of operating conditions of a model vehicle such as inclined angle of road and vehicle speed, the chosen route will encompass all of this as well as rural and urban driving.

Vehicle emissions contribute to the increasing concentration of gases that are leading to climate change. In order of significance, the principal greenhouse gases associated with road transport are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Road transport is the third largest source of UK greenhouse gases and accounts for over 20% of total emissions. Of the total greenhouse gas emissions from transport, over 85% are due to CO_2 emissions from road vehicles. The transport sector is the fastest growing source of greenhouse gases.

Other pollutants from road transport as stated by (Kebin et al. n.d.) are further sources of many local emissions concerns including benzene, 1,3-butadiene, carbon monoxide (CO), nitrogen oxides (NO_x) and particulates (PMs). Within urban areas, the percentage of contributions due to road transport is particularly high - in London road transport contributes almost 80% of particulate emissions. There is a growing body of evidence to link vehicle pollutants to human ill health including the incidence of respiratory and cardio-pulmonary disease and lung cancer.

In 1998 the Committee on the Medical Effects of Air Pollutants estimated that up to 24,000 people die prematurely each year in the UK as a direct result of air pollution. Similar findings are emerging from international research. According the World Health Organisations estimates air pollution was responsible for the death on 3.7 million people under the age of 60 in 2012 (Holgate 1998).

In 2013 the BBC News reported that there are now six miles of streets that have been deemed officially polluted in the capital of Scotland (BBC 2013). There has been a demand for fewer and cleaner vehicles to combat this statement.

3.5.5 Monitoring of ICE energy use

The Internal Combustion Engine (ICE) has been around since the 18^{th} century it has represented power, ingenuity and significant achievement this could be partially replaced by low carbon technologies as the changing role of the automotive engineer and new design engineers develop and improve the abilities of the BEV as a strong runner to compete with the petrol and diesel motor car. Today around 25% of the UK's domestic CO_2 emissions come from road vehicles. Reducing this will pose the biggest problem, as the requirements to better the government's requirement of reducing emissions by 26% over the next 10years. The goal is to largely decarbonise vehicles by 2050 and this will have a significant impact on the ICE and an alternative and upgraded transportation method will become a requirement.

3.5.6 Grey fleet

Grey fleet travel refers to mileage in employee-owned vehicles – a grey area, where millions of hidden miles are travelled each year and often overlooked by employers and employees alike.

In the public sector, evidence indicates that grey fleet makes up around 57% of total road mileage. According to the figures by the Office of Government Commerce, across the whole of the sector this could add up to as much as 1.4 billion miles every year!

Whilst managing the duty of care to employees driving for work is a legal requirement, and this includes employees driving their own vehicles for work (Act 1974).

As the Health & Safety at Work Act 1974 states that:

- "It shall be the duty of every employer to ensure, as far as is reasonably practicable, the health, safety and welfare at work of all employees."

Giving an alternative to ICE vehicles can be a sustainable option as in excess of 400,000 tons of CO_2 are emitted, on average, from grey fleet cars over 1.4billion public sector miles. This is an annual carbon profile that would take 550,000 UK trees their whole lifetimes to offset (Office of Government Commerce 2008).

3.6 BEV and the ICE vehicle

Although scepticism and uncertainty remain, it is now widely accepted that human activities are contributing to and accelerating the pace of climate change through the release of greenhouse gases (GHGs), carbon dioxide (CO_2) in particular, into the atmosphere. In order to avoid adverse impacts for future generations, global warming must be limited to no more than 2 degrees centigrade, which according to modelling by the International Panel on Climate Change (IPCC) would require GHG emissions reductions of at least 80% by 2050 relative to 1990 levels (Metz 2013).

The main advantage of electric vehicles is that they can be recharged using electricity generated from clean, renewable energy sources and at a lower environmental and monetary cost than a petrol or diesel car. Electric vehicles are not a new idea; many of the first mass-produced cars were electric. The main disadvantage of electric vehicles is that they have limited range and long recharge times compared to fossil-fuelled vehicles, and so cannot match the versatility of conventional cars.

The first electric car was built sometime between 1832 and1839 by Robert Anderson in Scotland (M. Knez et al. 2014). Breakthrough by Gaston Plante and Camille Faure increased battery energy storage capacity, which led to the commercialisation of battery electric cars in France and Great Britain in the 1880s. Battery electric vehicles (EVs) were quiet, clean and simple to operate, but their batteries took a long time to recharge, were expensive to replace and had limited range.

(Balea 2015) has stated that emerging market are finding different way to address the high new technology costs in a worldwide market as many factors make electric vehicles (EVs) an exciting alternative to gasoline-powered ones, including long-term savings and the environmental benefits. Still, there are challenges to widespread adoption, the biggest of which is the higher upfront purchase cost of EVs.

Automobiles are quite inefficient with 75% of the energy going into producing heat. Research and development is being carried out into manufacturing affordable electric automobiles that offer an improved overall thermodynamic efficiency and, in this respect, the car manufacturer Nissan has announced plans to produce 50 000 Nissan ‘LEAF’ electric vehicles in the UK starting in 2013 with a global production of 200 000 units per year (M. Knez et al. 2014).

3.6.1 Technology and developments

There are various PHEV powertrain configurations such as serial, parallel and serial–parallel. (Traut et al. 2012) detail the various PHEV powertrain configurations. In the serial configuration an engine turns a generator which generates electricity to drive an electric motor to turn the wheels; the parallel configuration is capable of transmitting torque to the wheels from two different energy sources; and the serial-parallel uses a planetary gear device to operate both in series and parallel. Charge sustaining HEVs have two complementary drive systems, a combustion engine and an electric motor with a battery. Both the engine and the electric motor can drive the transmission at the same time. HEVs cannot be recharged from the electricity grid, their energy comes from gasoline and from regenerative braking (Karabasoglu & Michalek 2013).

Nissan LEAF

Leading **E**nvironmentally friendly **A**ffordable **F**amily car

One of the vehicles used for this experiment work was the compact five door Nissan LEAF (figure 27) electric vehicle, this vehicle has Kinetic Energy Recovery Systems (KERS). Different KERS may be built purely electric, purely mechanical, or hybrid mechanical/electric differing for vehicle applications. As previously stated this vehicle has an all-electric energy recovery system to replace energy into the traction battery when braking or under over-run conditions.

Figure 26 Nissan LEAF automobile

Nissan LEAF (second generation)

Product information
Small Car with a length of 4.45 m x 1.77 m wide x 1.55 m height,

80 kW (109 HP) peak,
280 Nm maximum torque.
Max Speed of 145 km/h (90 mph)
175 km range (108 miles)
17.3 kWh / 100 km consumption

Battery & charging
Lithium ion, 24 kWh, standard charge in 6 to 8 hours (100%);
Quick charge in 30 minutes (80%),
Charging connectors front

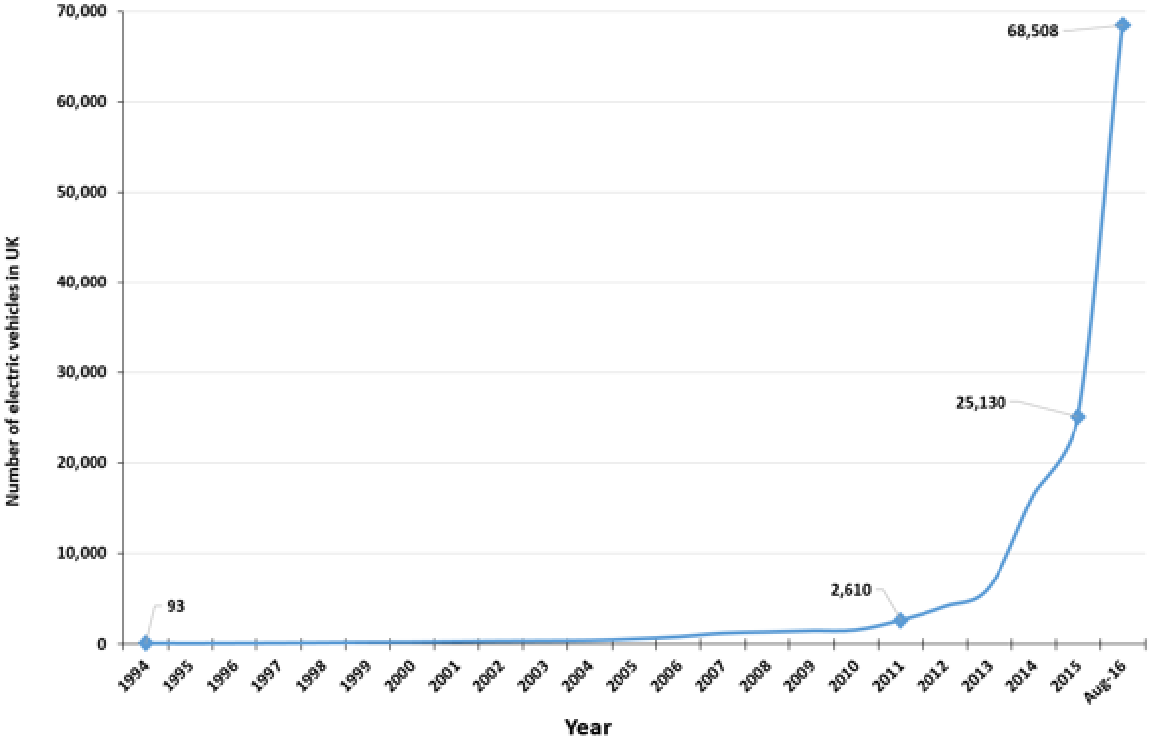
Price & market entry
£23,500 VAT included
Available in the UK since 2012

(Nissan UK 2016)

Table 8 Battery Electric Vehicles compared to previous economical diesel vehicles

	1977 2.1D Peugeot 504	1984 1.6D Ford Fiesta	2012 Mitsubushi i-MiEV	2014 Nissan LEAF Acenta
Best MPG	33	74	112 equivalent	169 equivalent
CO_2 (g/km)	222.6	127	0	0
Horsepower	59	54	66	109
Torque	82	70	145	254
Weight	1210	835	1070	1493
0-60	23 seconds	19 seconds	11 seconds	9.7 seconds
Top Speed	83	<90	81 (Limited)	93 (Limited)
Price	n/a	£15,000*	£23,499	£18,490

Table 8 gives key vehicle performance figures over a 37-year period used as comparison across makes and models, the author has compared old diesel engine vehicles with modern battery electric vehicles indicating a marked improvement across performance figures.



(Department for Transport 2013)

Figure 27 Number of BEV registrations in the UK 1994-2016

Public acceptance and wide spread adoption with government assistance has seen a sharp increase in the number of BEV registrations since 2013 as figure 28 illustrates.

3.6.2 Technical data

Types of Motors

Electric cars have traditionally used series wound DC motors, a form of brushed DC electric motor. More recent vehicles have made use of a variety of AC motor types, as these are simpler to build and have no brushes that can wear out. These are usually induction motors or brushless AC electric motors which use permanent magnets. There are several variations of the permanent magnet motor which offer simpler drive schemes and/or lower cost including the brushless DC motor (Nissan 2015).

Motor nomenclature can be seen in table 10.

EV Comparisons

Mitsubishi i-MiEV: (Mitsubishi technical 2015)

- Electric motor

49 kW (66 hp), 180 Nm (133 ft-lb) AC synchronous permanent magnet motor. Max 8000 rpm

Table 9 Traction motor and the internal combustion engine

Permanent magnet synchronous motor for i-MiEV	
Model Type	Y4F1
Power Source	AC 330v
Max Output	47kW
Max Torque	180Nm (from 0 rpm)
Max Speed	8500 rpm

Internal-combustion engine for petrol powered "I"	
Model Type	3B20 T/C
Power Source	Petrol
Max Output	47kW
Max Torque	94Nm (at 3000 rpm)
Max Speed	7500 rpm

- Transmission

Single speed constant ratio (6.066:1)

- Battery

16 kWh lithium ion battery pack (88 lithium-ion 3.7v/50Ah cells)

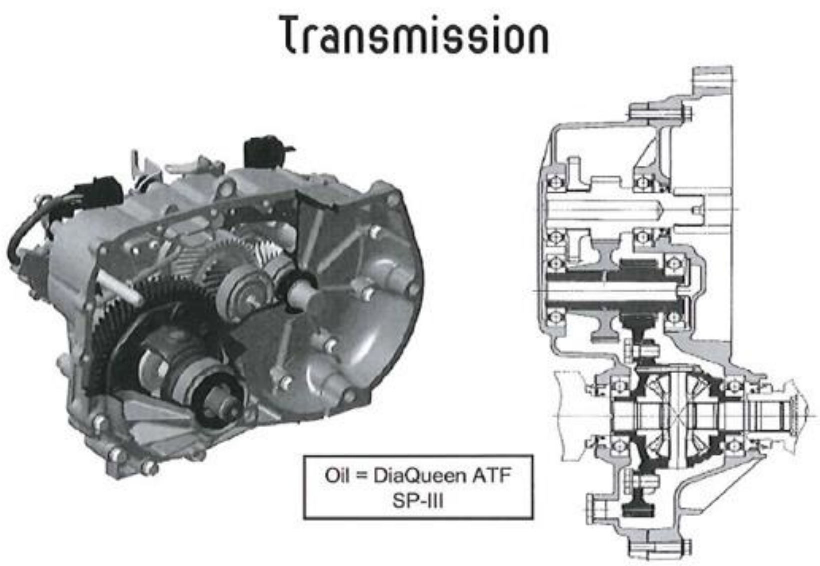


Figure 28 Transmission general layout

Because of the electric motor drive, the BEV does not require a normal transmission. Instead, a simple reduction gearbox is utilised.

Nissan LEAF:

(Detail taken from Nissan LEAF Technical Introduction Training manual NMTN9217AE)

- Electric motor

80 kW (110 hp), 280 Nm (210 ft-lb) synchronous motor. Max 11000 rpm
Motor Mass = 58.5 kg (129 lb)
Torque Density = 4.8 Nm/kg
Output Density = 1.4 kW/kg

- Transmission

Single speed constant ratio (7.94:1) model RE1F61A. Input Gear 17 teeth, Main Gear in/out 31/17 teeth, Final Gear 74 teeth. Oil capacity 1.1 litres.

- Battery

24 kWh lithium ion battery (192 air-cooled, stacked laminated battery cells with lithium manganite cathodes in 48 modules)

ZOE: (Renault UK 2015)

- Electric motor

Gen2 5A 65 kW (87 hp), 220 Nm (162 ft-lb) synchronous motor. Max 11300 rpm

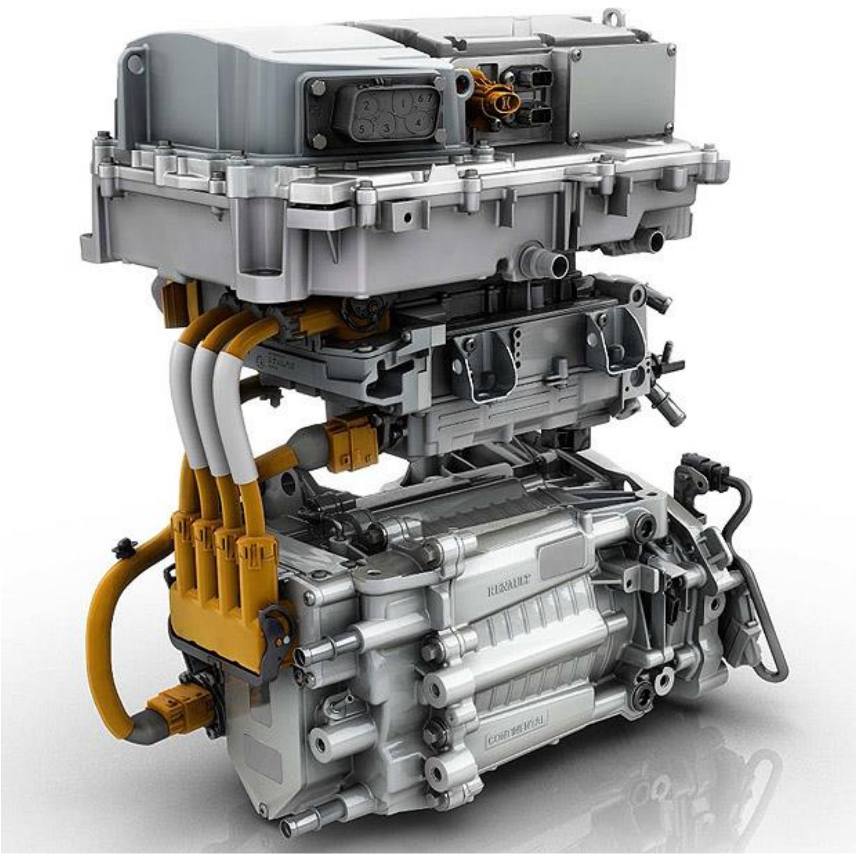


Figure 29 Motor drive assembly

- Transmission

Single speed auto (9.32:1)

- Battery

24 kWh lithium ion battery, 400 volts, 12 modules, 192 cells

3.6.3 BEV crash safety

If Electric propelled vehicles are to become approved for general public use then it is understood that vehicle manufacturers have rules and protocol to apply so as to ensure occupant protection in general usages and accidents as cited by (Sakurai & Suzuki 2010). Electrical components must be distributed having high voltage with their location place easily untouched from outside and wiring harnesses having high voltage are coloured orange. High voltage wiring must be suitable accessed by correctly trained operatives and part of the approved training is to ensure that connectors are not removed from the terminals by hand. Manufacturers must position the traction battery where damage is highly unlikely after accidents. There is no damage of harnesses after accidents. To fix firmly battery package after accidents. Liquid does not leak from the vessel of batteries.

As seen from these explanations, we have the regulations regarding EV’s but we have not yet established the regulations regarding crashworthiness (Sakurai & Suzuki 2010) and if they should exceed the standard set for ICE vehicle.

The voltage in electric vehicle batteries can deliver a lethal shock, much like that of an electric chair. Further, the voltage from an electric vehicle battery is Direct Current (DC), which carries a greater likelihood of death than Alternating Current (AC) due to the inability to ‘let go’ of the conductor. The threshold voltage where DC becomes dangerous can be as low as 55 to 60 volts and most electric vehicles have voltages in the region of 250 – 350 volts (AA1car 2014).

From the authors experience and through consultation at seminars, a percentage of the general public see the electric vehicle as dangerous. They are not if you have an awareness of wiring colouring conventions and treat them with respect. Training and awareness of the potential shock hazard, and follow the recommended safety procedure when working on one of these vehicles.

High voltage cables in electric vehicles are usually color-coded to warn you of their potential danger. On most, the high voltage cables are color-coded **ORANGE** as can be seen in figure 30.

Figure 30 Cable colour coding

All electric vehicle manufacturers in the vehicle design ensure that the batteries have a safety switch or disconnect mechanism to disconnect the battery from the vehicle's electrical system. The location of the battery isolator safety switch and the disconnect procedure will vary from one application to another, technicians must refer to the owner's manual or service literature for the specifics. This safety isolation device will be manufacturer specific and for the attention of trained personnel only.

3.6.4 Charging modes for electric vehicles

Charging points are primarily defined by the power (in kW) they can produce and therefore what speed they are capable of charging an electric vehicle at. There are four ways to charge your electric or plug-in hybrid vehicle, which are referred to as “modes” by charge point and vehicle manufacturers.

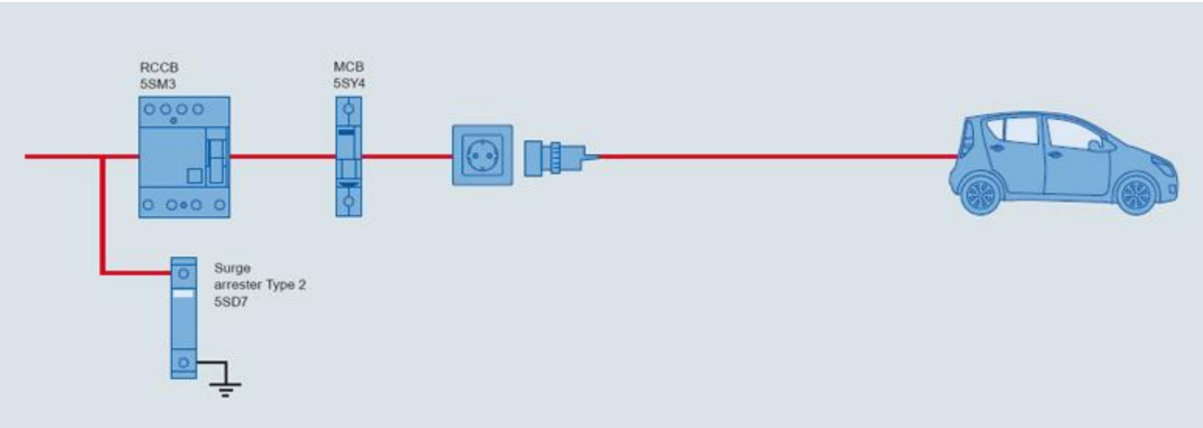
Solution packages for various requirements in accordance with IEC 61851

- Charging mode 1
- Charging mode 2
- Charging mode 3
- Charging mode 4

Charging mode 1

With charging mode 1, the electric vehicle is connected to a single-phase or three-phase AC network via a standardised socket see figure 31. The use of this charging mode requires both an overcurrent protective device (OCPD) and a residual current circuit breaker (RCCB) on the network side. Use of a surge arrester is recommended.

This charging mode is not permitted in certain countries (Anegawa 2010a) due to the absence of a control circuit and it utilises standard socket connection to the network.

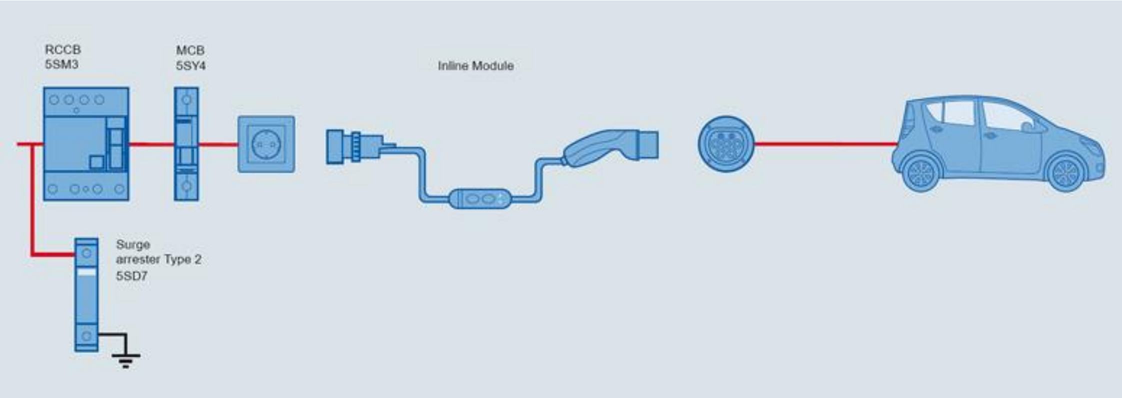


(Anegawa 2010c)

Figure 31 Layout of BEV charging mode 1

Charging mode 2

With charging mode 2, the electric vehicle is connected to a single-phase or three-phase AC network, with a charging control system pilot function, via an inline module in the charging cable. The inline module has an integral residual current protective device in order to increase the level of protection see figure 32. The use of this charging mode requires both an overcurrent protective device and an RCCB on the network side. Use of a surge arrester is recommended.

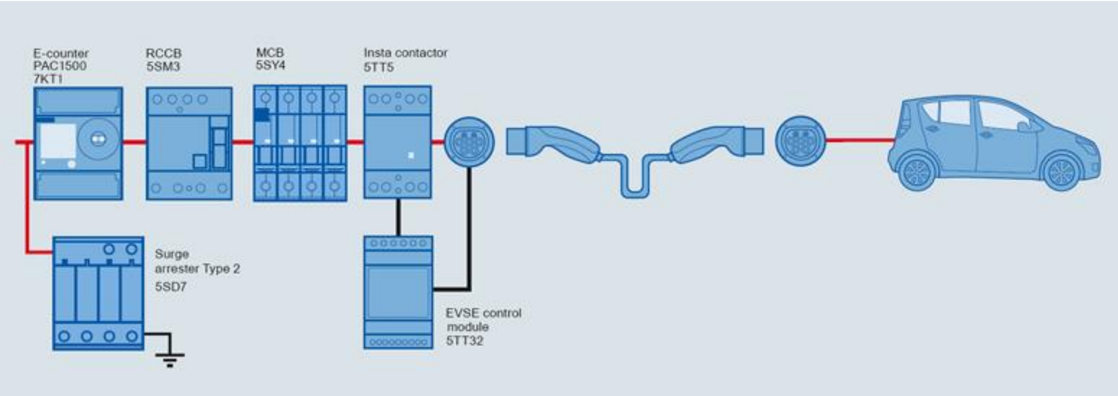


(Anegawa 2010c)

Figure 32 Layout of BEV charging mode 2

Charging mode 3

With charging mode 3, the electric vehicle is connected to a single-phase or three-phase AC network, with a charging control system pilot function, via an electric vehicle on-board charging device and an electric vehicle supply equipment (EVSE) control module in the charging installation. Figure 33 illustrates the use of this charging mode which requires both an overcurrent protective device and an RCCB on the network side. Use of a surge arrester is recommended.



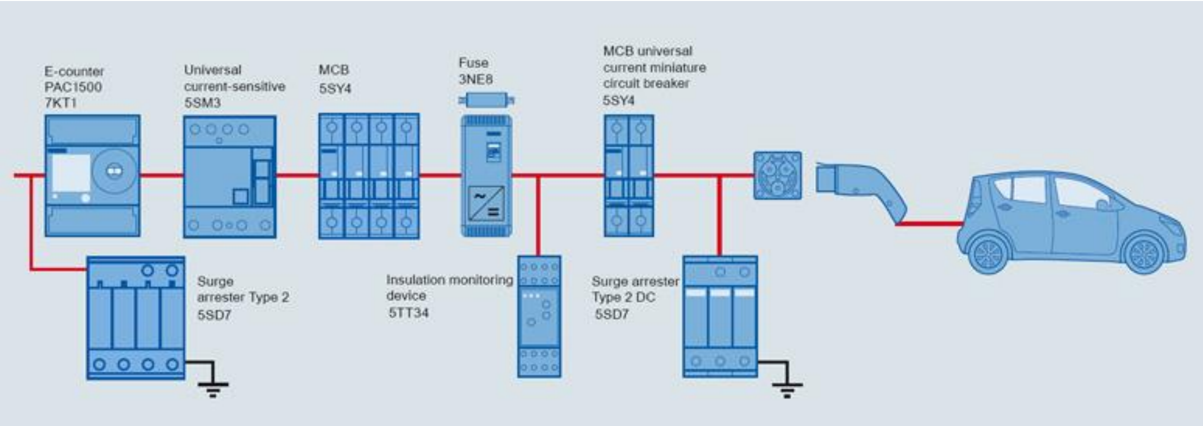
(Anegawa 2010c)

Figure 33 Layout of BEV charging mode 3

Charging mode 4

With charging mode 4 see figure 34, the electric vehicle is connected to a single-phase or three-phase AC network with a rectifier. This charging mode is generally used for rapid charging.

The use of this charging mode requires an AC/DC-sensitive RCCB on the network side, as well as overcurrent protective devices for AC and DC. Use of surge arresters is recommended.



(Anegawa 2010c)

Figure 34 Layout of BEV charging mode 4

3.6.5 Traction motors

Electric cars have traditionally used series wound DC motors, a form of brushed DC electric motor. More recent vehicles have made use of a variety of AC motor types, as these are simpler to build and have no brushes that can wear out. These are usually induction motors or brushless AC electric motors which use permanent magnets. There are several variations of the permanent magnet motor which offer simpler drive schemes and/or lower cost including the brushless DC motor.

Table 10 explains the features of BEV motor types.

Table 10 BEV motor types

Data from Nissan LEAF Technical Introduction Training manual NMTN9217AE

	DC Motor		**Induction Motor**		**Synchronous Motor**	
Components	Electric Motor	Controller	Electric Motor	Controller	Electric Motor	Controller
Features	Control is easy because the revolution speed is proportional to DC voltage. The motor cannot be driven at high revolution because of the existence of brushes.		The motor rotates due to electromagnet induction by AC power but does not synchronise. The controller is necessary to vary the revolution speed.		The motor rotates in synchronisation with the magnetic field by AC power. The controller is necessary to vary the revolution speed.	
Efficiency	Poor efficiency		Moderately high efficiency		High efficiency	
Size	Large	Small	Medium	Large	Small	Large
Structure	Complicated	Simple	Simple	Moderately complicated	Moderately complicated	Complicated
Maintenance	Brush	No need	No need	No need	No need	No need
Price	Middle	Cheap	Cheap	Expensive	Expensive	Expensive

(Nissan 2015)

Electric motors are typically three to four times more efficient than their petrol-fired counterparts. They also have far fewer moving parts, i.e. there are only five main moving parts in an electric vehicle drive train assembly (traction motor, epicyclic gearing, fixed gearing, final drive reduction gearing, and differential) as opposed to many hundreds in an internal combustion engine. It may easily be shown that the overall efficiency of all-electric vehicle (power plant - to – wheel energy chain) is around twice that of its petrol-engine counterpart, taking the tank-wheel chain for the latter vehicle. Trials conducted by the Norwegian ‘Think City’ car company has shown that the lithium-ion batteries can hold a charge that is worth 160 km of travel distance with the batteries themselves lasting more than 10 years (Raab et al. 2011). Furthermore, lithium is being sourced from dried salt lakes in South America and China. There are also plans for lithium to be extracted from salt water from sea. Work is also under progress for development of battery technology based on other light metals such as zinc or nickel.

3.6.6 Well to Wheel

Automobiles are quite inefficient with approximately 75% of the energy going into producing heat (David & Mackay 2009) In this respect reference is made to Table 11 which shows the automobile energy flows for the well - wheel chain. Research and development is being carried out into manufacturing affordable electric automobiles that offer an improved overall thermodynamic efficiency and in this respect the car manufacturer Nissan has announced plans to produce a global production of 200,000 units per year.

At the same time Chinese manufactured electric scooters are also increasingly making their entry in European cities with a typical scooter costing around 1,200 Euro. Such scooters emit around 33gCO_2/km if charged with fossil fuel electricity. The latter figure however drops to a significantly lower value of 1.3gCO_2/km if solar energy is deployed to charge the scooter's lead acid batteries (Muneer et al. 2008). Within the UK market the 'Charge' scooter company has made available an 'S1' electric scooter that uses lithium-ion batteries and costs 2,800 Euro. The 48-V, 40Ah battery requires 4 hours to add an 80% charge and can deliver a 55km trip. 'Charge' is also exploring the possibility of providing solar PV panels for an upcoming 400-home eco community in Newcastle, England with the view to charge their electric scooters. The PV panels will be sourced from 'China Solar' against a module cost of 1100 Euro/kW peak capacity (Acha et al. n.d.).

Table 11 Well to Wheel Energy Efficiency

Technology	Model	Fuel	η_{W2V}	P_{V2W}	P W2W
ICE	Civic	Crude Oil	0.82	2.27	1.86
HEV	Prius	Crude Oil	0.82	2.47	2.03
PHEV	Volt	Coal	0.35	4.00	1.40
EV	Leaf	Coal	0.35	6.66	2.33

(Urban Foresight 2014; Acha et al. n.d.)

Where:

η_{w2v} is the well to vehicle efficiency (dimensionless)

Pv2w is the vehicle to wheel performance (km/kWh)

Pw2w is the well to wheel performance (km/kWh)

3.6.7 BEV drivetrain - conventional approach

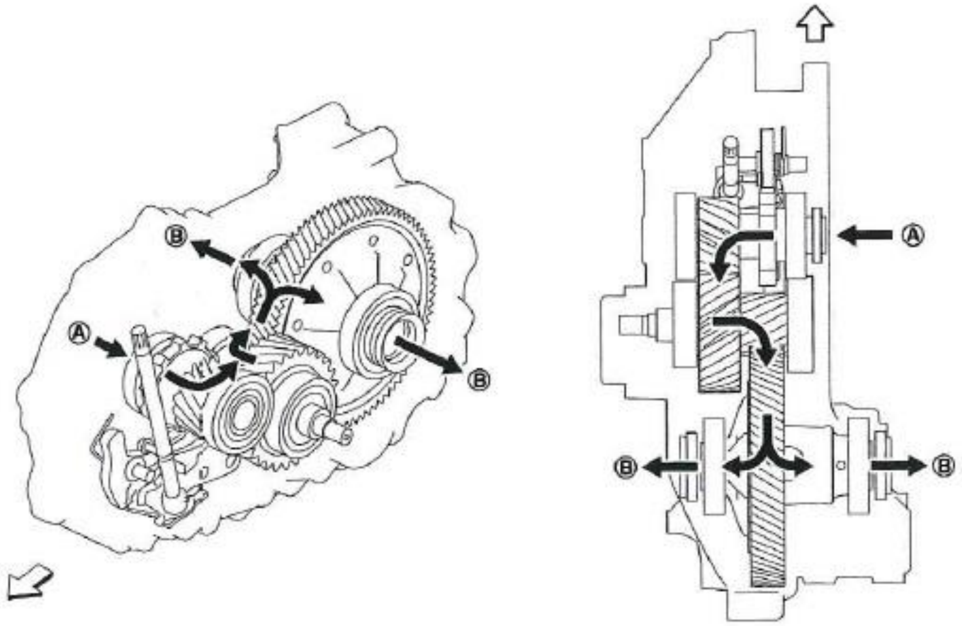


Figure 35 Transmission power flow

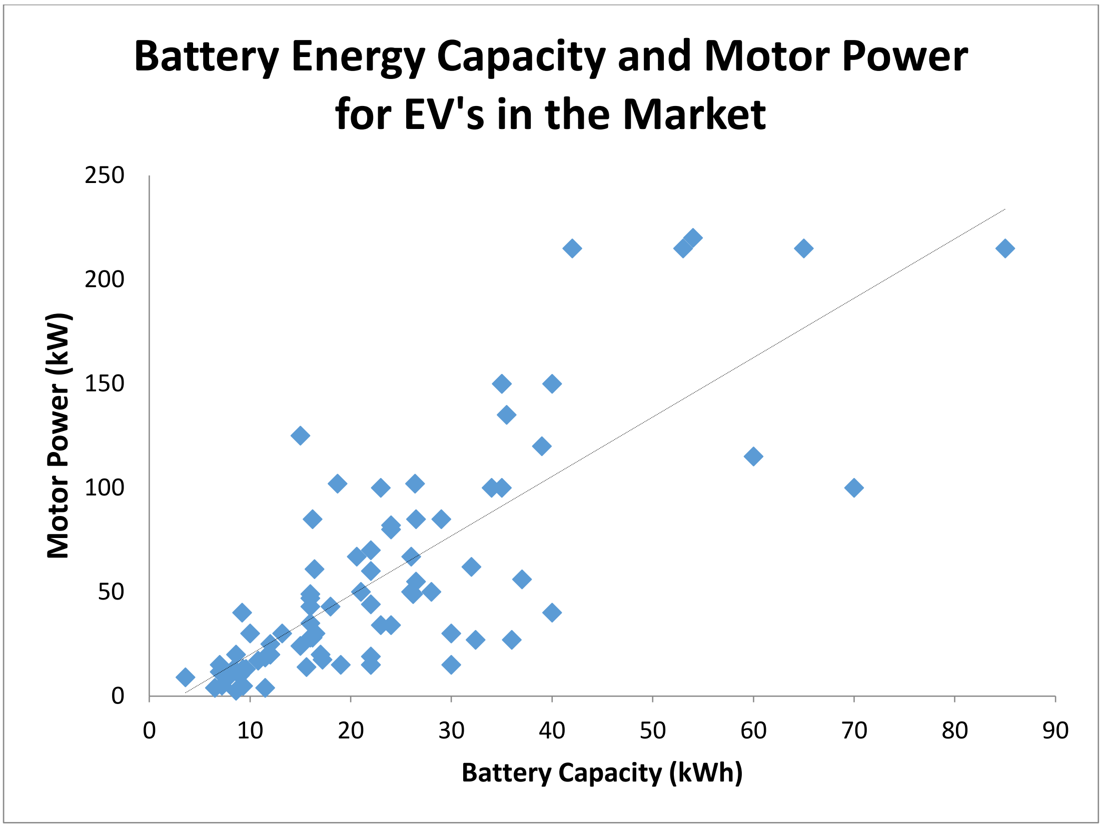
Figure 35 indicates the power flow through the BEV gearbox and final drive. Two major advantages here are that there are fewer moving parts that the power from the motor is a pure rotary motion and not translated from linear motion into rotary. This rotation is transferred into the gearbox at arrow 'A' and exits on the arrows 'B' to the road wheels as indicated in figure 35.

3.6.8 Cost and key performance indicators

It was noted by one Council Authority however that some workers were wary of the cars' 100 mile range as their location dictated use in a sprawling rural area. It came as new figures obtained by Scottish media revealed that the local authority had spent £57,600 on four electric Nissan LEAF's since 2011.Yet, in total, the cars have covered fewer than 26,000 miles in that time.

The local authority insisted the scheme had been "relatively successful" but admitted levels of usage were "considerably lower" than for conventional cars in its pool. It was added that "Staff have been asked to comment on use of the vehicles, and 'range anxiety' is certainly a consideration. It was remarked that "the quality of the drive is surprisingly good by those who have not driven an electric vehicle before" (Rutherford 2015).

3.7 Drivetrain Batteries



(Santiago et al. 2012)

Figure 36 Battery capacity and motor power

3.7.1 Battery technology developments

New battery technology is constantly being developed and the chemistry and charge time is changing to make the charge time quicker whilst keeping the energy density as high as possible. It is evident from the data in Figure 36 which indicates a spread of currently available motor and battery capacities.

In Singapore scientists from the Nanyang Technological University have developed ultra-fast charging batteries that can be recharged up to 70% in under two minutes, this will have a far reaching impact on the electric vehicle industry where one of the concerns of the consumer is being put off by long recharge times and relatively short life expectancy of the Li-ion battery. These new batteries have been reported to last over 20 years and can also dramatically increase the range with five minutes of charging.

Compared with the current Li-ion battery technology which have recharge times between 1 hour and 4 hours these new chemistries are in-line with the time taken to stop and fill the conventional vehicle with pump fuel which is an known and expected parameter of the modern vehicle usage (Xiaodong 2014).

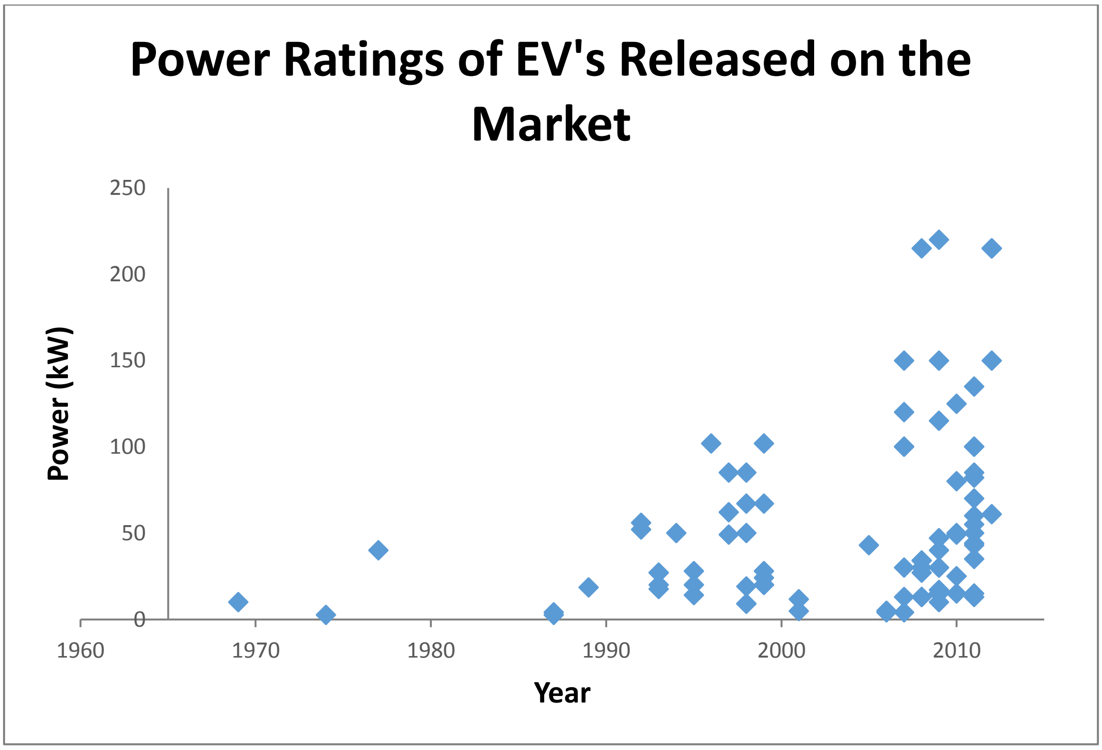


Figure 37 Power ratings of Battery Electric Vehicles

3.7.2 Environmental and safety considerations

Li-ion is a low-maintenance battery, an advantage that most other chemistries cannot claim. The battery has no memory and does not need exercising (deliberate full discharge) to keep it in good condition and with maximum capacity. Self-discharge is less than half that of nickel-based systems and this helps the fuel gauge applications. The nominal cell voltage of 3.60V, these cells can be multiplied to the required voltage for an electric vehicle offering simplifications and cost reductions over multi-cell designs. The drawbacks are the need for protection circuits to prevent abuse, as well as initial high cost. Figure 37 indicates the availability of current motor capacities and indicates the change over the years.

Lithium is the lightest of all metals, has the greatest electrochemical potential and provides the largest specific energy by weight currently available. Rechargeable batteries with lithium metal on the anode could provide extraordinarily high energy densities; however, it was discovered in the mid-1980s that cycling produced unwanted dendrites on the anode. These growth particles penetrate the separator and cause an electrical short.

The cell temperature would rise quickly and approach the melting point of lithium, causing thermal runaway, also known as “venting with flame.”
During a thermal runaway, the high heat of the failing cell inside a battery pack may propagate to the next cells, causing them to become thermally unstable also. A chain reaction can occur in which each cell disintegrates on its own timetable.
A pack can thus be destroyed in a few seconds or over several hours as each cell is being consumed. To increase safety, packs should include dividers to protect the failing cell from spreading to the neighbouring one (De-Leon 2013).
With the battery technology still being under development, manufacturers will consider alternatives to Li-ion chemistry.
The lithium ferrite phosphate ($LiFePO_4$) battery chemistry is an alternative construction which supports the mobile battery requirements. $LiFePO_4$ batteries are virtually incombustible this is a leading safety factor when used in a mobile situation such as a vehicle. This greater safety is an attribute as they will not catch fire or explode during rapid charging and this is due to the chemical stability of their Iron Phosphate cathode material. This battery has a long life cycle – greater than Li-ion and the self-discharge is amongst the lowest of all of the rechargeable battery systems. The $LiFePO_4$ battery is also environmentally friendly as it contains no toxic heavy metals or caustic materials which will benefit the manufacturer at ‘end-of-life’ as the battery can be recycled (Solar Stik 2012).
This technology is still in its infancy for automotive applications and a different battery chemistry will require additional power management devices for integration into existing applications, these expensive additions will drive up the cost to operate to the full potential.

3.7.3 Battery structure and components

Lead Acid Batteries (As fitted in the Edinburgh College Buggy - uses 12v, 100Ah, AGM ‘Deep Cycle’)

Electrochemical device invented in 1859 by Gaston Planté. ‘Sealed’ Lead Acid from 1970’s

Advantages:

- Inexpensive on cost-per-watt basis
- Dependable
- Cheap to manufacture
- Low self-discharge
- High specific power, capable of high discharge currents
- Good low and high temp performance

Disadvantages:

- Short cycle life
- Prone to failure if treated badly (discharging/charging/storage)
- Toxic materials
- Poor energy to weight ratio
- Slow to charge
- Flooded version requires regular maintenance

Construction

Automotive Batteries are made up of multiple cells, usually 6, which combined give a charged voltage of 12.6 volts. The cells are made up electrodes and an electrolyte. Two different types of Lead make up the electrodes, a 'negative' cathode and 'positive' anode. While the electrolyte is a Sulphuric Acid solution. One type of Lead has more electrons than the other and so when combined with the electrolyte a chemical reaction between the two dissimilar metals results in a voltage being generated as electrons flow from the negative terminal to the positive. This electrical energy can then be used to create mechanical energy – for instance powering an electric vehicle's motor.

Older automotive batteries were of a wet type, or 'flooded' cells as shown in figure 38. In these, the electrolyte was in liquid form. These batteries could only be stored or used horizontally and required periodic topping up with water to maintain the electrolyte. The technology has now been superseded by Gel and AGM (Absorbed Glass Mat) batteries which are maintenance free and can be used in any orientation. In the former, the electrolyte is a thick paste, while in the electrolyte is contained in a soaked glass fibre mat. In all lead acid batteries, the negative and positive electrodes are made up of sandwiched lead plates, separated by a non-reactive material. The lead in the plates is often combined with other metals such as antimony, calcium, tin or selenium (Woodbank Communications 2005) to create a strong, lighter alloy, ease manufacture, and provide a longer chemical life.

All batteries contain either a vent or a valve to help release the gasses that build up during a discharge or recharge cycle.

During the recharge cycle the chemical process that created a voltage is reversed through the application of an external voltage back into the battery. Over time this repeated cycling will degrade the battery as the chemical ingredients are used up, plate material falls off, or cells short-circuit through wear. To prevent degradation lead acid batteries are best kept at a full charge. Some though are specially designed for longer life under challenging full discharge and recharge conditions. These 'Deep Cycle' batteries, with thicker plates, are often used in electric vehicles. They provide less peak current than a 'Starter Battery', which has thinner plates giving a greater surface area and higher current.

A diagram of a typical lead acid battery is shown in figure 38.

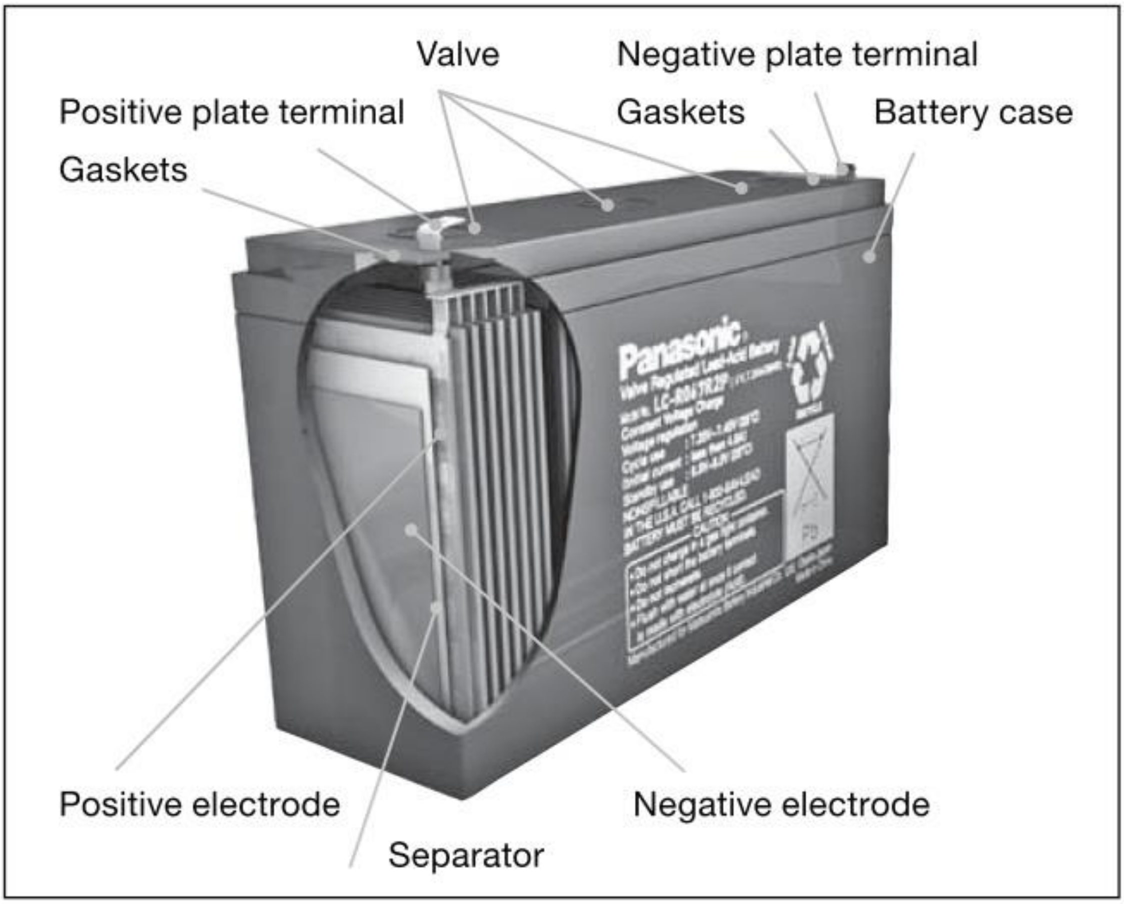


Figure 38 Lead acid battery components

For electric vehicle applications, multiple batteries are often connected in series to give a larger overall voltage and therefore more power to give the vehicle traction. However, the weight of the batteries can reach up to 50% of the vehicle's mass so they are far from ideal despite their cheapness and time-tested technology.

An installation example is shown in figure 39.

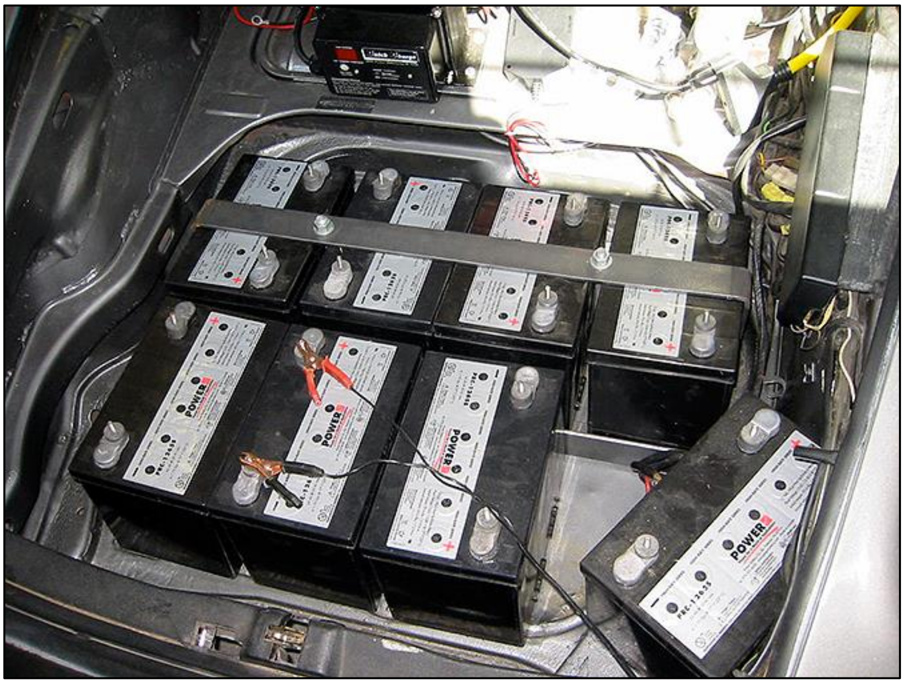
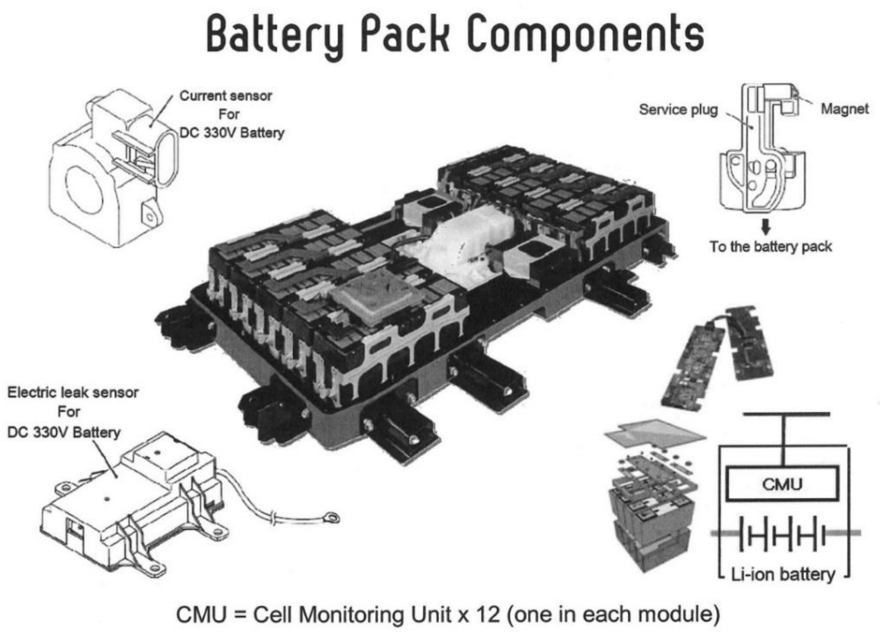


Figure 39 Edinburgh College own vehicle - multiple lead acid battery pack

3.7.4 Current technology and unit components



(Nissan 2015)

Figure 40 Battery control components

Inside the battery there is a leak detection circuit see figure 40. If any leakage of current is detected, the contactors inside the battery are switched off and there is no power outside the battery.

This is a safety feature to protect any person from contact with the high voltage system when there is a failure.

The nominal battery voltage is 330 Volt. The voltage at full charge is about 365 Volt and the one LED status is 315 Volt. On the one LED status there is still 5% in the battery to protect battery life. For safety reasons the car will not stop driving until the battery is fully drained, though doing so will inevitably damage the battery.

Each module has a battery cell monitoring unit (CMU) which monitors all 88 cells for voltage and temperature, and can pin point a specific cell by fault code. It is not possible to replace a cell. The battery pack is sealed and is in a 'black box enclosure' which requires manufacturer specialists at this component level. There is no logic in combining a brand new cell with ones already aged. There are 12 CMU's located inside the battery pack.

3.7.5 Battery temperature control

From work conducted by (Wang et al. 2007) he states that the SOC is a relative quantity that describes the ratio of the remaining capacity to the nominal capacity of the battery.

Equation 3 State of charge

The state of charge equation is given by:

$$S(t) = S(0) - \int_0^t \frac{\eta\, I(t)}{C_n}\, \mathrm{d}t$$

(Wang et al. 2007)

Term nomenclature:

S (t) Battery state of charge at time (%)
S (0) Battery initial state of charge (%)
I Charge/discharge current (A)
t Time (h)
C_n Battery capacity (Ah)

However, this method does not satisfy the requirement as the battery's current changes dramatically in EV's. Thus, the accurate estimation of the SOC of the battery pack is the key factor for managing batteries efficiently. In addition, the accurate estimating battery SOC is also the basis of the power distribution strategy for hybrid electric vehicles (HEV). Estimating the battery's SOC is complicated by the fact that the SOC depends on many factors such as temperature, battery capacitance and internal resistance. Some SOC estimation approaches are presented with the development of EV technology. As stated by (Junping et al. 2009) the main SOC estimation approaches including the discharge test approach, the Ah counting approach, the open-circuit voltage approach, the load voltage approach, the inherent resistance approach, the neural networks approach and the Kalman filtering (KF) approach in addition (Wang et al. 2007) stated that Ah counting is not a satisfactory method for the estimation of the state of charge (SOC) of a battery, as the initial SOC and coulomb efficiency are difficult to measure.

To address this issue, an equivalent coulomb efficiency is defined and a new SOC estimation method, denoted as ''KalmanAh'', is proposed. This method uses the Kalman filtering method to correct for the initial value used in the Ah counting method.

Discussion of temperature effects and thermal management indicated by (Woodbank Communications 2005) assert that it is essential to determine the working temperature operating limits as all batteries depend for their action on an electrochemical process whether charging or discharging and we know that these chemical reactions are in some way dependent on temperature.

Nominal battery performance is usually specified for working temperatures somewhere in the +20°C to +30°C range however the actual performance can deviate substantially from this if the battery is operated at higher or lower temperatures.

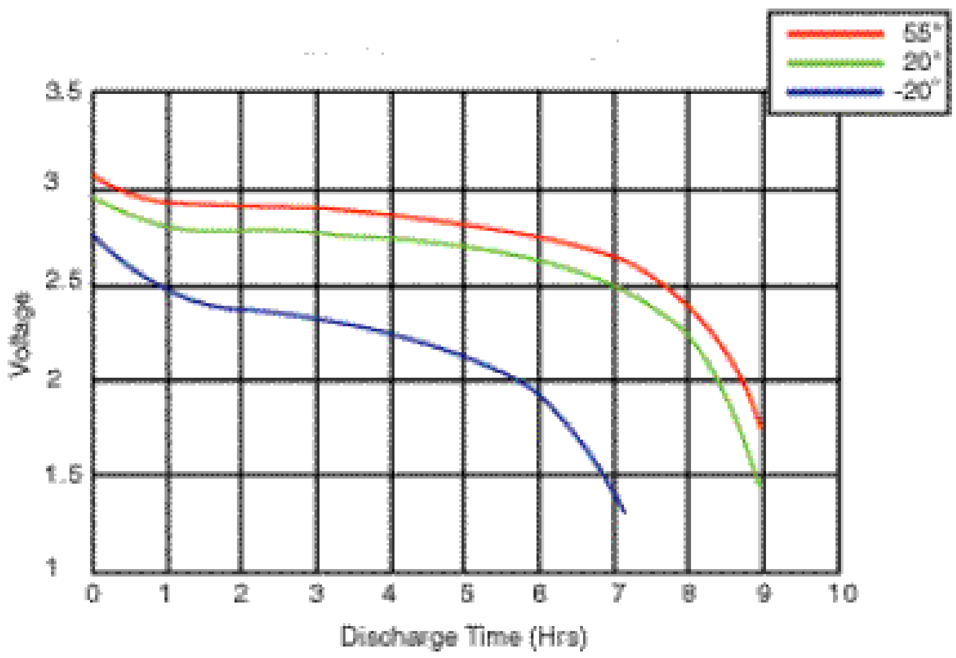


Figure 41 Temperature performance curves – Celsius scale

The lower curve on figure 41 performance chart, illustrates the characteristics of the cells performance when subject to -20°C.

Equation 4 Arrhenius law

Arrhenius law equation is stated by:

$$k = A\exp\left(\frac{-E}{RT}\right)$$

(Ramesh & Krishnamurthy 2015)

Term nomenclature:

k	the rate constant (s)
E	activation energy (kJ/Mol)
R	gas constant (kJ/K Mol)
T	temperature (K)
A	frequency factor (n)

Arrhenius Law (equation 4) tells us that the rate at which a chemical reaction proceeds, increases exponentially as temperature rises. This allows more instantaneous power to be extracted from the battery at higher temperatures. At the same time higher temperatures improve electron or ion mobility reducing the cell's internal impedance and increasing its capacity.

At the upper end of the scale the high temperatures may also initiate unwanted or irreversible chemical reactions and / or loss of electrolyte which can cause permanent damage or complete failure of the battery. This in turn sets an upper temperature operating limit for the battery.

At the lower end of the scale the electrolyte may freeze, setting a limit to low temperature performance. But well below the freezing point of the electrolyte, battery performance starts to deteriorate as the rate of chemical reaction is reduced. Even though a battery may be specified to work down to -20°C or -30°C the performance at 0°C and below may be seriously impaired.

Note also that the lower temperature working limit of a battery may be dependent on its SOC (State of Charge). In a Lead Acid battery for instance, as the battery is discharged the Sulphuric Acid electrolyte becomes increasingly diluted with water and its freezing point increases accordingly.

Thus the battery must be kept within a limited operating temperature range so that both charge capacity and cycle life can be optimised. A practical system as stated by (Woodbank Communications 2005) may therefore need both heating and cooling to keep it not just within the battery manufacturer's specified working limits, but within a more limited range to achieve optimal performance.

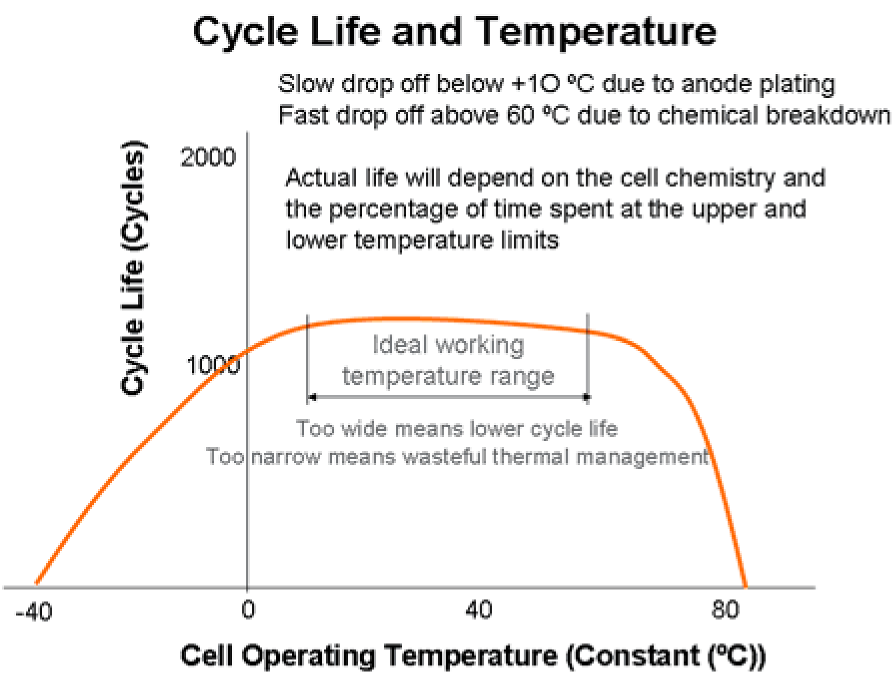
Thermal management however is not just about keeping within these limits. The battery is subject to several simultaneous internal and external thermal effects which must be kept within control.

Electrical Heating (Joule Heating):
The operation of any battery generates heat due to the I^2R losses as current flows through the internal resistance of the battery whether it is being charged or discharged. This is also known as Joule heating. In the case of discharging, the total energy within the system is fixed and the temperature rise will be limited by the available energy. However, this can still cause very high localised temperatures even in low power batteries. No such automatic limit applies while charging as there is nothing to stop the user continuing to pump electrical energy into the battery after it has become fully charged.

This can be a very risky situation with dangerous results in respect of the overcharging. Battery designers aim to keep the internal resistance of the cells as low as possible to minimise the heat losses or heat generation within the battery but even with cell resistances as low as 1milliOhm the heating can be substantial.

Thermochemical heating and cooling:
In addition to Joule heating the chemical reactions which take place in the cells may be exothermic, adding to the heat generated or they may be endothermic, absorbing heat during the process of the chemical action (Woodbank Communications 2005). Overheating is therefore more likely to be a problem with exothermic reactions in which the chemical reaction reinforces the heat generated by the current flow rather than with endothermic reactions where the chemical action counteracts it. In secondary batteries, because the chemical reactions are reversible, chemistries which are exothermic during charging will be endothermic during discharging and vice versa. So there's no escaping the problem. In most situations the Joule heating will exceed the endothermic cooling effect so precautions still need to be taken.
Lead acid batteries are exothermic during charging and VRLA batteries are prone to thermal runaway (Bulletin n.d.). NiMH cells are also exothermic during charging and as they approach full charge, the cell temperature can rise dramatically. Consequently, chargers for NiMH cells must be designed to sense this temperature rise and cut off the charger to prevent damage to the cells.

By contrast Nickel based batteries with alkaline electrolytes (NiCad's) and Lithium batteries are endothermic during charging. Nevertheless, thermal runaway is still possible during charging with these batteries if they are subject to overcharging.
The thermochemistry of Lithium cells is slightly more complex, depending on the state of intercalation of the Lithium ions into the crystal lattice. During charging the reaction is initially endothermic then moving to slightly exothermic during most of the charging cycle. During discharge the reaction is the reverse, initially exothermic then moving to slightly endothermic for most of the discharge cycle.
In common with the other chemistries, the Joule heating effect is greater than the thermochemical effect so long as the cells remain within their design limits. Figure 42 indicates the ideal working temperature range of a cell.



(Woodbank Communications 2005)

Figure 42 Lithium Battery ideal working temperature range

External thermal effects:
The thermal condition of the battery is also dependent on its environment. If its temperature is above the ambient temperature it will lose heat through conduction, convection and radiation. If the ambient temperature is higher, the battery will gain heat from its surroundings. When the ambient temperature is very high the thermal management system has to work very hard to keep the temperature under control. A single cell may work very well at room temperature on its own, but if it is part of a battery pack surrounded by similar

cells all generating heat, even if it is carrying the same load, it could well exceed its temperature limits.

Temperature - The accelerator:

The net result of the thermo-electrical and thermo-chemical effects possibly augmented by the environmental conditions is usually a rise in temperature and as stated will cause an exponential increase in the rate at which a chemical reaction proceeds. We also know that if the temperature rise is excessive this will give undesirable effects. Such as the active chemicals expand causing the cell to swell.

Mechanical distortion of the cell components may result in short circuits or open circuits

Irreversible chemical reactions can occur which cause a permanent reduction in the active chemicals and hence the capacity of the cell.

Prolonged operation at high temperature can cause cracking in plastic parts of the cell

The temperature rise causes the chemical reaction to speed up increasing the temperature even more and could lead to thermal runaway

Toxic or inflammable chemicals may be may be given off, pressure builds up inside the cell and the cell may eventually rupture or explode.

Thermal Capacity:

Battery engineers strive to cram more and more energy into ever smaller volumes, the applications engineer has increasing difficulty to get it out again. The great strength of new technology batteries is unfortunately also the source of their greatest weakness.

The thermal capacity of an object defines its ability to absorb heat. In simple terms for a given amount of heat, the bigger and heavier the object is, the smaller will be the temperature rise caused by the heat.

For many years lead acid batteries have been one of the few power sources available for high power applications. Because of their bulk and weight, temperature rise during operation has not been a major problem. But in the quest for smaller, lighter batteries with higher power and energy densities, the unavoidable consequence is that the thermal capacity of the battery will be decreased. This in turn means that for a given power output, the temperature rise will be higher.

The result is that heat dissipation is a major engineering challenge for high energy density batteries used in high power applications. Cell designers have developed innovative cell construction techniques to get the heat out of the cell.

Battery pack designers must find equally innovative solutions to get the heat out of the pack.

Electric vehicle battery thermal considerations:

Similar conflicts occur with EV and HEV batteries. The EV battery is large with good heat dissipation possibilities by convection and conduction and subject to a low temperature rise due to its high thermal capacity. On the other hand, the HEV battery which must handle the same power is less than one tenth of the size with a low thermal capacity and low heat dissipation properties which means it will be subject to a much higher temperature rise. Taking into account the need to keep the cells operating within their allowable temperature range the EV battery is more likely to encounter problems to keep it warm at the low end of the temperature range while the HEV battery is more likely to have overheating problems in high temperature environments even though they both dissipate the same amount of heat. In the case of the EV, at very low ambient temperatures, self-heating (I^2R heating) by the current flow during operation will most likely be insufficient to raise the temperature to the desired operating levels because of the battery's bulk and external heaters may be required to raise the temperature. This could be provided by diverting some of the battery capacity for heating purposes. On the other hand, the same heat generation in the HEV battery working in high temperature environments could send it into thermal runaway and forced cooling must be provided.

Thermal Runaway:

The operating temperature which is reached in a battery is the result of the ambient temperature augmented by the heat generated by the battery. If a battery is subject to excessive currents the possibility of thermal runaway arises resulting in catastrophic destruction of the battery. This occurs when the rate of heat generation within the battery exceeds its heat dissipation capacity. There are several conditions which can bring this about:

Initially the thermal I^2R losses of the charging current flowing through the cell heat up the electrolyte, but the resistance of the electrolyte decreases with temperature, so this will in turn result in a higher current driving the temperature still higher, reinforcing the reaction till a runaway condition is reached. As reported by (De-Leon 2013) with Lithium-ion batteries, the management of heat dissipation during discharge is a key factor in preventing extensive damage and explosive thermal runaway.

During charging the charging current induces an exothermic chemical reaction of the chemicals in the cell which reinforces the heat generated by the charging current.

Or during discharging the heat produced by the exothermic chemical action generating the current reinforces the resistive heating due to the current flow within the cell.

Inadequate cooling:

Unless some protective measures are in place the consequences of the thermal runaway could be meltdown of the cell or a build-up of pressure resulting an explosion or fire depending on the cell chemistry and construction.
The thermal management system must keep all of these factors under control.

Heating:
Low temperature operating conditions are relatively easy to cope with. In the simplest case there is usually enough energy in the battery to power self-heating elements which gradually bring the battery up to a more efficient operating temperature when the heaters can be switched off. In some cases, it is enough to keep the battery on its recharging cycle when it is not in use. In more complex cases for example with high temperature batteries such as the Zebra battery running at temperatures well above normal ambient temperatures some external heating may be required to bring the battery up to its operating temperature on start-up and special thermal insulation may be needed to maintain the temperature for as long as possible after it has been switched off (Woodbank Communications 2005).

Cooling:
For low power batteries the normal protection circuits are sufficient to keep the battery within its recommended operating temperature limits. High power circuits however need special attention to thermal management.

Design objectives and protection from overheating:
In most cases this simply involves monitoring the temperature and interrupting the current path if the temperature when the temperature limits are reached using conventional protection circuits. While this will prevent damage to the battery from overheating it can however cut off the battery before its current carrying limit is reached seriously limiting its performance.

Dissipation of Surplus Heat Generated:
Removing heat from the battery allows higher currents to be carried before the temperature limits are reached. Heat flows out of the battery by convection, conduction and radiation and the pack designer's task is to maximise these natural flows by keeping the ambient temperature low, by providing a solid, good heat conducting path from the battery (using metallic cooling rods or plates between the cells if necessary), by maximising its surface area, by providing good natural air flow through or around the pack and by mounting it on a conductive surface.

Uniform Heat Distribution:

Even though the battery thermal design may be more than sufficient to dissipate the total heat generated by the battery, there could still be localised hot spots within the battery pack which can exceed the specified temperature limits. This can be a problem with the cells in the middle of a multi cell pack which will be surrounded by warm or hot cells compared with the outer cells in the pack which are facing a cooler environment. This issue has been reported by (De-Leon 2013) and will be affected by incorrect pack design or utilising a 'standard' pack across multiple vehicles.

A temperature gradient across the battery pack can seriously affect the life of the battery. Arrhenius' Law indicates that for every 10°C increase in temperature, the chemical reaction rate approximately doubles. This puts an unbalanced stress on the cells in the battery and also exacerbates any age related deterioration of the cells.

Separating the cells will avoid this problem but adds to the overall volume of the battery pack.

Passive dissipation can be improved still further by mounting the cells in a block of thermally conductive material which acts as a heat sink. Heat transfer from the cells can be maximised if a phase change material (PCM) is used for this purpose since it also absorbs the latent heat of the phase change as it changes from the solid to the liquid state (Woodbank Communications 2005). Once in the liquid state, convection also comes into play increasing the potential for heat flow and for equalising the temperature across the battery pack. High conductivity graphite sponge materials saturated by wax which absorbs extra heat when the temperature reaches the melting point are available for this application.

Minimum Addition to the Weight:

For very high power applications, such as traction batteries used in EVs and HEVs, natural cooling may be insufficient to maintain a safe working temperature and forced cooling may be required. This should be the last resort as it complicates the battery design, adds weight to the battery and consumes power. If forced cooling is unavoidable however, the first choice would normally be forced air cooling using a fan or fans. This is relatively simple and inexpensive but the thermal capacity of the thermal fluid, air, which is intended to carry the heat away is relatively low limiting its effectiveness. In the worst case liquid cooling may be required.

For very high cooling rates working fluids with a higher thermal capacity are required. Water is normally the first choice because it is inexpensive but other fluids such as ethylene glycol (anti-freeze) which have a better thermal capacity may be used. The weight of the coolant, the pumps to circulate it, the cooling jackets around the cells, the pipework and manifolds to carry and distribute the coolant and a radiator or heat exchanger to cool it, all add dramatically to the total weight, complexity and cost of the battery. These penalties could well outweigh the gains expected to be achieved by using high energy density battery chemistries.

Heat Recovery:
In electric vehicles applications, there is the opportunity to use the waste heat for heating the passenger compartment and most automotive systems include some form of integrating the battery thermal management with the vehicle climate controls. This is however only beneficial during cold weather. In hot climates the high ambient temperature places an added burden on the battery thermal management.

3.7.6 Future battery developments

Prototypes storage batteries are being developed that are made from a range of cheap and abundant materials and shows promise for high-efficiency battery performance.
This new technology uses iron sulphide (pyrite) crystal technology for the cathode, sodium as the electrolyte and magnesium for the anode.
All of these ingredients are relatively inexpensive and abundant, with materials such as iron sulphide nano-crystals being made by simply milling sulphur with dry metallic iron, whilst a kilogram of magnesium is some 15 times cheaper than a comparable quantity of lithium. In addition, iron, magnesium, sodium, and sulphur are 4^{th}, 6^{th}, 7^{th}, and 15^{th} in order of abundance on Earth by mass, respectively (Jeffrey 2015).
Research and development of new battery technologies looking at chemistries such as lithium-sulphur which is under development as trials have indicated that it can deliver greater energy density than lithium-ion.
Other pioneering chemistry technology is based on sodium (salt) which is not only a widely available resource, but can be produced at a significantly lower cost than lithium. Future developments indicate that sodium-ion batteries could significantly reduce the cost of electric vehicles by a projected 30% if sodium-ion batteries were in series production. Apart from being cheaper to produce they are safer and can be readily transported by air freight (IMI 2015).
As energy production moves towards solar and wind-powered alternatives, battery systems to store intermittently-produced electricity have never been more important. Unfortunately, many of the materials needed to make high-performance batteries for this purpose are rapidly diminishing and becoming increasingly expensive as a result.
Further savings could also be realised in the construction of the battery, as aluminium foil is perfectly adequate to accumulate and conduct electricity from it, whereas lithium-ion

batteries need comparatively expensive copper foil to perform the same role as reported in a study by (Jeffrey 2015).

The developments in battery technology that are happening around the world and are emerging at an accelerated pace, and the new technologies that come onto the market has the potential to revolutionise the supply of batteries for the BEV application making them cheaper, readily available, safer and potentially giving greater vehicle range.

3.8 Transportation infrastructure analysis

There are three main EV charger types: 'slow' charging units (up to 3kW) which are best suited for 6-8 hours overnight; 'fast' chargers (7-22kW) which can fully recharge some models in 3-4 hours; and 'rapid' charging units (43-50kW) which are able to provide an 80% charge in around 30 minutes. Rapid chargers also come in two charge point types – AC and DC – depending on whether they use alternating current or direct current.

It is evident from the data presented by (Anegawa 2010a) that the existing present technology of low-output 3 to 7 kW AC electric vehicle chargers are the norm for the charging infrastructure installed in residential areas and business offices. In order to shorten the charging times, there is a belief that it would be best to implement changes that would increase the kW output. However, from previous research results the conditions surrounding the charging process shows such modifications are not necessary (Anegawa 2010a).

There is a sufficient amount of charging time available especially if the user and drive cycle is considered. Further to this the upgrading of the distribution power grid would require the installation of additional high-power electrical equipment that would ultimately burden users and at an elevated expense and ground works that may not generally be required.

Nevertheless, in some cases, fast charging is necessary. Hence, in order to fulfil this need, the installation of a moderate number of quick chargers would be more effective than increasing the output of the individual AC chargers in a halfway manner. The role of this quick-charging infrastructure would primarily be supplementary and in order to achieve a substantial reduction in the charging time, the output would have to be boosted up to around 50kW. Such upgrades would increase the risks associated with high voltage electricity such as electric shocks, burn injuries and fires and therefore such chargers must be intrinsically safe to both the vehicle user and the general public.

Infrastructure charger manufacturers in discussion with the BEV manufacturer must decide on the standardisation of the car connecter have centred on utilising the same connector for outputs between 3 to 50 kW. Given that the safety design is premised on being able to handle maximum voltage and current, the connecter itself must be enlarged with further safety parameters to be addressed. Further, the design and manufacturing should be conducted with enough margin to account for the potential risks connected to life degradation.

On the other hand, for daily use, the connector needs to be small, lightweight and easy-to-use. Fulfilling these requirements in light of the aforementioned safety margin is a challenge that needs to be properly addressed and to date connector types are either type 1, 2 or 3 within the UK.

Vehicle charging and the grid supply is a concern of the electricity suppliers as if the charging option is 240v and at home this has the potential risk of users to home charge when they return from work and at peak times. If the charging draw from three cars was around 6.6kW each from the grid this would be the equivalent of adding three new homes to the street. Press reports have indicated that this will put a great strain on the supply and primarily on the street level transformers that are traditionally the weakest link of the grid. Smart technologies are essential to ensure that the peak demand is not created by the Battery Electric Vehicle and user encouragement will be required to take advantage of overnight charging and thus utilising the lower tariff cost for the electricity. Embedded Smart Technologies can remove the network upgrades and align charging when other demands are low and when renewable sources are available but this will have to be the expected method of charging for the greatest effect and demand ensuring the minimum grid load.

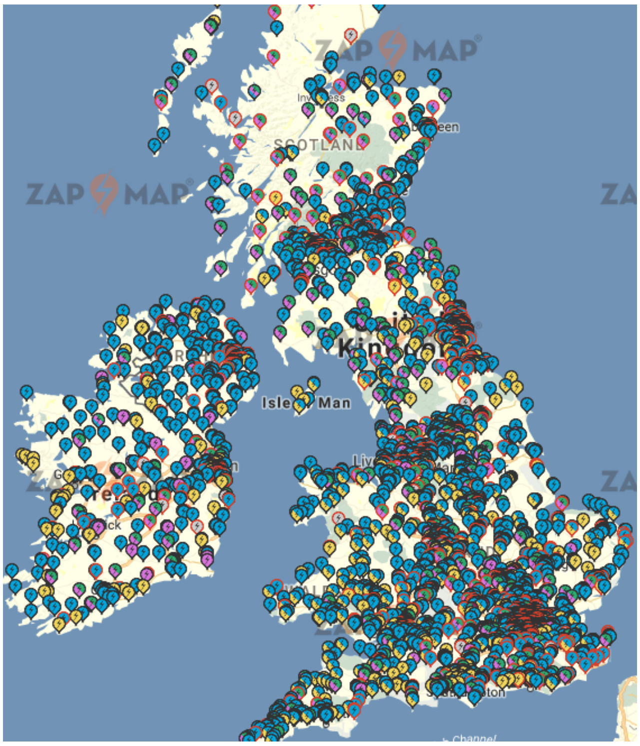
3.8.1 Charging stations and infrastructure

If the batteries of BEV are to be charged at home from a standard outlet or on a road side charger these extra electrical loads have an impact on the distribution grid which must be kept constant and free of power losses and voltage deviations. Without coordination of the charging, the vehicles are charged instantaneously when they are plugged in or after a fixed start delay. This uncoordinated power consumption on a local scale can lead to grid problems. Therefore, coordinated charging is proposed to minimize the power losses and to maximize the main grid load factor.

In order to satisfy the growing expectation for energy efficient eco-friendly transportation a number of Battery Electric Vehicle (BEV) requirements have emerged.

Vehicle dynamics necessitate careful sizing of on board battery storage systems and as the use of electric vehicles, in both the public and private sector increases, the requirement to facilitate and utilise them is becoming paramount.

Zap-map as illustrated in figure 43 are one of the providers of instant live charging maps and will assist with route finding and location/availability issues.



(Zap-Map 2016)

Figure 43 Zap-map live – national conglomeration of charging stations

Fast charging will not only put a significant strain on the electric vehicle battery but will also put a great strain on the suppliers of the electricity from the national grid. Fast charging at 9kW is a significant draw from the grid (Narich et al. 2011) states that two cars fast charging at the same time would equal the power requirements for an average office building.

Battery life is reduced with all charging and the average electric car battery can withstand approximately 5000 charges (Renault UK 2015), but fast charging can put a significant higher strain on the battery lowering its life expectancy. Renault UK 2012 range of electric vehicles has decided to lease the battery to the car owner with a cost per month. This is in attempt to remove the 'worry' from the vehicle purchaser as the battery is the significant cost constraint within the purchase price and is development continually as battery technology evolves.

The increasing demand from electric vehicles could pose a serious challenge for the network as EV loads have the potential to exacerbate the peaking of the load curve. This can happen at the same time with increased electrification from other applications, such as heating and cooling that could also contribute to increasing demand at peak hours. The electricity generation in the EU-28 is estimated to reach 3,806 TWh by 2035, and the European peak demand 617 GW.

Assuming the hypothetical scenario of 100% car electrification as in figure 44, EV loads would add 92 GW to the load average and 130 GW to the peak load by 2035. In case the charging is uncontrolled, the additional demand from EVs could raise the peak demand by 21.1% by 2035 according to the expected growth in the co-efficient peak load by that year. This assumes that the load is uniformly spread across the peaking of the load curve. However, we can also expect that in some cases the peak load could be much higher. There could be a scenario where the peak load at the European level could increase further to 30%, assuming a case when the co-efficient peak load doubles (Eurelectric 2015).

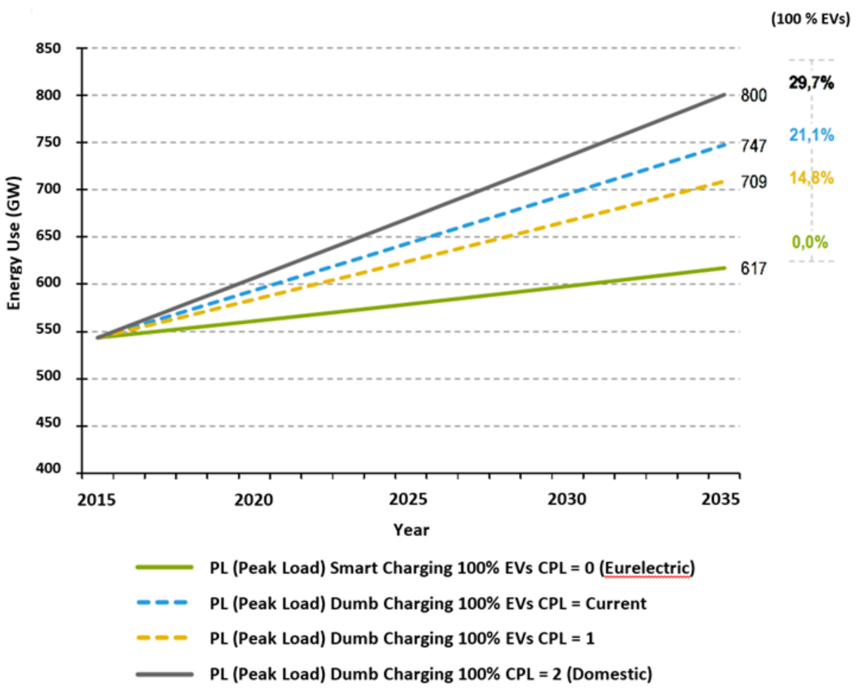


Figure 44 European peak load for market penetration of BEV's

3.8.2 The V2G concept

As the light vehicle fleet moves to electric drive (hybrid and battery vehicles) an opportunity opens for "vehicle-to-grid" (V2G) power. Direct current energy is stored in the vehicle battery, the batteries can only be charged and not discharged, meaning that the energy flow in unidirectional and currently the vehicle-to-grid concept is not considered (Venables 2008). Under V2G conditions the vehicle is parked and plugged into the electric grid, BEV's will absorb energy and store it, being also able to deliver electricity back to the grid. The latter is the distinctive feature of the V2G concept, allowing the provision of several ancillary services like peak power and demand reserves.

Work conducted by Lopes et al (2011) states that in order to be able to provide these services, each EV must have some extra equipment like an electronic interface for grid connection, to allow controlled electric energy exchanges to and from the vehicle (Lopes et al. 2010).

To satisfy the demand of large-scale penetration of EV's the issues of increased electricity consumption, during charging periods will have to be overcome.

Therefore, power flows, grid losses, and voltage profile patterns along the grid will change considerably. Additionally, EV capability to provide energy to the system will also impact the grid flows. The combination of all these effects might oblige to reinforce the grid at some locations. Nonetheless, depending on the EV charging strategy to be adopted, reinforcement postponements may be achieved.

When parked and plugged into the electric grid, EVs will absorb energy and store it, being also able to deliver electricity back to the grid. The latter is the distinctive feature of the V2G concept, allowing the provision of several ancillary services like peak power and spinning reserves. In order to be able to provide these services, each EV must have some extra equipment like an electronic interface for grid connection, to allow controlled electric energy exchanges, a meter device, and a bidirectional communication interface to communicate with an aggregator entity, which will be in charge of managing a high number of EV's.

A large deployment of EV's will involve:

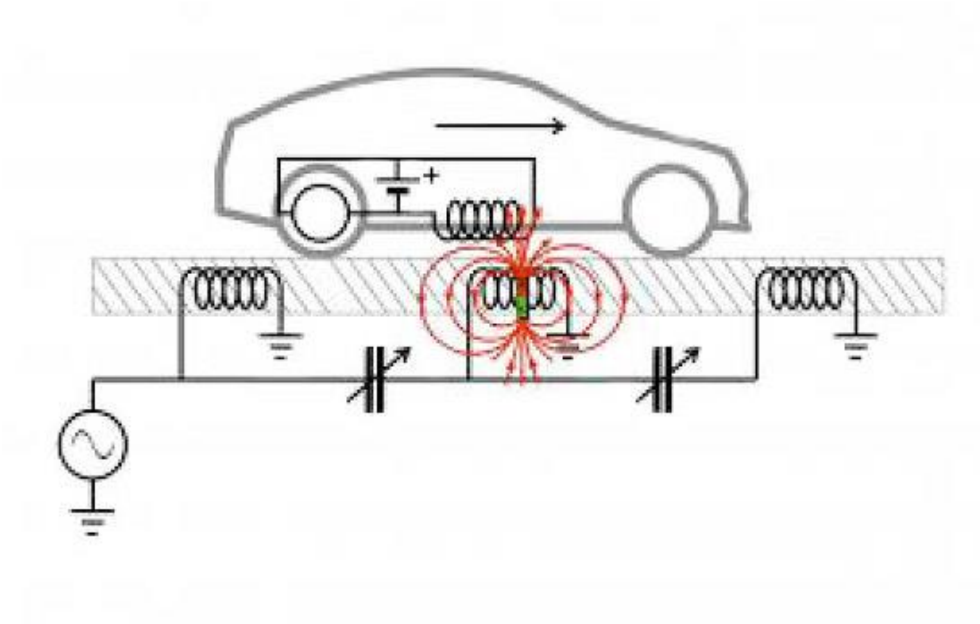
- Evaluation of the impacts that battery charging may have in system operation.
- Identification of adequate operational management and control strategies regarding batteries' charging periods.
- Identification of the best strategies to be adopted in order to use preferentially renewable energy sources to charge EVs.
- Assessment of the EV potential to participate in the provision of power systems services, including reserves provision and power delivery, within a V2G concept.

(Lopes et al. 2010)

3.8.3 Wireless charging

The wireless transfer of power to an electric vehicle when parked or in motion could extend driving range and enhance the convenience of recharging. This convenience could further differentiate EVs from internal combustion engine vehicles and other alternative propulsion fuels.

There are a number of applications of wireless charging. The first is stationary, where wireless systems remove the need to plug in vehicles when they are parked. The next is semi-dynamic which allows vehicles to receive short top-ups when they temporarily stop as part of a journey, such as at a road junction or bus stop. The third is fully dynamic, where a vehicle charges in motion drawing current from technology embedded in the lanes of main roads and highways as illustrated in figure 45. The system can wirelessly recharge the vehicle using magnetic fields to transmit large currents between metal coils located approximately one metre apart under the surface of the road.
One key advantage of a wireless charging system is that the vehicle requires a smaller battery than a 'conventional' BEV as the charging methods are adapted to align with this technology.



(Beiker 2015)

Figure 45 Wireless dynamic recharging system

Irrespective of the type of wireless charging there will be considerable cost incurred with the required ground works to offer an effective infrastructure to support this method of recharging. Reducing the battery size will be beneficial however, this will shift the high cost of battery ownership from the vehicle owner/user to the local authority as they will have to re-lay sections of road which will essentially become 'charging' lanes.

3.9 Conclusion

(Balea 2015) has stated that emerging market are finding different way to address the high new technology costs in a worldwide market as many factors make electric vehicles (EVs) an exciting alternative to gasoline-powered ones, including long-term savings and the environmental benefits. Still, there are challenges to widespread adoption, the biggest of which is the higher upfront purchase cost of EVs. It's what industry players call the "premium for being green." This upfront cost is largely attributed to an EV's most critical component: its battery.

With the understanding of the current volatility of the petrol and diesel costs and the introduction of a new mobility exercise within Edinburgh College that is in conjunction with the transportation policy. This chapter has covered review of vehicular energy models and driving cycles that the commuter user will experience within business use.

Vehicular emissions have been reported briefly and compared relatively among the BEV and conventional internal combustion engine vehicles. BEV and PHEV technology developments have been presented. Different charging modes for electric vehicles have been discussed considering overcurrent protection as well as residual current circuit breaker and surge arrestor.

Traction motors of BEVs with transmission gear systems have been discussed and also the variation of battery capacity with the ratings of the traction motors have been reported. Different types of battery technologies have been analysed. Thermo-electro-chemical analysis have been reported and can be used for designing the cooling system of the BEVs based on driving patterns. Also briefly vehicle to grid opportunity has been reported and it can be used for demand side management.

Chapter 4 Battery and Charging Points

4.0 Overview

This chapter deals with the research conducted on the BEV battery and the trials on new battery technology achievable by a switch from current Lithium-ion cells to the safer and cost effective ($LiFePO_4$) Lithium Ferrite Phosphate chemistry that could be an alternative energy source to power electric automobiles.

As such in the present research programme the amount of traction and regeneratively-recoverable energy was tested in a specific purpose built (VLDC) **V**ariable **L**oad **D**uty **C**ycle equipment operated within our own test facility.

Complementary to the battery study, vehicle usage and recharging facility was critically investigated to determine the activity, frequency, supply and demand cost from one strategically positioned triple head rapid charger within one of the recharge hubs.

In order to satisfy the growing expectation for energy efficient eco-friendly transportation a number of Battery Electric Vehicle (BEV) requirements have emerged. Vehicle dynamics necessitate careful sizing of on-board battery storage systems and as the use of electric vehicles, in both the public and private sector increases, the requirement to facilitate and utilise them is becoming paramount.

As an alternative option to purchasing Edinburgh College opted to design and manufacture a bespoke model of Electric Vehicle (EV) charging post designed with on-charge/off-charge illumination for the user, these will be strategically positioned on routes and at businesses that will have the maximum impact to the BEV user without the attached high cost from a proprietary version.

4.1 Introduction

Introducing the battery electric vehicle into Edinburgh College brings important societal benefits as reported by (Weiss et al. 2014) it improves energy efficiency, air quality and urban noise, and reduces CO_2 emissions. Hierarchically and as part of the corporate travel plan all mobility activity should be subject to the required analysis initially determining whether the journey is absolutely necessary.

The deployment of electric vehicles for inter-campus travel was a strategic forward thinking decision which will utilise the electric power system grid with a sector carbon intensity of 330g CO_2/kWh in 2010, a typical electric vehicle would result in emissions of around 66g CO_2/km, compared to an average of 126g CO_2/km for new internal combustion engine vehicles in 2013.

The current technology and modern battery chemistry of the BEV utilises Li-ion technology as the preferred chemistry for the high voltage traction battery this has a high density to weight ratio and is able to be discharged and recharges (cycled) well in excess of 1500 times giving it excellent properties as an energy source for the vehicle.

Traction battery rechargers can fall into one of the following categories (Zap-Map 2016):

- **Rapid charge**

  DC - Rapid DC chargers provide a high power direct current (DC) supply with power ratings of up to 50kW. At these charging rates, charging an electric vehicle to 80% typically takes half an hour.

  The most common type of Rapid charging unit, Rapid DC chargers are equipped with a tethered cable with a non-removable connector which is coupled with an appropriate inlet socket. Rapid DC chargers are fitted with either a JEVS (CHAdeMO) or a 9-pin CCS (Combo) connector.

  Rapid AC chargers are typically rated at 50kW (125A).

  All units provide a tethered cable with a non-removable Type 2 (Mennekes) vehicle connector so as to remove any risk associated with the high power.

- **Fast charger**

  Fast chargers are typically rated at 7-22kW (1- or 3-phase, 32A).

  Most units have a Type 2 (Mennekes, IEC 62196) or Commando (IEC 60309) supply-side socket – occasionally, units provide a tethered cable with a non-removable Type 1 (J1772) or Type 2 (Mennekes) vehicle connector.

  Charging an EV on a fast charger usually takes 3-4 hours (depending on battery capacity and on-board vehicle charger specifications).

- **Slow charger**

  Home or workplace overnight charging is the most common type of charging cycle. Although a standard single-phase 13 amp three-pin domestic socket is adequate for home charging, a dedicated EV unit should be installed. Alternatively, a qualified electrician should conduct a house survey to ensure that the wiring will safety support the relatively long periods of charging.

  Slow chargers are typically rated at 3kW (1-phase, 13/16A).

  Most units have a standard 3-pin (BS 1363) or Commando (IEC 60309) supply-side socket – alternatively units provide a tethered cable with a non-removable Type 1 (J1772) vehicle connector.

  Charging an EV on a slow charger usually takes 6-8 hours or more (depending on battery capacity).

If the main charging mechanism for the EV slow charger, (Anegawa 2010b) discussed that quick chargers are not utilised all of the time and the extra demand from the grid will be minimum. It is also stated that it is unlikely that the grid will be utilised to the maximum due to vehicles being simultaneously rapid charged.

When EV's are being rapid charged the capacity of the grid will need to be taken into account. It is likely that this facility will be in commercial areas where there will be high existing demand on the grid which can deal with significantly more than the demand. Anegawa states that the rapid 50kW is only a small percentage of the total capacity and thus has little or no impact to the network infrastructure.

4.2 Battery and charging

At the introduction of the BEV project within the College there was not an infrastructure to support the vehicles. All recharging was conducted within the workshop areas using UK conventional 3 pin plugs into the wall sockets. As the project became embedded and accepted by staff the vehicles were moved from this temporary arrangement to a dedicated area for BEV charging.

4.2.1 College concept – an experimental charge point

In the early trials Edinburgh College manufactured six charging posts for its own needs and the use does differ from the government demand for fast charging as the vehicles are used through the day and are always returned at night for charging – this was the nature of College business for the initial trials.

Figure 46 illustrates the experimental charge point. This was a 3kW slow charger with simple operation which had two LED functions; one for on-charge and the other for off-charge. A locked-off compartment ensured that the supply to the vehicle could not be interrupted without authorisation.

Edinburgh College designed charge post is a Scotland first and production has been increased to 12 posts by the end of 2012 with CE approval requested in line with the IET code of practice for electric vehicle charging equipment installations standards.

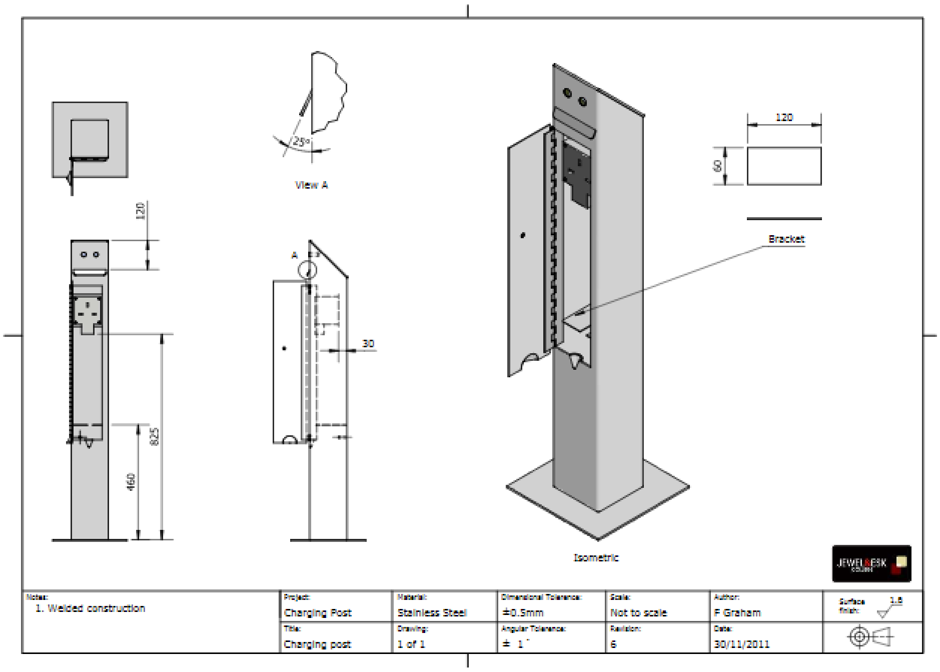


Figure 46 Authors own design – College concept post

The design of the concept charging post was determined as necessary to be of absolute minimum maintenance and ease of use for the user.
The charging post was designed in-house using welded stainless steel box section which will be an easier section to manufacture for quick fabrication.
The Standard Operating Procedure (SOP) is attached in Appendix 4.
The post height was determined to be sufficiently tall so it could be seen from all positions within the average vehicle thus reducing the risk of damage due to vehicle impact. These posts will be bolted to the ground at College strategic locations.

Figure 47 Authors own design installed – College concept post

These slow charger posts were the fore-runner to the fast charge posts which were recently installed as part of a major Edinburgh College project offered to all colleges across Scotland. In total 24 fast charge points were installed across Scotland UK as part of this Edinburgh College BEV project.
The uptake of College electric mobility will ultimately necessitate improved control over ‘dumb charging’ that is to monitor the activity and electricity supplied to the vehicle.

4.2.1 The northern infrastructure

There are three main EV charger types: 'slow' charging units (up to 3kW) which are best suited for 6-8 hours overnight; 'fast' chargers (7-22kW) which can fully recharge some models in 3-4 hours; and 'rapid' charging units (43-50kW) which are able to provide an 80% charge in around 30 minutes. Rapid chargers also come in two charge point types – AC and

DC – depending on whether the vehicle manufacturer has specified alternating current or direct current use.

One of the main concerns of the potential BEV user is charging availability and will the BEV infrastructure remain robust enough to support it.

As at July 2014 this was not the case, the figure 48 indicates the state of the rapid charger network in Scotland. Red posts are the ones out of service at that moment in time. Figure 49 indicates the charger network in July 2015 and there is a clear improvement of service and a greater number of posts available to the user.

Figure 48 Scotland charger network July 2014

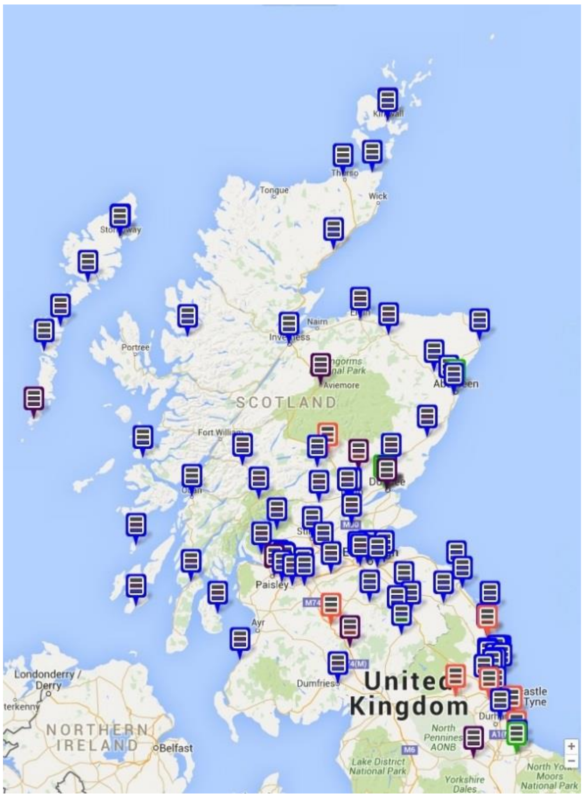


Figure 49 Scotland charger network July 2015

A key goal within the Scottish Governments Transport Scotland publication 'Switched on Scotland Electric Vehicle Roadmap' (Alba n.d.) was to ensure that as an increasing number of electric vehicles enter the market they will require a robust grid and sufficiently well-managed charge points that will accommodate further changes in demand. This will further realise the potential of BEV's to support the development of a cleaner and smarter energy system.

This demand on the grid will feed into a further study by the Scottish Government as they develop a ‘Scottish Energy Strategy’ publication which will be published in the summer 2017 and will refresh the ‘Switched on Scotland EV Roadmap’ (Alba n.d.).

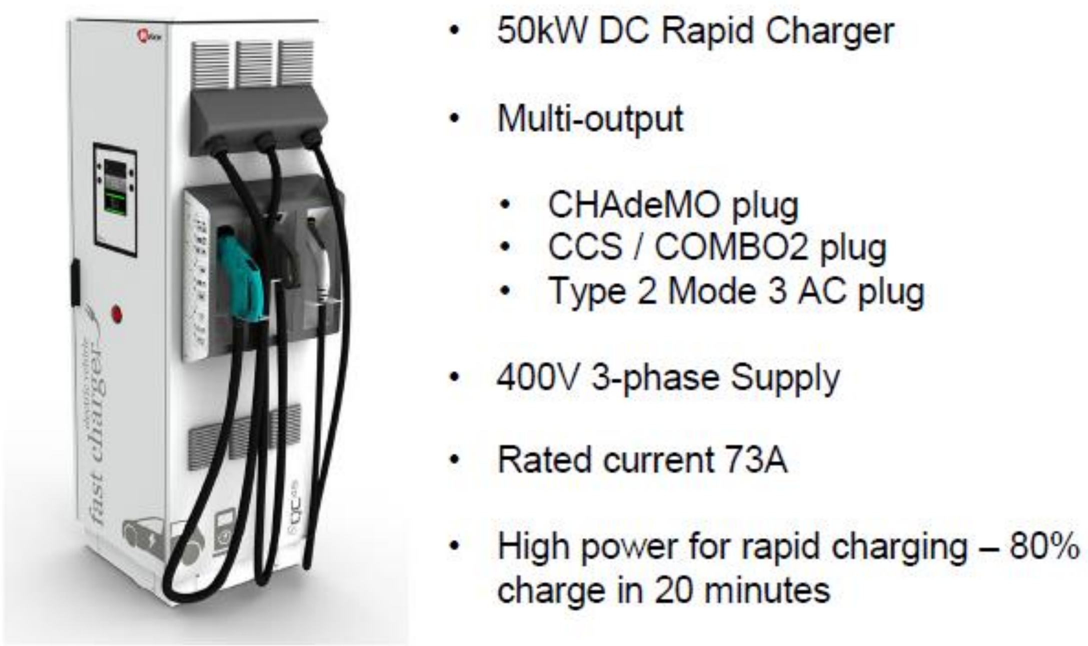
4.3 Environmental and economic performance of an energetic charge station

4.3.1 Contribution to the infrastructure

The Edinburgh College Milton Road Rapid Charger has been a valuable addition to the EV charging infrastructure in the area. Its location at the Northern end of the A1 trunk road has proved popular with local drivers, businesses, and authorities – plus EV users travelling through or visiting the area.

This Siemens/efacec QC 45 AC/DC Triple-Head rapid charger is a reliable addition to the Transport Scotland's publically accessible road-side chargers. It is currently free to use as part of the ChargePlace Scotland scheme (Energy Savings Trust 2015).

See figure 50 for illustration.



(Siemens QC n.d.)

Figure 50 Siemens QC 45 charger

4.3.2 Strategic consideration

All-electric journeys in EVs and PHEVs offer the greatest emissions reduction and therefore should be facilitated as much as possible. Transport Scotland plans to deploy a network of rapid chargers at intervals of least every 50 miles on Scotland's primary road network.

The majority of journeys undertaken in Scotland are well within the driveable range of an EV.

The Transport Scotland literature suggests that ninety-four per cent of journeys in Scotland are under 40km, with the average trip length in a car being only 12.1km (Transport Scotland 2016).
For many users, ownership of an EV is unlikely to be a constraint on their ability to make longer distance journeys. Findings have indicated from the 2010 the National Travel Survey that 37 per cent of households in Scotland with regular access to a car also had access to a second vehicle (Transport Scotland 2011), which would allow the use of a fossil-fuelled vehicle for longer journeys.

From a trial conducted by one of the test Nissan LEAF vehicles the following key points were ascertained:

- **576 kWh** energy used
- **2181** miles travelled
- **248** trips
- **82** charging sessions (average duration 3hrs, 39 minutes)
- Mobile for **13%** of month
- Plugged in for **34%** of month
- Idle/Parked for **52%** of month

The 'street post' energy meter accuracy standard stated in this thesis is in accordance with BS EN 50470-3 (class b +/- 1%), this standard is stated in the APT installation manual with document reference 'EV-202-USE'.
This Nissan LEAF trial indicated 3.77miles per kWh, but the unacceptable mobility period of only just over 13%. It does however indicate the 'typical' 87% idle/parked/plugged-in time which is indicative of a fossil fuel vehicle 'parked time' as research by the RAC Foundation in 2013 which reports this is 90-95% (Barter 2013).

4.3.3 Report and discussion – annual impact

One of the features of further study is the Edinburgh College photovoltaic solar array. This encompasses 2600 PV panels that offset the grid requirements to the College. The photovoltaic array on average will produce an annual 650,000kWh. This energy is supplied directly back to the grid, but unlike some and as discussed by (Kolhe 2009) does not support independent battery storage at this application. The approximate annual figure to recharge all vehicles plugged into all of Edinburgh College charge points was 27,000kWh whether College owned or general public owned.
This is only a requirement of 4% of the total energy produced from the PV array and will be a source of future study out with the scope of this current thesis.
Appendix 7 gives an overall view for the usage report for the period June 2015 – May 2016 for the Edinburgh College rapid charger compared with a rapid charger in Aberdeen and

Edinburgh City. Table 12 illustrates the annual impact in both frequency and financial of the strategically sited rapid charger.

Table 12 Edinburgh College Rapid Charger

Edinburgh College Rapid Charger – Usage Report (June 2015 to May 2016)	
Total Sessions (All Users)	**786**
Total Energy Supplied	**5242 kWh**
Total cost of Energy Supplied	**£378**
Edinburgh College Only Sessions	**178**
Edinburgh College Only Energy Supplied	**1490 kWh**
Cost of Edinburgh College Only Energy Supplied	**£105**
Connector Used	**Frequency**
DC (CHAdeMO)	**692**
DC (CCS)	**55**
AC	**39**
Vehicle	**Sessions**
Aixam Mega City Electric	1
BMW i3 (BEV)	0
BMW i3 Rex	56
Mitsubishi i-MiEV	29
Mitsubishi Outlander	213
Nissan E-NV200	63
Nissan LEAF	332
Peugeot iOn	1
Renault ZOE	18
Smart FourTwo ED	2
Tesla Model S	4
Volkswagen eGolf	1
Volkswagen Golf GTE	13
Unspecified	53
2015 Electricity Use & Costs	
'Day' rate charge sessions (07:00 to 00:00)	618
'Day' rate energy supplied	4042 kWh
'Day' rate cost (@ £0.073401 per kWh)	£297
'Night' rate charge sessions (00:00 to 07:00)	36
'Night' rate energy supplied	259 kWh
'Night rate cost (@ £0.063384 per kWh)	£16
2016 Electricity Use & Costs	
'Day' rate charge sessions (07:00 to 00:00)	122
'Day' rate energy supplied	878 kWh
'Day' rate cost (@ £0.069268 per kWh)	£61
'Night' rate charge sessions (00:00 to 07:00	10
'Night' rate energy supplied	62 kWh
'Night' rate cost (@ £0.057455 per kWh)	£4

<u>All Vehicles & Sessions</u>

Total Charge Sessions: **786**

Total Energy Supplied: **5242 kWh**

Number of Unique Users: **77**

Connectors used & frequency:

• DC (CHAdeMO)	692
• DC (CCS)	55
• AC	39
	786

Types of vehicle using post and frequency:

• Aixam Mega City Electric	1
• BMW i3	0
• BMW i3 Rex	56
• Mitsubishi i-MiEV	29
• Mitsubishi Outlander	213
• Nissan E-NV200	63
• Nissan LEAF	332
• Peugeot iOn	1
• Renault ZOE	18
• Smart FourTwo ED	2
• Tesla Model S	4
• Volkswagen eGolf	1
• Volkswagen Golf GTE	13
• Unspecified	53
	786

Electricity rates (per kWh):

01/04/2015 to 31/03/2016 – Day £0.073401 / Night £0.063384
01/04/2016 to 31/03/2017 – Day £0.069268 / Night £0.057455

2015/16 rates:

'Night' rate charge sessions (00:00 to 07:00): **36**
'Night' rate energy supplied: **259 kWh.** 'Night rate cost (@ £0.063384 per kWh): **£16**

'Day' rate charge sessions (07:00 to 00:00): **618**
'Day' rate energy supplied: **4042 kWh.** 'Day' rate cost (@ £0.073401 per kWh): **£297**

2016/17 rates:

‘Night’ rate charge sessions (00:00 to 07:00): **10**
‘Night’ rate energy supplied: **62 kWh.** ‘Night rate cost (@ £0.057455 per kWh): **£4**

‘Day’ rate charge sessions (07:00 to 00:00): **122**
‘Day’ rate energy supplied: **878 kWh.** ‘Day’ rate cost (@ £0.069268 per kWh): **£61**

TOTAL cost of electricity supplied: **£378**

Edinburgh College Vehicles Only:

As well as being publically accessible, the Rapid Charger is used for Edinburgh College’s own pool car fleet. The statistics from their use of the asset over the last 12 months are:

2015/16 rates:

‘Night’ rate charge sessions (00:00 to 07:00): **31**
‘Night’ rate energy supplied: **235 kWh.** ‘Night rate cost (@ £0.063384 per kWh): **£15**

‘Day’ rate charge sessions (07:00 to 00:00): **104**
‘Day’ rate energy supplied: **918 kWh.** ‘Day’ rate cost (@ £0.073401 per kWh): **£67**

2016/17 rates:

‘Night’ rate charge sessions (00:00 to 07:00): **10**
‘Night’ rate energy supplied: **62 kWh.** ‘Night rate cost (@ £0.057455 per kWh): **£4**

‘Day’ rate charge sessions (07:00 to 00:00): **33**
‘Day’ rate energy supplied: **275 kWh.** ‘Day’ rate cost (@ £0.069268 per kWh): **£19**

Cost of electricity supplied for Edinburgh College vehicles only: **£105**

Charge Durations:

Average Duration (across all 786 sessions): **29 minutes 28 seconds**

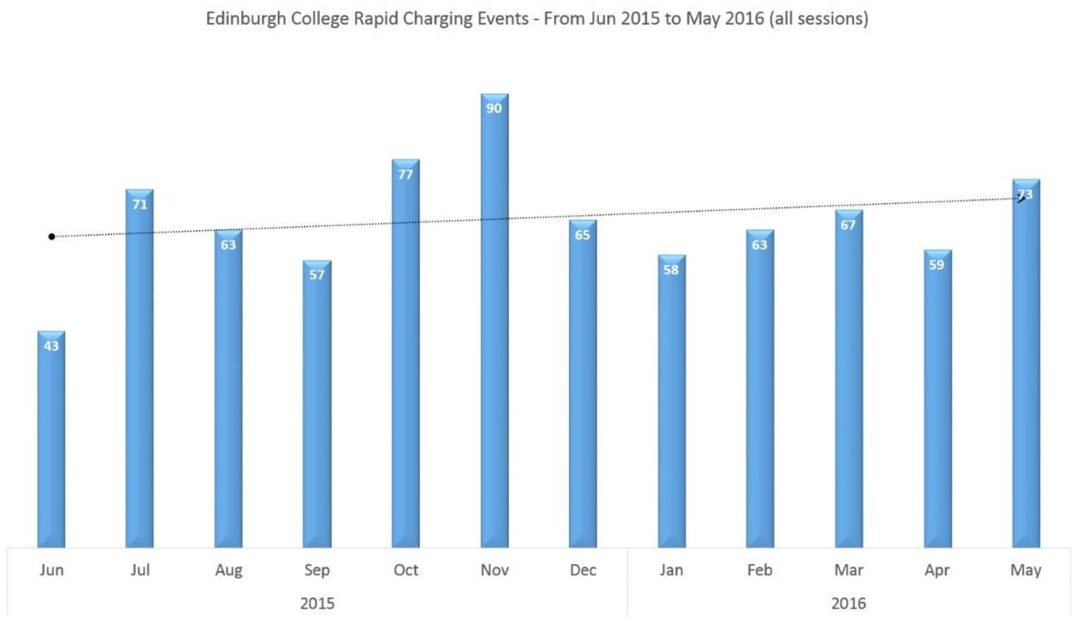
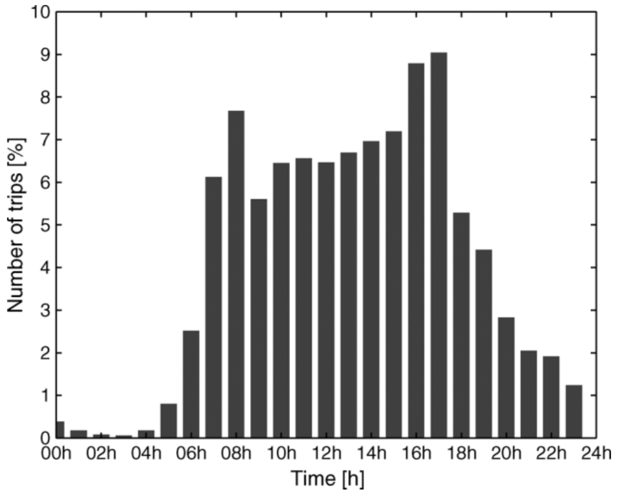


Figure 51 Edinburgh College rapid charger usage frequency

Taking the 2014/2015 financial year as an example, we revealed that 85.47% of trips are less than 10 miles long, and the most popular time of travel is midday – with 15.75% of trips carried out between 12.00 & 13.00 hours. This information is used to inform policy and procedures relating to EV's. For instance, when vehicles are likely to be on charge and the likely impact of Grid CO_2 intensity during that demand time.



(Clement et al. 2010)

Figure 52 Percentage of trips for each hour

Figure 52 shows findings by (Clement et al. 2010) this indicates the percentage of all trips by vehicle each hour. At that moment, they are not available for charging.

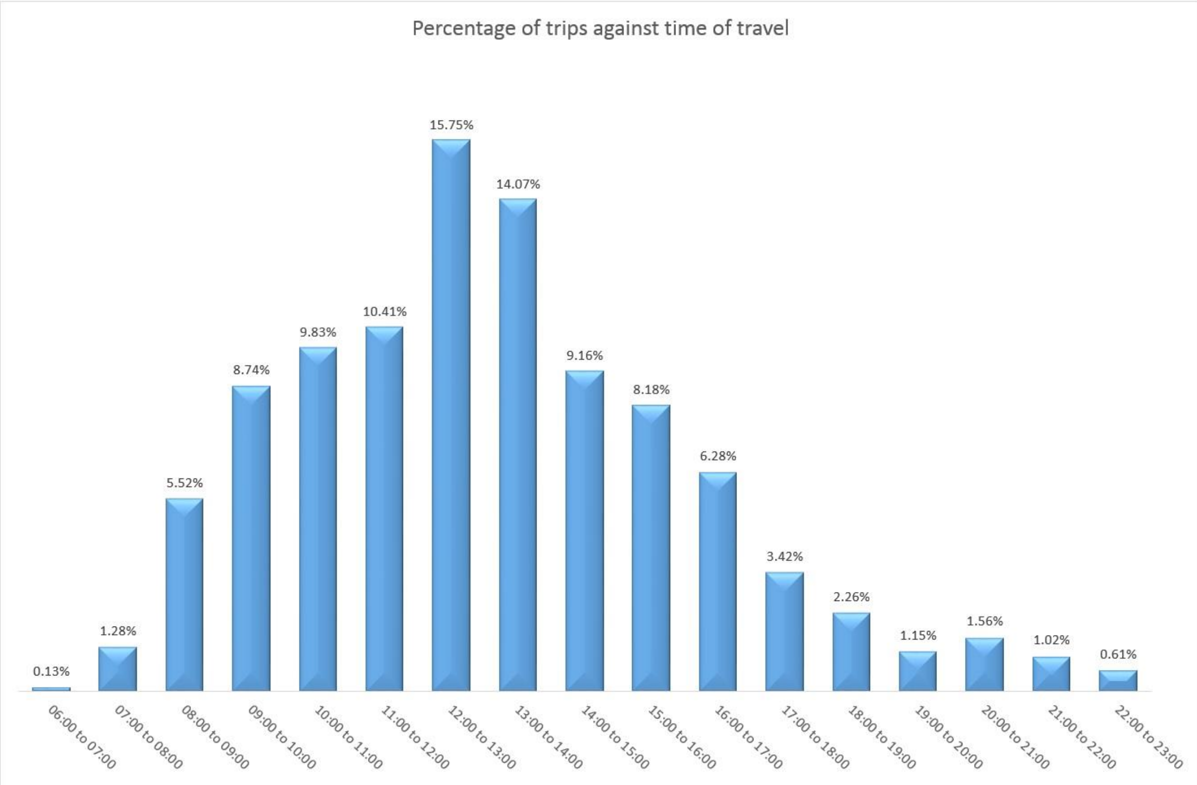


Figure 53 Typical Edinburgh College travel times 2012

The hourly trip findings from (Clement et al. 2010) matches the Edinburgh College study see figure 53 and based on the present research findings, three important charging strategies are proposed.

1. The first charging period is during the evening and through the night utilising fast charging. Most of the vehicles are parked from 23h00 until 06h00 in the morning. Some BEVs are immediately plugged in on return to the allocated campus in order to be ready to use throughout the evening if required.
2. The second charging period takes place between 13h00 and 16h00 utilising fast charging when the vehicle can be parked at a destination campus.
3. The third charging period can be on demand utilising the Milton Road campus rapid charger.

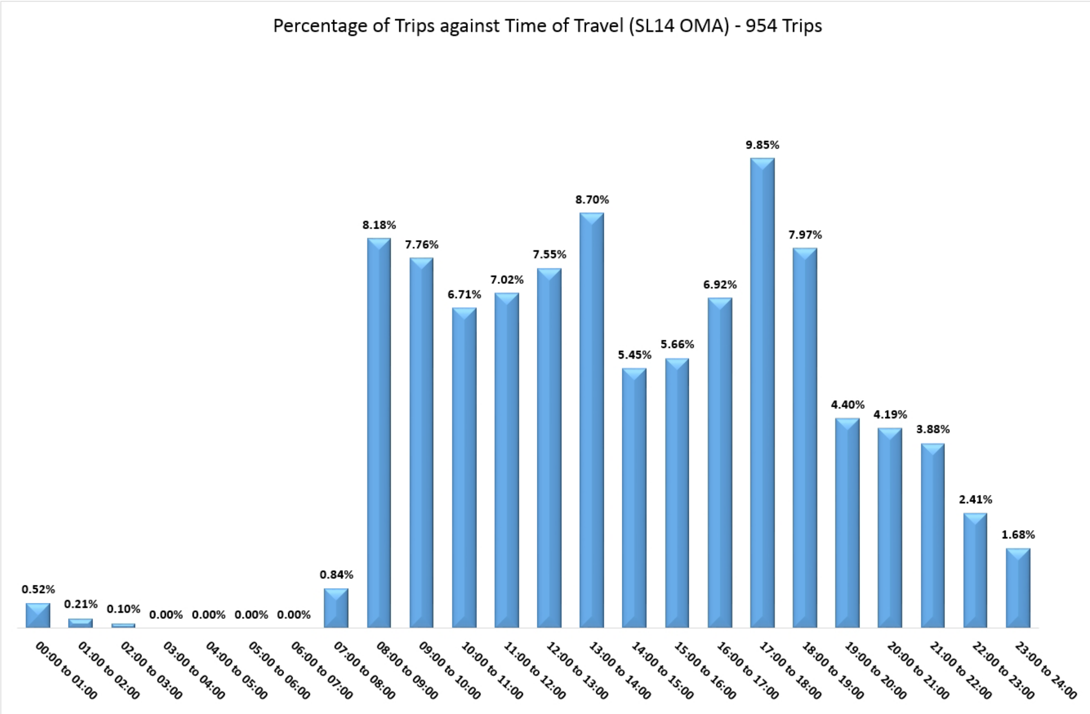


Figure 54 Typical Edinburgh College inter-campus travel times and frequency 2016

In the comparison of figures 53 and 54 it is evident that the staff through operational changes and user confidence have gone from a single high demand 2012 profile when the highest frequency usage which led up to 12.00 and from 14.00 it began to reduce. It was also understood that from 19.00 till 07.00 there was negligible usage and activity and this gave a twelve hour 'on-charge' time. This usage pattern was aligned to a single extensive recharge within the 24hour period.

When compared with the earlier study the 2016 user profile frequency is active from 09.00 till 18.00 see figure 54. This frequency of constant day use indicates greater confidence from the user and that they are adapting a just-in-time charge strategy (Chen et al. 2016). There is now vehicle usage up till 24.00 as the BEV's are being utilised by the securities staff commuting between campuses out with College hours.

The energy generation mix is expressed in table 13 for a given time frame, it has been reported by (Hawkes 2014; Ma et al. 2012) that is of more relevance to state the 'marginal' grid intensity as well as the average intensity. The extra electricity demand currently is likely to be met utilising fossil fuels rather than renewable sources.

Table 13 Energy generation mix

SK65 NMF – Rapid Charges with Emissions, May 2016

Start Date (2016)	Start Time	End Time	Duration	kWh	Cost	CO_2e (kg)	Energy Mix (%)								
							Coal	Nuclear	CCGT	Wind	Pump. Hydro	Hydro	Oil	OCGT	Other
01/05	09:48	10:23	0:35	11.95	£0.83	3.03	8.02	25.93	43.50	11.43	2.05	1.02	0.00	0.00	8.06
02/05	18:28	19:19	0:51	14.29	£0.99	3.48	7.48	24.23	42.92	14.87	1.72	1.90	0.00	0.00	6.87
11/05	00:04	00:53	0:49	8.95	£0.52	1.98	2.02	29.65	49.21	9.86	0.00	0.59	0.00	0.00	8.68
12/05	20:26	21:16	0:50	3.6	£0.25	0.83	1.67	21.40	54.18	12.23	2.91	0.72	0.00	0.00	6.89
13/05	02:35	03:26	0:51	9.15	£0.53	1.55	0.00	33.37	38.42	17.07	0.00	0.63	0.00	0.00	10.50
15/05	15:40	16:25	0:45	13.35	£0.93	3.33	2.72	27.13	55.57	3.90	1.57	0.88	0.00	0.00	8.23
16/05	00:20	00:53	0:33	4.39	£0.26	1.05	2.03	32.02	52.96	2.51	0.00	0.54	0.00	0.00	9.94
16/05	02:28	03:17	0:49	9.71	£0.56	2.29	2.16	32.71	51.54	2.92	0.00	0.55	0.00	0.00	10.11

CCGT/OCGT = Closed or Combined/Open Cycle Gas Turbine

Other = eg. Biomass (Drax Power Station)

Oil = Thick Fuel Oil, or Bunker Oil power stations.

Electricity rates: 2016/17 – Day (07:00 to 00:00) £0.069268 / Night (00:00 to 06:59) - £0.057455 per kWh

NB. Sources of energy from renewables are underestimated. Most Solar PV sites and up to 50 of Hydro are unmetered (Elexon 2016).

Sources:
Charging Data: Charge Your Car (Charge Your Car 2016).
Vehicle Tracing Data: TrackYou (Trackyou 2016).
Energy Mix Data: BM Reports (Elexon 2016).
Conversion factors: Grid Carbon (Rogers & Parsons 2016).

Total kWh: 75
Total cost: £4.87
Average $kgCO_2e$ per kWh = 0.23

Figure 55 illustrates the total energy supplied to the on-campus fast chargers, this gives an indication of the energy consumption for the one-year period of April 2014 to April 2015 and the similarity between campus locations.

Table 14 illustrates the comparison figures for April 2015 to April 2016

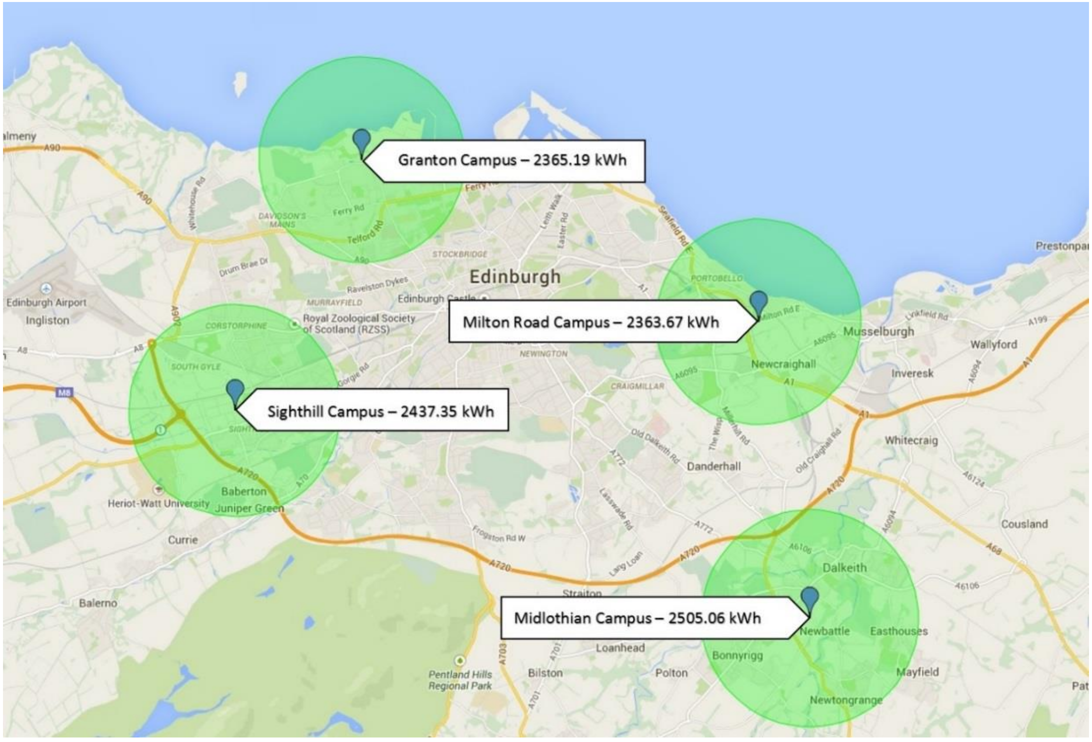


Figure 55 Energy at Campus locations

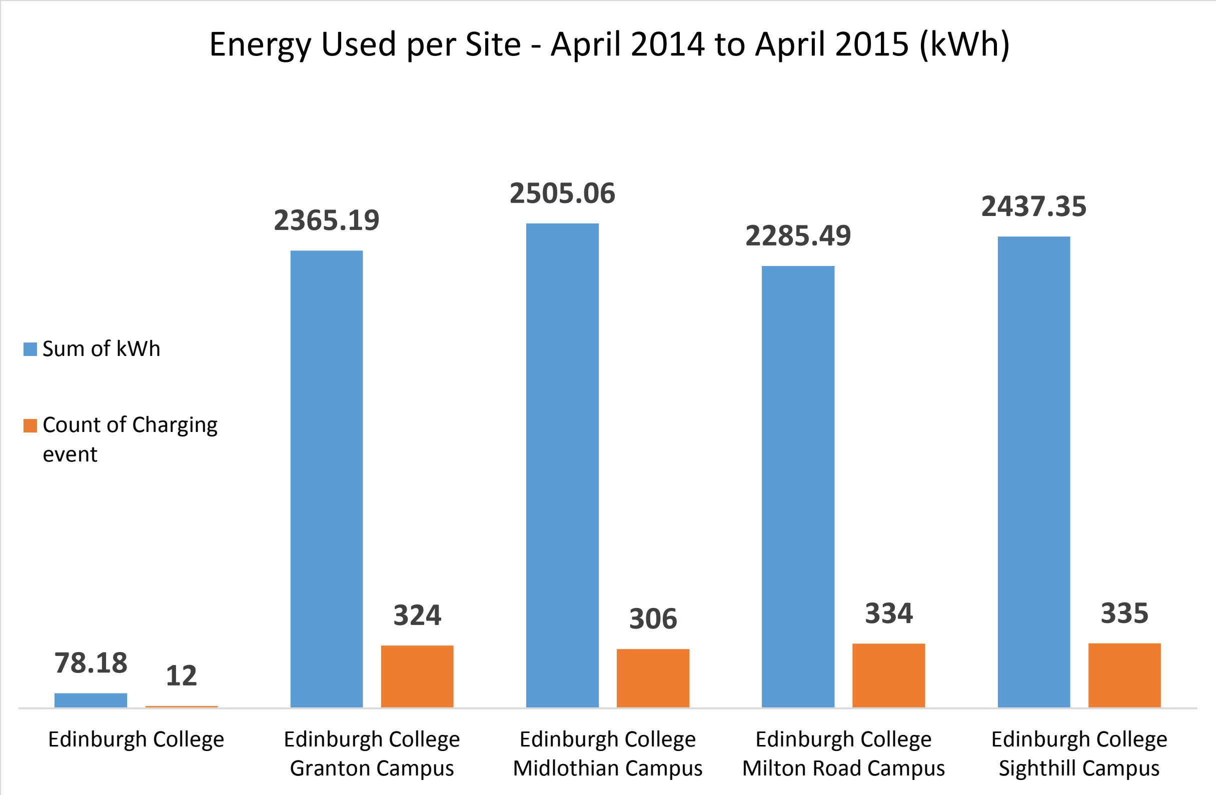


Figure 56 Overview of energy and frequency per site

Figure 56 illustrates a twelve-month breakdown of frequency and energy consumption across the four campus locations. This figure gives an indication of the similar demand on the fast charge infrastructure and the user uncertainty and lack of confidence of the recently installed rapid charger. A series of training sessions was offered to all staff to build confidence in this new equipment.

Table 14 Overview of energy consumed per campus

	Energy Used (kWh)	
Site	**2014 - 2015**	**2015 - 2016**
Granton Campus	2365	6891
Midlothian Campus	2505	4912
Milton Road Campus	2285	6681
Sighthill Campus	2437	3726
Milton Road Rapid Charger	78	5103

Data recorded within the range: 01/04/2015 to 31/03/2016 through the ‘back office’ data capture from ‘Charge your car’ (CYC). This consumption data is logged each and every time the CYC card is displayed to activate the charge post (Charge Your Car 2016).

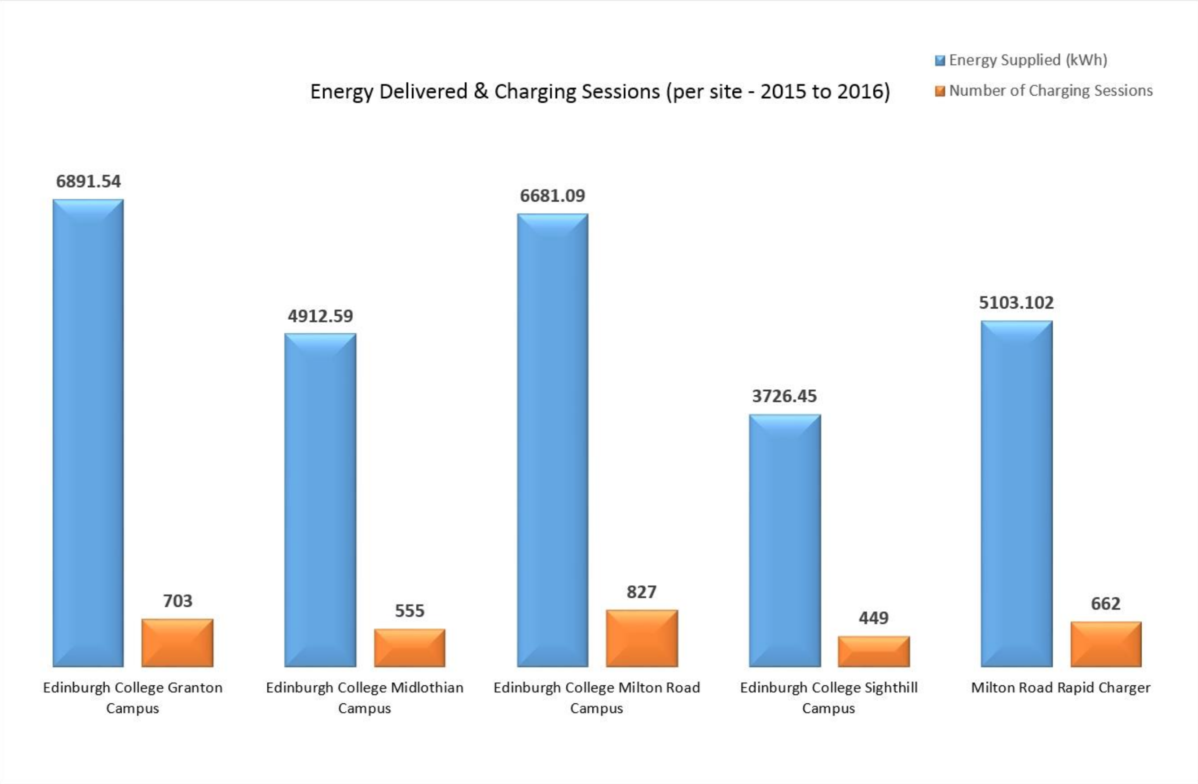


Figure 57 Illustration of energy and use for session April 2015 – April 2016

Figure 57 illustrates fast charger points being utilised to a greater extent, this will be required due to the increase in vehicles and greater demand on the infrastructure. The charger posts are being utilised now by the general public, and the staff training and confidence building has resulted in the rapid charger being used as in accordance with just-in-time charging. Planned activity for 2017 is to increase the charging infrastructure for the Sighthill campus as it currently only has a single post. This single post is creating a ‘bottleneck’ situation and users are anxious that if they stop the charging session and vacate the charge point that they are likely to not find it available on their return. This is reducing the activity associated with this fast charger.

The Milton Road campus fast chargers are not being used as consistently as previous as the users now can rely on the rapid charger option and this is becoming accepted and preferred for recharging.

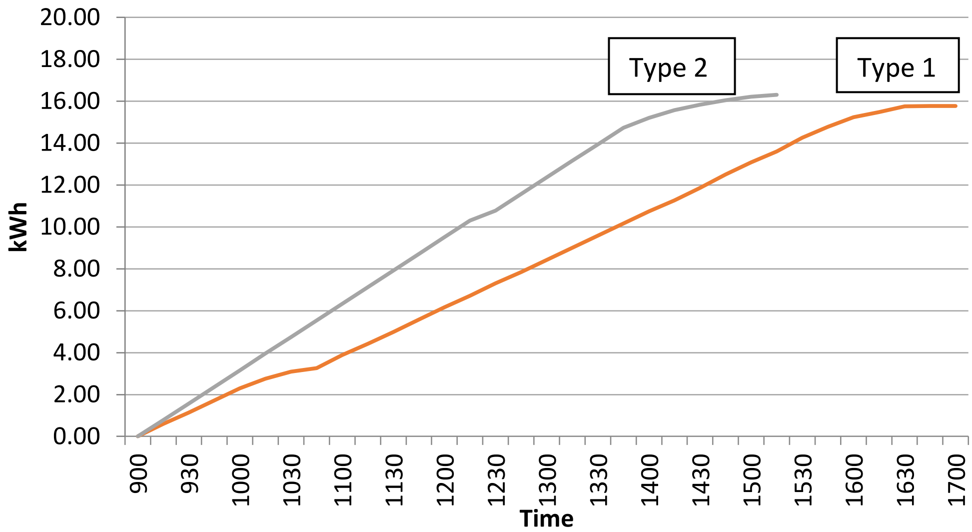
4.4 Expectations of battery technology

The battery energy requirements of BEV depend on numerous factors such as weather conditions, driver style plus demands on the vehicle systems. A battery has to be selected to have the repeatability in its recharging capacity, a high energy density, and safety as well as being lightweight for the mobility application.

The speed at which BEV can penetrate the market depends on both the rate of progress in new battery technology and the rate that battery technology improvements are perceived by consumers.

This technology has to become financially viable and have a certain expected lifecycle to failure.

4.4.1 Li-Ion battery recharge analysis



Key: type 1 response curve (orange)

type 2 response curve (silver)

Figure 58 Mitsubishi battery pack recharge response curves

Under a controlled test condition the Mitsubishi i-MiEV 16kWh battery was put on charge and the time and energy supplied was monitored for both type 1 and type 2 charge modes. Figure 58 indicates that the type 2 mode recharged the battery pack in 6hrs 15minutes whereas the 10-amp type 1 mode 1 recharged the pack in 8hrs. An overall reduction in recharge time of 22% when recharged at the higher energy rate.

The Mitsubishi test commenced fully charged (16 bars indicated). Travelled 62.29 miles as indicated by GPS tracker under various loads and conditions. Heater and AC were on for most of the time. High speed runs on bypass. Assuming full 16kWh of battery used, energy consumption calculated at 3.89 miles per kWh. Mitsubishi quoted efficiency is 4.6 miles per kWh as stated by (Mitsubishi technical 2015).

It should be noted that petrol has a theoretical specific energy of 13,000 Wh/kg, which is over 100 times higher than the specific energy of 120 Wh/kg of typical Li-ion batteries as stated by (Young et al. 2013).

4.4.2 Li-Ion battery discharge analysis

The graph in figure 59 shows typical discharge curves for cells using a range of cell chemistries when discharged at 0.2C rate. Note that each cell chemistry has its own characteristic nominal voltage and discharge curve. Some chemistries such as Lithium-ion have a fairly flat discharge curve while others such as lead acid have a pronounced slope.

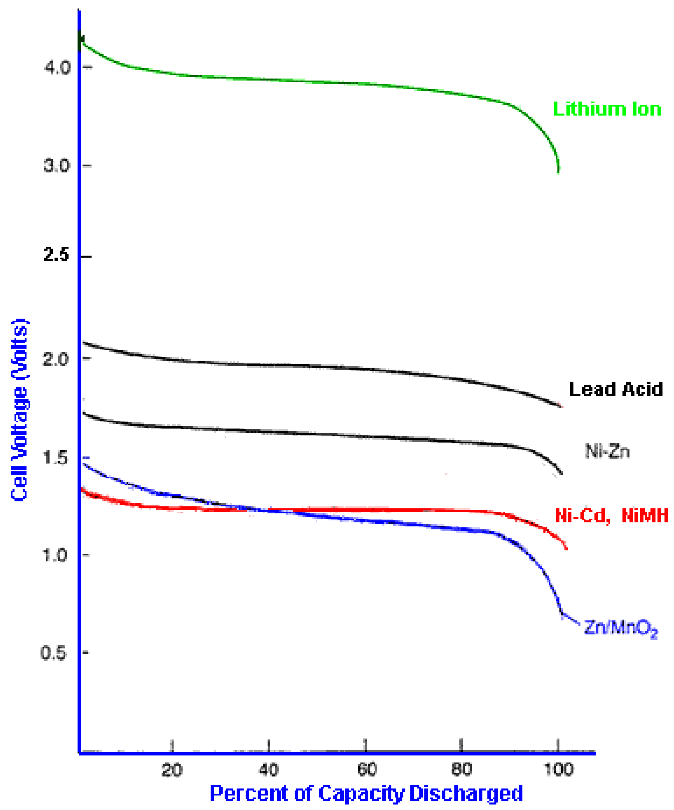
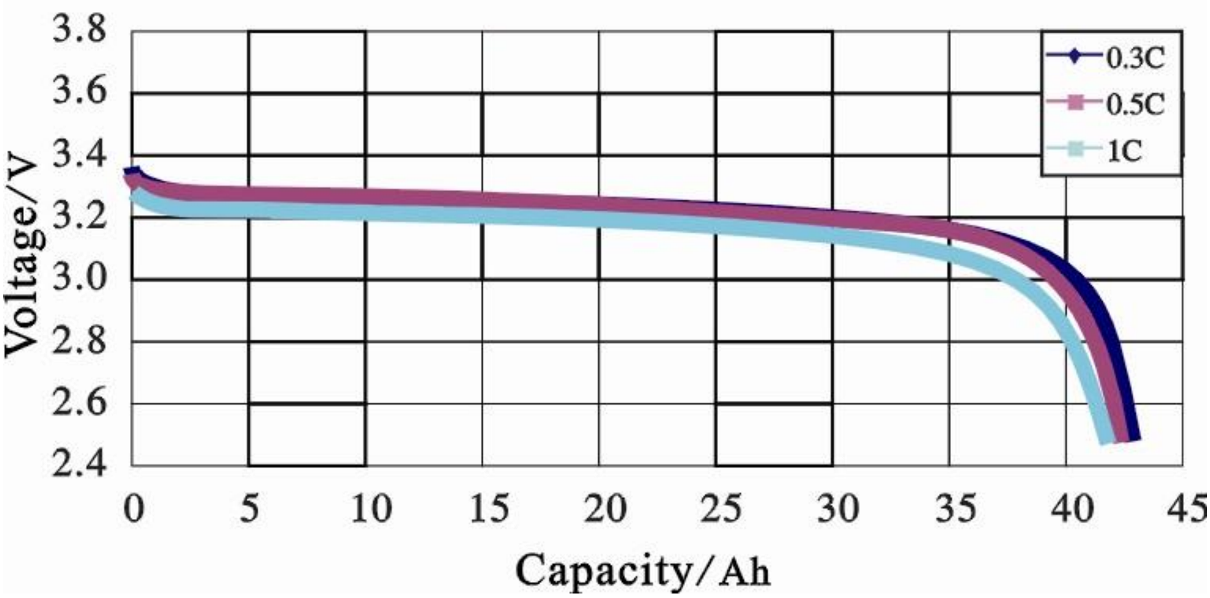


Figure 59 Differing cell chemistry discharge behaviour

It is this ‘flat’ section of the discharge curve and the higher cell voltage that gives Lithium-ion superior performance when compared to lead acid chemistry.

4.5 Experimental battery technology

In this section Lithium ferrite phosphate was under investigation to determine if it could be used as an alternative to current Lithium-ion battery technology. Tests were conducted on $LiFePO_4$ batteries on our bespoke VLBT (**V**ariable **L**oad **B**attery **T**ester), this equipment cycled the batteries on and off variable loads against time frames. The results were analysed after this rigorous testing and compared with the current market chemistry. The method was to determine if the new chemistry batteries had comparable characteristics.



(CALB 2011)

Figure 60 $LiFePO_4$ discharge curve (typical – manufacturer Calb)

The author would like to thank the manufacturer for giving the laboratory team an opportunity to plot results in our own testing facility.

Tests were conducted with the CALB CA40 series cell, the battery voltage against the depth of discharge at 0.3C, 0.5C and 1C capacity, cell performance was analysed (figure 60). This cell will have a maximum discharge capacity of 2C with a cut off voltage of 2.5V. Charging time are between 1hr for fast charging to 4hrs for standard charging (CALB 2011).

This cell has been rated to withstand 2000 cycles when discharged at 0.3C and 80% depth of discharge.

See appendix 9 for technical specifications.

4.5.1 Energetic analysis and economic modelling of battery behaviour

To determine actual characteristic under independent test conditions Edinburgh College and Edinburgh Napier University have designed and manufactured a $LiFePO_4$ (Lithium Ferrite Phosphate) variable load battery tester.

Battery cells will be put into the circuit which will introduce a maximum of four timed resistive loads as shown in figure 61. This resistance will load the battery and discharge its capacity over a period of time.

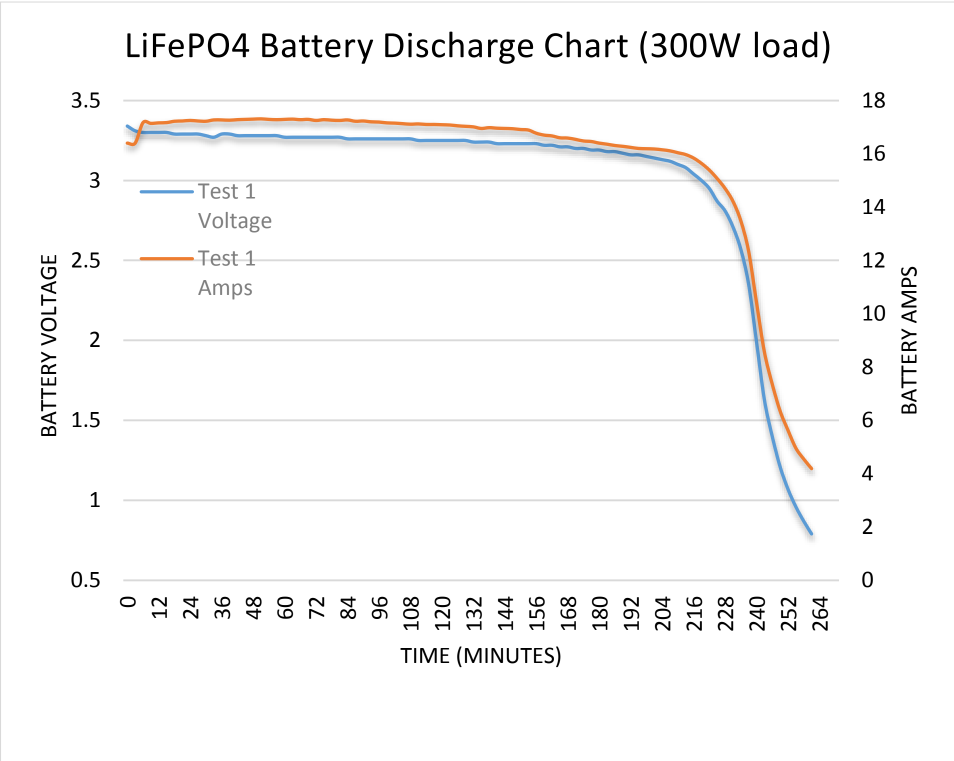


Figure 61 LiFePO₄ discharge curve (experimental)

The $LiFePO_4$ cells were fully charged as directed by the manufacturer prior to conducting any testing. The VLBT can control up to four loads of 100W each (maximum 400W) and the timing can be infinitely variable.

Figure 61 indicates the response curve when subject to a 300W load. The cell had the capacity to hold a constant 300W resistive load for approximately 222 minutes.

The accuracy of the equipment was considered and from the manufacturers was given as - OMRON K3GN amp meter, LEM DK 100 B420 DC current Transducer and Hengstler tico 731 digital timer ammeter conforms to the following specifications: UL508, CSA C22.2 No. 61010-1. All equipment has a measurement accuracy noted as ±0.1% full scale ± one-digit max. (at 23±3°C).

Variable Load Battery Tester (VLBT)

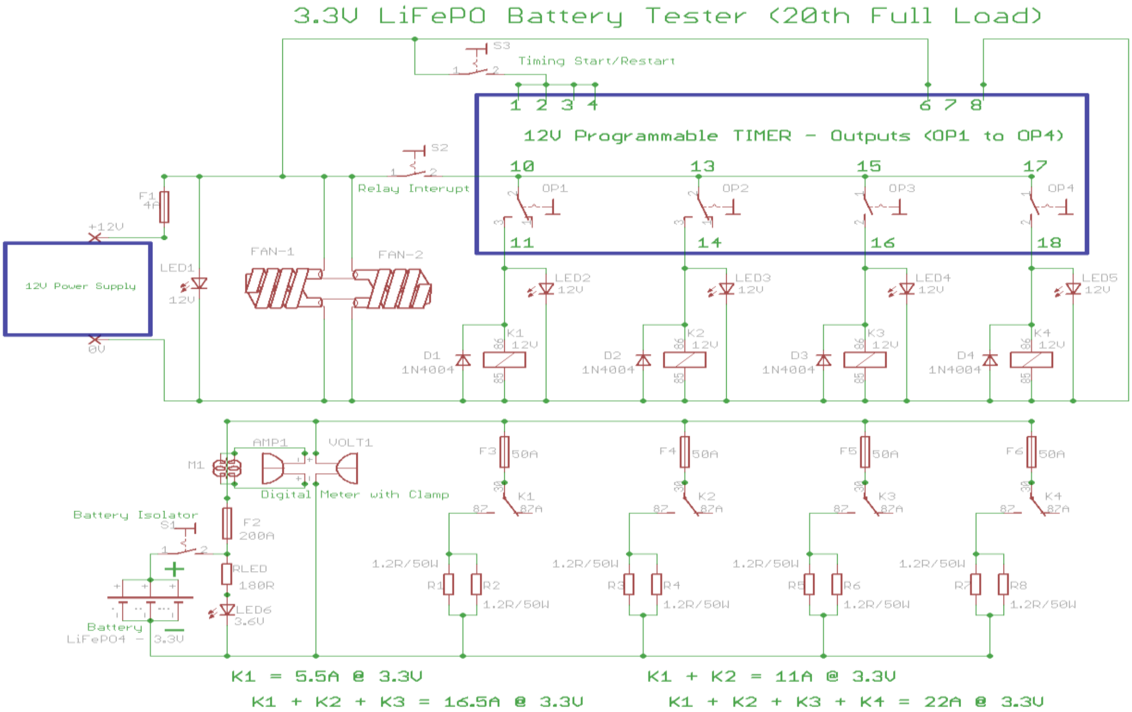


Figure 62 Variable Load Battery Tester schematic

4.5.2 Battery financial evaluation

In 2016 the industry standard average lithium-ion BEV battery pack is estimated at £275 per kWh, this is expected to reduce to £75 per kWh by 2022. These are the cell costs; a complete battery pack will be approximately 20% above the cost of the cells (Wesoff 2016). One focal purpose within this new battery testing section was to determine an alternative chemistry source that could be a cost effective option when compared to conventional lithium-ion.

The CALB cells on test were BEV quality – essentially lithium-ion but with lithium ferrite phosphate ($LiFePO_4$) being used as the cathode material. These batteries are currently approximately £35 per kWh offering a significant cost saving when compared to the conventional battery.

The cost savings, low toxicity and the inherent safer chemistry technology is of paramount interest and as the thermal stability making this a potential contributor and will warrant further study.

4.6 Results and discussion

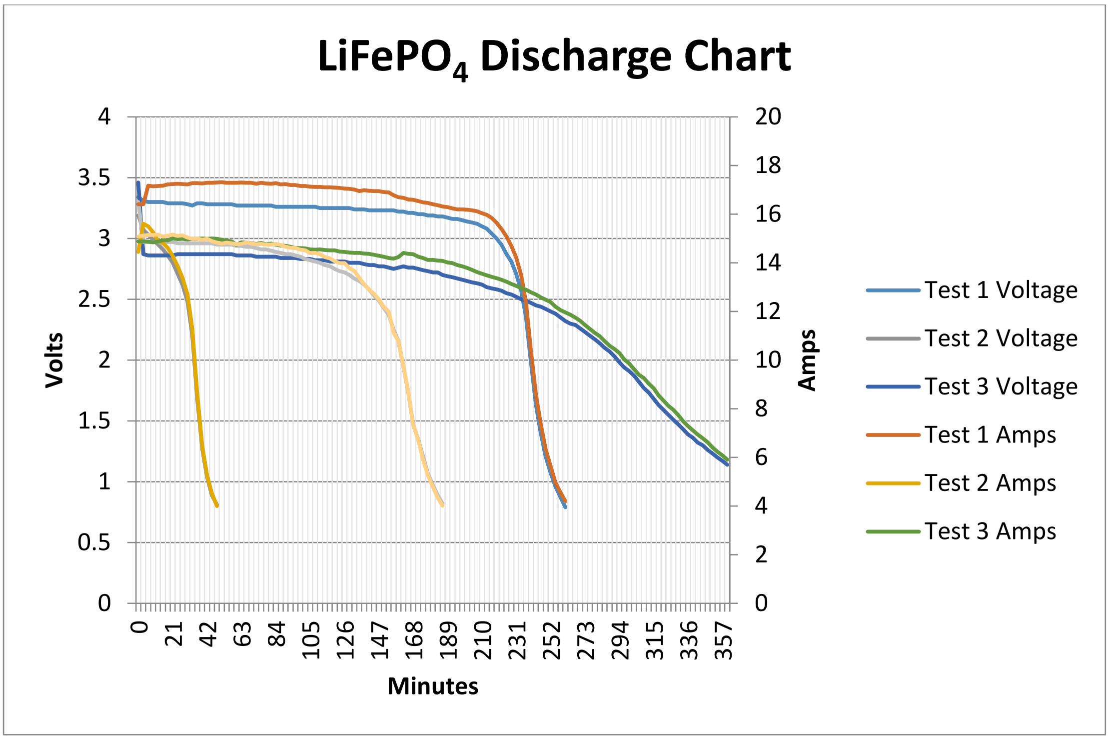


Figure 63 LiFePO₄ discharge curve (test – manufacturer CALB)

Under test conditions $LiFePO_4$ (CALB CA40FI) discharge characteristics are shown in figure 63.

Table 15 $LiFePO_4$ 30 minute characteristics – all loads

Time (Minutes)	0	3	6	9	12	15	18	21	24	27	30
Test 1 Voltage	3.34	3.31	3.3	3.3	3.3	3.3	3.29	3.29	3.29	3.29	3.28
Test 1 Amps	5.5	5.5	5.5	5.5	5.5	5.48	5.45	5.45	5.44	5.44	5.44
Test 2 Voltage	3.29	3.27	3.25	3.25	3.25	3.24	3.24	3.24	3.2	3.21	3.2
Test 2 Amps	11.44	11.44	11.4	11.4	11.37	11.35	11.3	11.28	11.2	11.1	11.1
Test 3 Voltage	3.46	3.37	3.2	3.16	3.15	3.1	2.96	2.9	2.9	2.87	2.87
Test 3 Amps	16.88	14.88	14.86	14.84	14.86	14.93	14.92	15.01	14.97	14.99	14.96

Table 15 gives the detailed results of the battery characteristics when subject to loads. These results were obtained after repeated experimental work with the resistive load ranging between 100W and 300W for the first thirty minutes of the test procedure.

Test 1 = 100W, Test 2 = 200W, Test 3 = 300W

4.7 Environmental impact of strategic BEV charging

From a study by (Van Vliet et al. 2011) uncoordinated charging would increase national grid peak load by 7% at a 30% penetration rate of BEV which may exceed the capacity of existing electricity distribution infrastructure. At 30% penetration of EV, off-peak charging would result in a 20% higher, more stable base load and no additional peak load at the national level and up to 7% higher peak load at the household level. Therefore, if off-peak charging is successfully introduced, electric driving need not require additional generation capacity, even in case of 100% switch to electric vehicles.

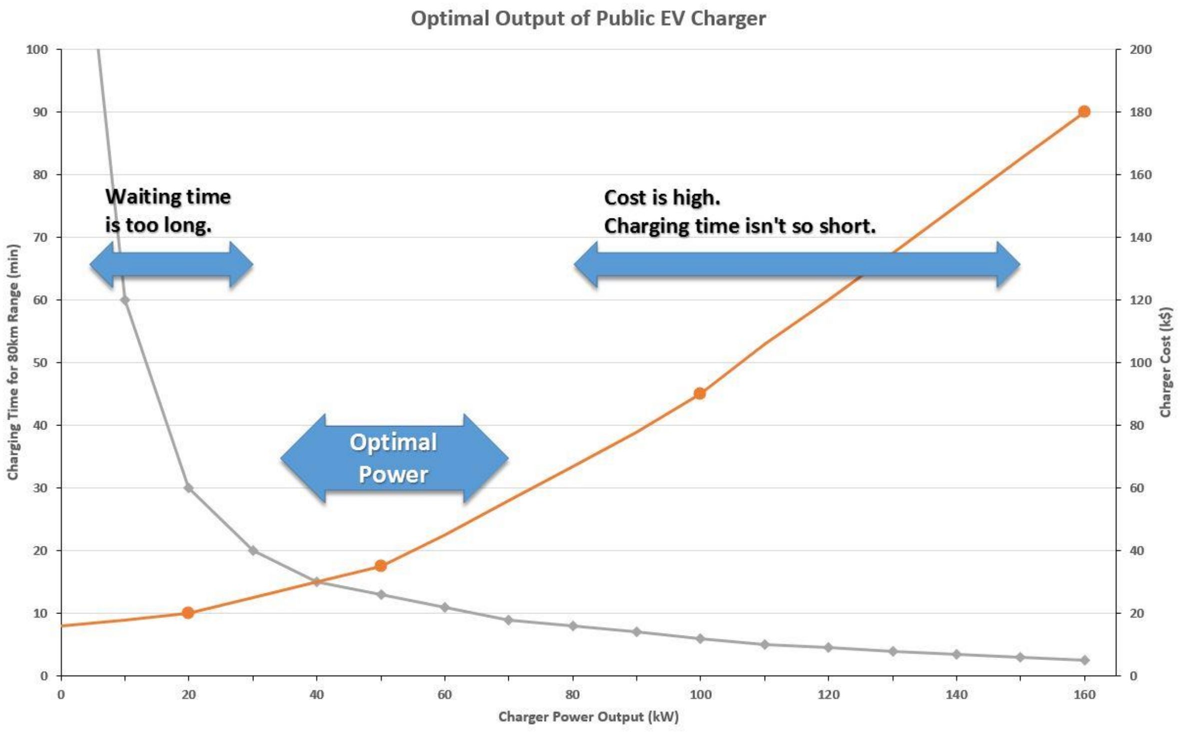


Figure 64 Cost versus charge time

For roadside BEV charging the accepted solution to the recharge is the use of publically accessible rapid chargers due to their short user waiting time. Figure 64 indicates that less than 20kW chargers create a long waiting time whereas 100kW chargers are high cost and this will be a limitation to infrastructure.

The accepted range for both low cost and short waiting time is a charger with a 50-80kW capability which will recharge in 20-30minutes.

4.8 Conclusion

The challenge of seamlessly integrating the presence of electric vehicles for an enhanced and reliable grid operation is paramount for power system, transport, and environmental engineers.

By considering the influence power demand can have and load control strategies, this chapter has expanded the awareness and has presented analysis on switching of BEV battery technology from the lithium-ion to lithium-ferrite-phosphate type. Variable load battery tester has been reported, which have been used for analysis of these battery technologies under variable load duty cycle. Also, results of the traction load and regenerative breaking have been reported using variable load duty cycle equipment operated within the test facility of the Edinburgh city college. A very interesting experimental charging point designed by this PhD thesis author is presented and discussed. A battery usage report with different electric tariffs have been presented. Yearly breakdown of travels and energy consumptions among different campuses of the Edinburgh College have been reported and these results can be used for doing transport planning among corporate users and the demand of electricity due to BEV charging on the network of that areas. Results and the reported testing facility can be extended further for doing more innovative applied research (e.g. on analysis of charging/discharging cycles, combining different types of battery technologies with different types of traction motors for acceleration/deceleration etc.).

The strategic framework for the optimal integration of EVs into the operation of distribution networks by analysis of the demand on the charger infrastructure was considered. As a result, and within an UK context, the economic issues spot energy and carbon markets will bring to future energy systems being installed to support other business's needs.

Tests have identified that BEVs are restricted by range requirements. They do play a significant role in sustainable transportation and offer a part GHG solution. Even when range requirements are dramatically reduced, when compared to a conventional vehicle the BEV range is adequate for only the average trip rather than all trips and being a direct replacement for the conventional vehicle.

The BEV when utilised in this application have identified significant cost savings in both monetary and energy consumption.

The electric vehicle should not be considered to be a direct replacement for all vehicles due to their limitations, but even with current battery technology they will suffice the range expected by a vehicle when subject to this business application.

Chapter 5 Mobility and software systems

5.0 Overview

This chapter will examine vehicle performance in particular; the effects of motor on/off controls and the effects of the drive distance for evaluation, because they have significant impact on BEV's environmental viability as a contender to the conventional vehicle.

One of the main objectives of the study is to analyse the impact of the market share increase of different vehicle technologies in terms of energy consumption and CO_2 emissions in a main route into Edinburgh from East Lothian. An extensive characterisation of how road vehicle technologies energy consumption and CO_2 emissions compare in a full life cycle perspective for comparison.

The principle theory is conservation of energy and factors such as rolling resistance, aerodynamic drag, and mechanical efficiency of power transmission for the general driving performance of the BEV on this route which will be conducted by a professional driver. Regenerative charging of the BEV will be monitored with respect to the change of operating conditions of a model vehicle such as inclined angle of road and vehicle speed, the chosen route will encompass all of this as well as rural and urban driving.

The electric vehicle has to be taken as a serious alternative to the conventional engine vehicle and there are many questions surrounding their practical use. From purchase costs, running costs to their practicality and what changes have to occur to the users' lifestyle, journey route and time.

Monitoring their use to determine if they are a practical alternative has to be investigated for the effective implementation and this will be within the scope of the research. The **Ve**hicle **D**ynamics and **E**nergy **C**onsumption (VEDEC) simulation tool will be used to model energy use and will be compared with the actual energy used for the multi-mode energy consumption across test routes selected as part of this mobility trial.

5.1 Introduction

In this chapter a critical review of the present energy demand of UK and its over dependence on imported fuel oil to support the transport sector is carried out. By way of having a closer examination of the energy needs for the corporate business vehicle fleet, experimental work was undertaken for Scotland - Edinburgh. The latter city represents a typical municipality in UK with the possibility of replication of the present work to other similar conurbations. The work entailed monitoring of the driving cycle.

The VEDEC software program that has been expressly developed for this type of exercise was then used to ascertain the savings in fossil fuel that may be achieved via use of electric vehicles. It has been presently argued that the use of electricity-propelled, two-and four-wheelers offers a sustainable solution to the vehicle previously used for these routes.

5.2 Three 'E's

A Three 'E' analysis is a holistic analysis that investigates Energy, Economic and Environmental impacts of a project.

Specific energy consumption is an important factor when determining the assessment of BEV emissions. Energy efficiency will influence the energy consumption of the vehicle. Energy efficiency has an impact on the driving range or the battery capacity, increasing the battery capacity will increase the weight and in turn the cost. GHG emissions from electric driving depend most on the fuel type (coal or natural gas) used in the generation of electricity for charging.

The next generation electric vehicles will need to further enhance their energy efficiency to keep up with this change.

5.3 Sustainable transport solution

With the UK's population continually growing, intelligent transport systems are needed to reduce congestion and develop a sustainable infrastructure for future generations. In line with this commitment the government will invest over £70 billion in UK transport networks between 2015 and 2020 and will enable local communities to invest in smart technology through the £170 million local sustainable transport fund (Pojani & Stead 2015).

Edinburgh College has prepared a Travel Plan in line with the business requirements which encompasses all campuses under the College's control; this includes the main campuses located at Granton, Milton Road, Sighthill and Midlothian. The development of this Travel Plan has been informed by the recent Transport Strategy supporting the recent Edinburgh College merger and also current information provided by the College.

Overall, the College caters for approximately 22,000 students and 1,500 staff. The locations of the four main campuses are illustrated in Figure 65 (Edin College 2016).

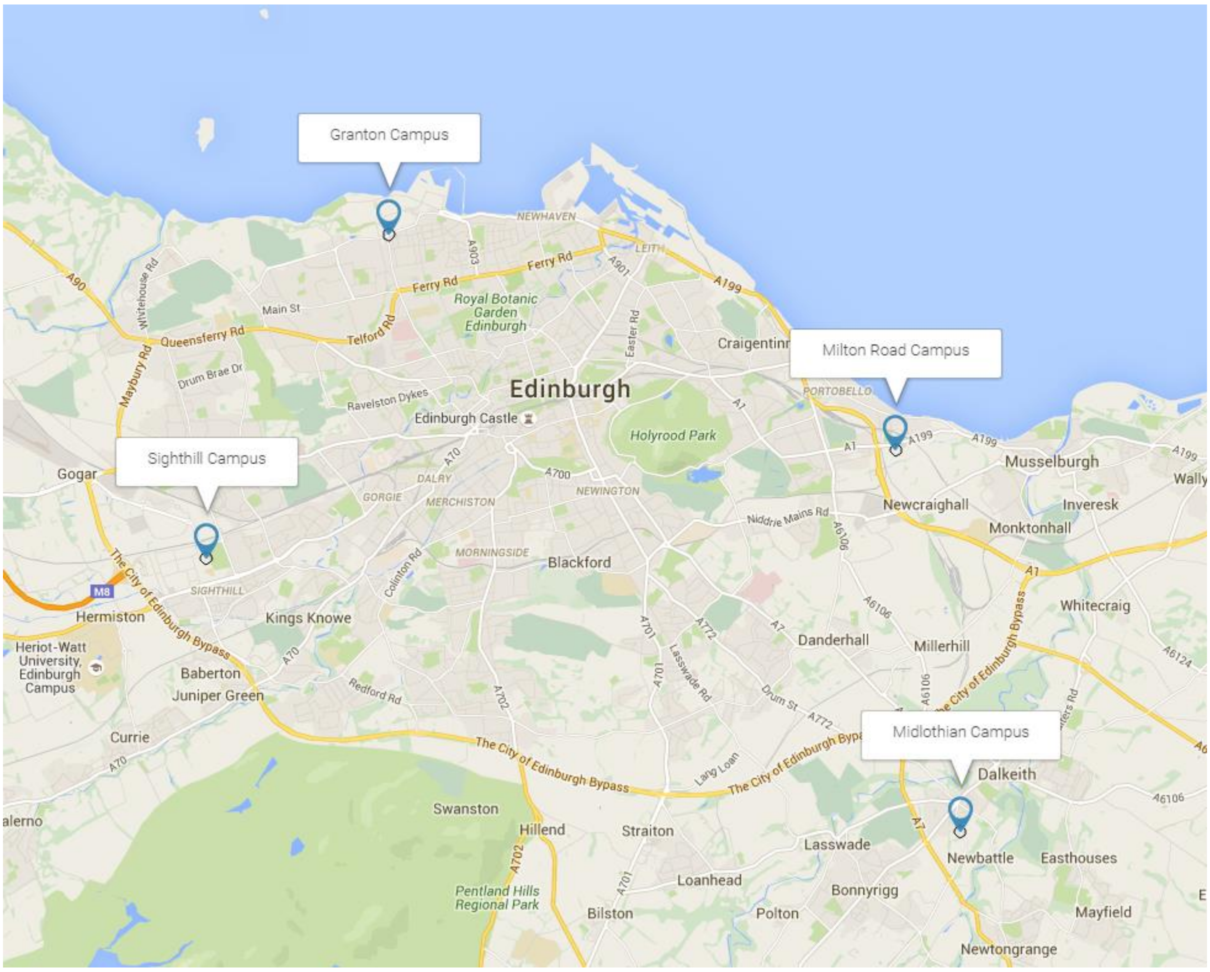


Figure 65 Location of the College campuses

The aim of the travel is to reduce the environmental impact of car-based travel resulting from the College's operations by encouraging the use of more sustainable forms of transport.

The objectives of the Travel Plan are to:

- To reduce the number of staff and students travelling by car to the College (particularly single occupancy vehicle (SOV) trips)
- To encourage staff, students and visitors to walk and cycle to and from the College
- Inter-campus travel to be reduced to a minimum unless business critical
- Full utilisation of the battery electric vehicles as main mode of transport when commuting across College sites.
- To maximise and promote the use of public transport for all trips to and from the College
- To improve the health and fitness of students and staff at the College.

5.3.1 A comparative journey – lessons and errors

This comparative journey is illustrated in figure 66 and was the first in an attempt to drive a College electric vehicle from Edinburgh to Aberdeen utilising the existing infrastructure available in October 2013 and being reliant on recharge posts being active and physically available. This is a route that is currently undertaken by Edinburgh College ICE vehicles but to further explore BEV capabilities this extended range route was considered as a required journey.

Within this present study the route was evaluated again eight months later in May 2014 and comparisons were drawn.

This journey took the BEV out with the single charge range and introduced the interaction with the available infrastructure. The route used was the primary thoroughfare into the north east of Scotland and comparing the results with an identical journey 12 months later. This application of the BEV will remove the local mobility confidence from the user and the vehicle will be completely reliant on road side charging.

This comparative journey may help to make more reliable and realistic statements to what extent BEV's can be used without restrictions such as vehicle range, available energy management, and charge strategies.

This is a practical full vehicle test application with takes in real world changes and the consequences of the movements of other vehicles.

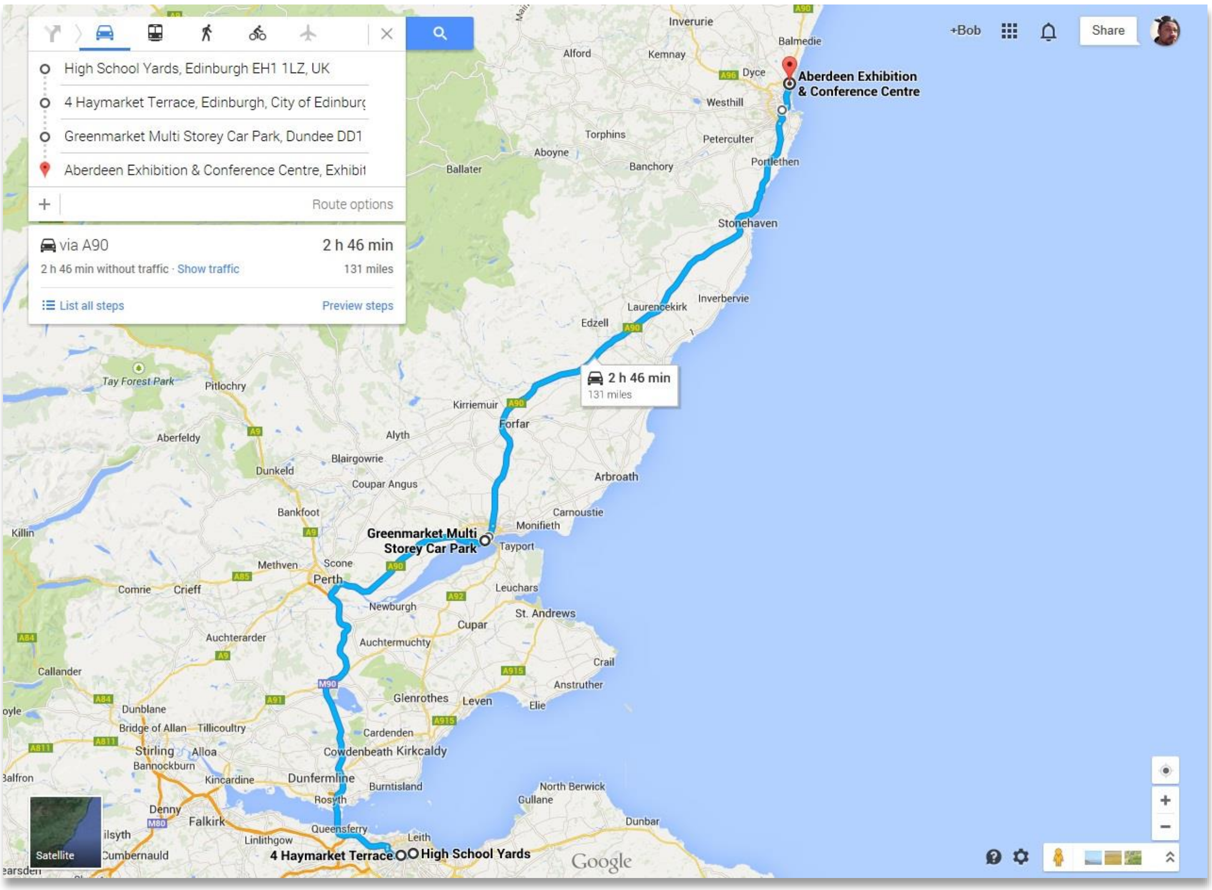


Figure 66 2013 evaluative journey – Edinburgh to Aberdeen

<u>October 2013 data</u>

Vehicle: Mitsubishi i-MiEV (16kWh)
Distance: 131.0 miles
Estimated Fuel Cost: £21.16 (compact vehicle equivalent to Mitsubishi i-MiEV @ £1.34 per litre). Calculated using Google maps

Start range: 94 miles indicated on dashboard.
Single occupant.
Cabin, seat heaters and AC switched off.
CD player/Radio on, volume 18+.
Lights ON
Fans ON (low speed)

On this journey a Type 1 to Type 2 charging cable only was utilised because the Mitsubishi i-MiEV is not supplied with a Type 2 connection as standard, only the 13 amp 3 pin EVSE frequency modulator with the Type 1 end to plug into the car. The first recharge stop was the Type 2 AC charger at Kinross on the A90 but authorisation failed on presentation of the 'eVolt' card. None of the eight cards brought, or the yellow 'Elektrobay' data tag would work. The cards had been supplied by the installers of the Type 2 posts at the college and worked fine with those, so it was assumed that the posts in Kinross simply were not active or commissioned this was a failure to correctly communicate the infrastructure requirements. This Kinross stop was initially set as the first stop on the trip as there is a 'CHAdeMO' 50kw DC unit here which should have charged the car to 80% battery capacity in 20 to 30 minutes allowing enough range to achieve Dundee where the next Rapid Charger was located. Card authorisation failed again though, the post could not be activated because the RFID cards were not recognised. At this point there was not enough charge in the car to return to Edinburgh so an alternate charge point was investigated. Again, a fault with the post was suspected as communication with the infrastructure was not possible.

After checking multiple charge-point applications a Type 2 'Pod Point' was identified and available at the 24hr ASDA supermarket. On arrival, the posts were active but no one inside the store had a card to unlock them. The 'eVolt' cards would not authorise the post. This meant that the car could not be charged so another alternative had to be found.

On arrival at Greenmarket car park Dundee the charger bay was free and although none of the RFID tags would work, the staff there had a card which they used to activate the 'CHAdeMO' 50kw DC post. Once a charge was completed the car was able to continue the trip.

Charge time was around 25 minutes to 80% but reliant on support from the operatives at Greenmarket car park.

Next charge stop was meant to be Laurencekirk, but given the issues with RFID tags and the experiences learned during this trip it may not be possible to charge there – although Charge Your Car (CYC) had advised over the phone that they were able to remotely activate the post.

The next and final stop was Angus Council to use their 'Elektobay' post. This would allow enough of a charge to reach Aberdeen should the Laurencekirk CHAdeMO not be available. The yellow 'Elektrobay' data tag worked first time.

Just off the A90, this Rapid Charger between Aberdeen and Dundee is strategically placed as a stop for BEV users. Unfortunately, CYC were not able to activate the post remotely so it was not possible to charge here.

At this point contact was made to a representative of Aberdeen Council for the use of their Rapid Chargers in the city this was arranged and authorised by council staff.

On arrival in Aberdeen it was apparent that this type of transport requires a robust infrastructure and must align itself with one means of charge post authorisation and all of this must be possible without being reliant on 'local' knowledge and staff that might be able to give assistance.

Observations – Charging infrastructure present, but not all posts are active and correct cables plus operational RFID cards are essential for any trip. Forward planning and fall-back options also required for long distance journeys. Average speed was low and the timescale was much longer than would be for Internal Combustion Engine (ICE) cars. Comfort was minimal due to heaters etc. being switched off. However, the cost of travelling was free to the user at this time as the Scottish Government are not charging electric vehicle drivers for the electricity used at present.

<u>May 2014 data</u>

Vehicle: Nissan LEAF Ascenta (24kWh)
Distance: 131.0 miles
Estimated Fuel Cost: £21.16 (compact vehicle equivalent to Mitsubishi i-MiEV @ £1.34 per litre). Calculated using Google maps (Google 2014).

Start range: 93 miles indicated on dashboard.
Two occupants.
Cabin, seat heaters and AC switched off.
CD player/Radio on.
Lights ON
Fans ON (low speed)

<u>Outbound:</u>

(1st section to Greenmarket Car Park, Dundee)

- Distance travelled = 60.8 miles
- Departed ECCI, High School Yards, Edinburgh @ 05:40
- Arrived Greenmarket Car Park, Dundee @ 07:15
- Time on Road = 1hr 35mins
- Stopped time before next section = 35mins

Edinburgh to Dundee was carried out at economical driving speed of less than 60mph. Start range indicated was 93 miles on a 100% charge. There were still 25 miles of range remaining on arrival at Dundee. A rapid charge (CHAdeMO, 50kW DC) to 90% battery capacity took around 35 to 40 minutes. CYC card and charger was activated with no issues. Energy used was 14.38kWh. Parking and charging was free.

(2nd section to Aberdeen Exhibition & Conference Centre)

- Distance travelled = 69.2 miles
- Departed Greenmarket Car Park @ 07:50
- Arrived AECC @ 10:15
- Time on Road = 2 hrs 25 minutes

The 2nd section was carried out at similar speeds, ranging from 45 mph to the speed limit on the A90 of 60 mph. Range available at the start of the trip was 85 miles. Traffic leaving Dundee and entering Aberdeen was quite congested resulting in an increased journey time. A twelve-mile range remained on arrival at the AECC and the car was down to 2 bars indicated (<20% charge). A 'low battery' visual and audio warning was activated. The LEAF was plugged into a 7kW Type 2 'Pod-Point' which took it back to a 100% full charge in around 3 hours 56 minutes. Energy used was 20.20kWh.

<u>Outbound Summary:</u>
2 sections
2 charges
130 miles travelled
Start Time: 05:40
End Time: 10:15
Duration: 4 hours, 35 minutes.
On Road time: 4 hours
Stopped time: 0 hours 35minutes

<u>Return</u>
Two occupants. Heater and AC switched off. Radio ON, Lights OFF and fans ON (low)
Drive mode 'B' + Eco for most of trip.

(1st section to Greenmarket Car Park, Dundee)

- Distance travelled = 70 miles
- Departed AECC, Aberdeen @ 16:11
- Arrived Greenmarket Car Park, Dundee @ 18:26
- Time on Road = 2hrs 15minutes
- Stopped time before next section = 32minutes

Departing Aberdeen for the return journey, 101 miles were indicated as the range available from the 100% charge. On arrival at Dundee the Nissan LEAF displayed a range of 20 miles remaining, with battery charge level of 18%. It was noted that the range available had dropped to 13 miles before the long downhill section of road into Dundee and subsequent effects of regenerative braking. The charge back to 90% capacity took around 32 minutes. The CYC card and charging unit worked well. Energy used was 15.38kWh parking and charging was free.

(2nd section to ECCI, High School Yards, Edinburgh)

- Distance travelled = 60.5 miles
- Departed Greenmarket @ 19:07
- Arrived ECCI @ 20:50
- Time on Road = 1hr 43minutes

The indicated range available at the start of this section was 85 miles with the battery charged to 90% capacity. During this section cruise control was employed for the first time to keep the car at a steady 60mph. It was noted that the vehicle used more energy than it did when the speed/acceleration/regeneration was being managed by the driver. At the end of the trip 16 miles of range remained from a displayed battery charge level of less than 18%.

Return Summary:
2 sections
1 charge
130.5 miles travelled
Start Time: 16:11
End Time: 20:50
Duration: 4 hours, 39 minutes.
On Road time: 3 hours 57minutes
Stopped time: 42minutes

Observations – Compared to the same trip in the Mitsubishi i-MiEV, this was a much more comfortable, quicker, and less troublesome journey. The charging infrastructure was robust, with multiple fall back options along the route if needs be. The impact on range of heating was minimal, though clearly displayed in the car when the climate control system is activated. Cruise control proved useful but tended to use more energy in ascending terrain. The efficiency measures in place such as 'Eco' mode, plus the real time energy information, allowed the driver to focus on the most economical driving style. This allowed improved performance with 'safety margin' range availability if needed.
Total energy used was 49.96kWh, which if charged at a UK average of 12.5p per kWh means the trip would cost £6.25.

5.3.2 Legislation – merits and demerits

Traffic reduction policies, although necessary, can be highly controversial since it is an aspect that affects either directly or indirectly the whole population. Reducing traffic and therefore pollution in congested areas such as city centres is not by itself an optimum solution. According to (National Travel Survey 2015) public transportation journeys take, on an average, three times as long as equivalent car journeys.

This means that either agencies are able to tackle public and private transport policies simultaneously or face the consequent congestion caused by, for example, closing main arteries of the city centres, which will inevitably result in additional levels of pollution. Another aspect of controlling the flow of privately owned cars flowing through the city centre is that it leads to the loss of commerce on the part of local businesses.
The example of the city of Edinburgh is one such case. In the year 2003 the City of Edinburgh Council introduced legislation to restrict parking of cars within city centre as well as in the vicinity of the centre. As a result, a large number of smaller businesses folded up. Subsequently, a referendum was carried out to seek the public's view related to charging of cars that enter the city centre. The latter was overwhelmingly rejected by a factor of 2 to 1. Tables 16 and 17 respectively present the pros and cons of privately-owned automobiles, and two- and four-wheelers. One solution to tackle the problem of congestion and pollution within city centres around the world is to use electricity-powered, two-wheelers or ultra-compact four-wheelers such as those being previously developed at MIT laboratory in the US (Wbcsdmobility 2001). The ultra-compact cars weigh less than 450kg and occupy less than two-third length of a conventional compact car.

Table 16 Why own an automobile?

Advantages	Disadvantages
Freedom of movement	Air pollution, major contributor towards climate change
Personal (driver/passenger) security	Road congestion
Large employment sector	Fossil fuel exhaustion
Personal or work space	Loss of building material
Ability to travel long distances	Space consumption on roads
Increased speed	Society stratification
Enjoining of communities	Accidents

(Muneer et al. 2011)

Table 17 Merits and demerits of the use of electric scooters as opposed to cars.

Merits	Demerits
Significant reduction in congestion	No network of recharging stations
Significant reduction in emissions	High insurance costs
Better flow of traffic	Road safety
Nil road tax	Limited repair facilities

It has been argued (Esteves-Booth et al. 2001) that due to the quantity of information required to determine the different parameters related to traffic emissions, direct measurements become impractical and expensive. Thus models for predicting emissions and energy use represent a cost effective alternative. It has also been argued in the above cited reference that use ought to be made to measure and use driving cycle for a particular area rather than using a standard cycle that will not accurately represent the reality.

A driving cycle of any vibrant city environment is a dynamic entity which is continuously changing and evolving. Knowledge of the driving cycle, which describes the exact patterns of the city in question, is of paramount importance with reference to its understanding and the role it will play in forecasting vehicular emissions and energy use.

5.3.3 Ownership and mobility expectations

Total cost of ownership (TCO) of a vehicle is the sum of the annualised fixed (purchasing) costs of the vehicle, variable costs composed of maintenance, repair and tyres and fuel or electricity costs, for a standard distance driven per year. The purchasing costs of the vehicle consist of the platform, and any applicable combination of ICE, transmission, battery, and electric generator and motors.

(Wu et al. 2015) states that although the TCO of electric vehicles may become close to or even lower than that of conventional vehicles by 2025, our own findings add evidence to past studies showing that the TCO does not reflect how consumers make their purchase decision today and the ownership is based on preference or tailpipe emissions.

5.4 Edinburgh College and staff mobility

Due to the nature of the College transport requirements over 85% of journeys are under 10 miles long due to the travel distance between campuses and the local journeys that the vehicles are mainly used for. Similar figures have been reported by (Weiss et al. 2014) in a previous study. Figure 67 confirms the frequency of travel over 19000 recorded trips for BEV short range mobility.

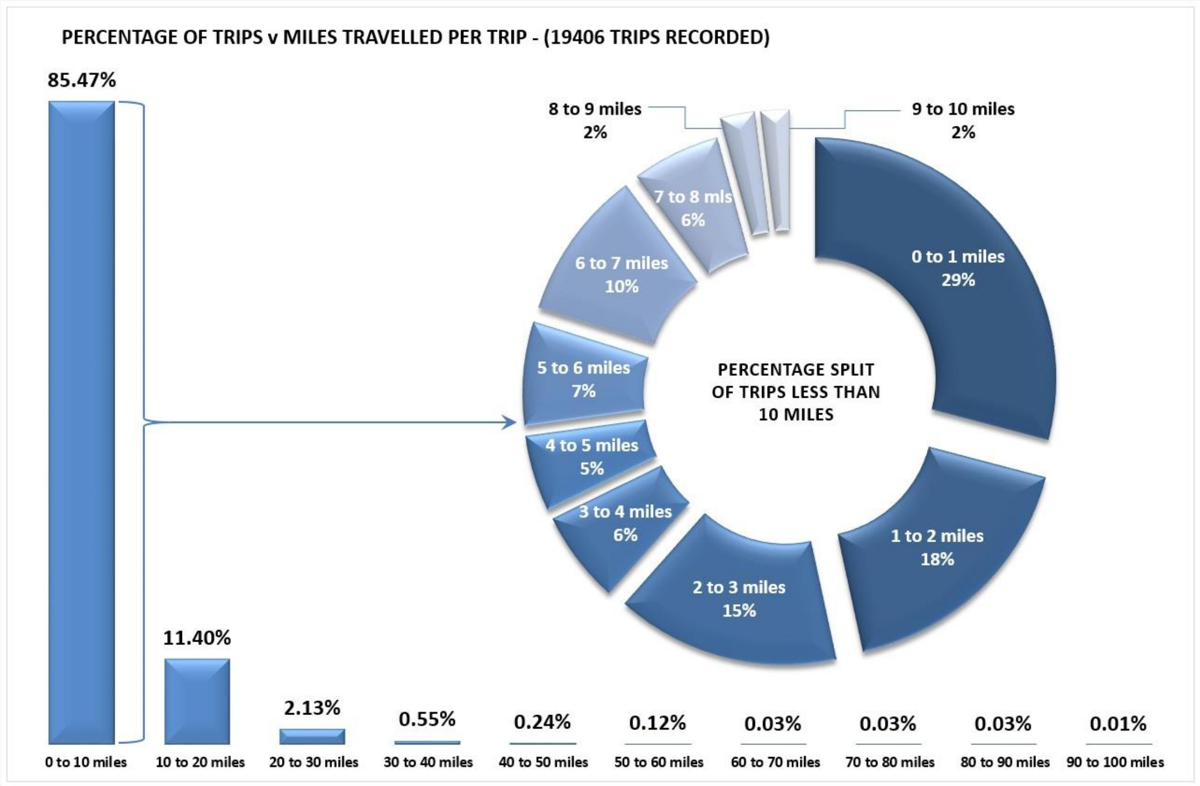


Figure 67 Percentages of travel distance

The field data used in this study was collected as part of a nationwide BEV project in Midlothian, Scotland, UK. Nissan LEAF's, eNV200's and Mitsubishi i-MiEV's were trialled for a six-month period. The participants were selected from different genders and geographical areas in order to achieve a representative sample of the drivers in the area.

The data loggers installed in the vehicles were configured to read information from vehicle sensors available on the vehicle's CAN (Control Area Network) bus and to store these data in the logger's internal memory along with the vehicle's GPS position. GPS data and CAN bus messages were logged every five seconds and every one second respectively when the vehicle ignition was on. Specifically, the vehicle's velocity was logged every second from the CAN bus.

Transient real-world driving cycles are essential for EV powertrain design, battery management systems, battery range estimation and the provision of better information to EV users. The developed driving cycle would aid in the design of EVs that are operating in urban, rural areas and medium sized cities. In addition, the developed driving cycle would allow electricity grid analysis, economic and lifecycle studies to be conducted with a higher degree of confidence for the government and the vehicle buyer.

The route is depiced below in figure 68, travelling by the most direct route and utilising the A7 primary trunk road at all times both on the outward and return journey. The test was conducted both in the summer and winter weather conditions where the ambient external air temperature was between 16°C and 2°C and the vehicle internal temperature was set to 20°C.

The driver was operating the vehicle within the legal limitations of the road and surrounding traffic conditions.

This mobility experiment was conducted utilising live data when the vehicle was driven on a journey and then a return journey was concluded. The elevation and the drive cycle is outlined in figures 69 and 70.

The journey was from Dalkeith, Midlothian to Galashiels in the Scottish Borders region and the vehicle was being driven by a staff member. This is in regard to the method used to record the data as indicated by (Chaari & Ballot 2012) distinguished by (Andre 1996) that stated that:

- The car chasing technique is used to measure the driving conditions presenting a lower risk of influencing the driver’s behaviour.
- The vehicle is being driven by its usual ‘daily’ driver.

Midlothian to Galashiels, South East of Edinburgh city, Scotland UK

It is also necessary to obtain a full working knowledge of the traffic situations and road conditions to accurately determine whether there is a real benefit from the BEV under real world driving conditions. The test cycles will be conducted on a primary route into the City of Edinburgh for realistic urban and rural road conditions. The test cycles will be obtained from quantitative measured data and the tests will represent the actual traffic/vehicle journey at differing times of the day and night (Esteves-Booth et al. 2001).

The primary trunk road A7 - highlighted on map below was used for the 50 mile monitoring experimental trials as the topographical location encompasses mixed driving styles.

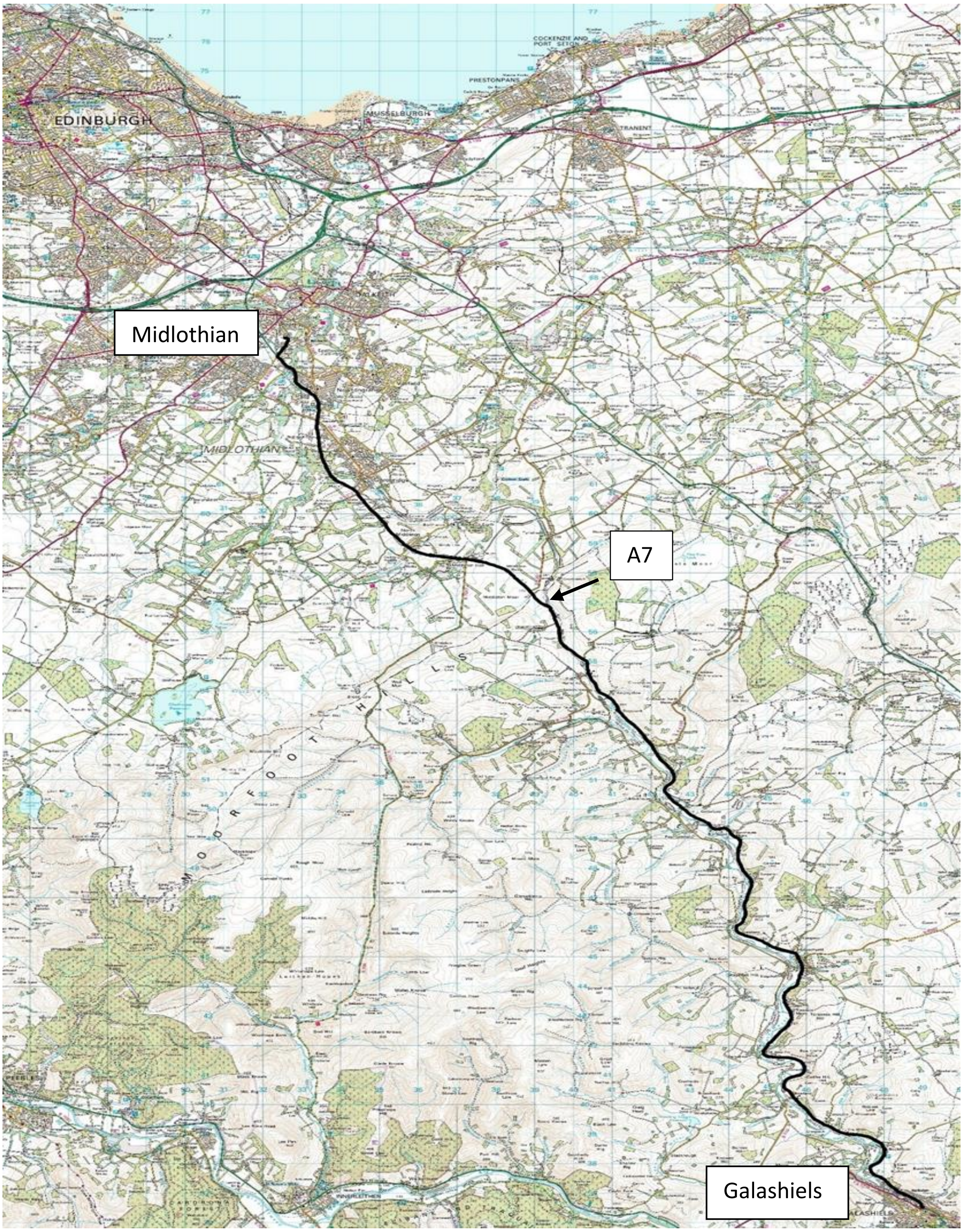


Figure 68 Experimental commute route

The A7 is one of the primary routes from Scotland to England in the UK, and is a main thoroughfare for passenger cars and commercial vehicles accessing the Borders region.

This review utilises a section of road between Dalkeith, Midlothian region and Galashiels in the Borders region.
This controlled comparitive drive and recharge utilised the same road section for three different manufacturers of BEV currently available in the European market.

- Nissan LEAF
- Renault Kangoo ZE
- Nissan eNV200

The objective was to compare the energy usage to cover the same distance over the same road section. The route was driven by all vehicles and data was collected to reflect the energy useage. The Nissan eNV200 van was driven twice, unladen and repeated again laden with 500kg as a payload.

The initial section of the journey has an incline to a maximum elevation in excess of 300m above sea level followed by a decent to the destination, this data has a mirror image for the return journey as the same route was used.

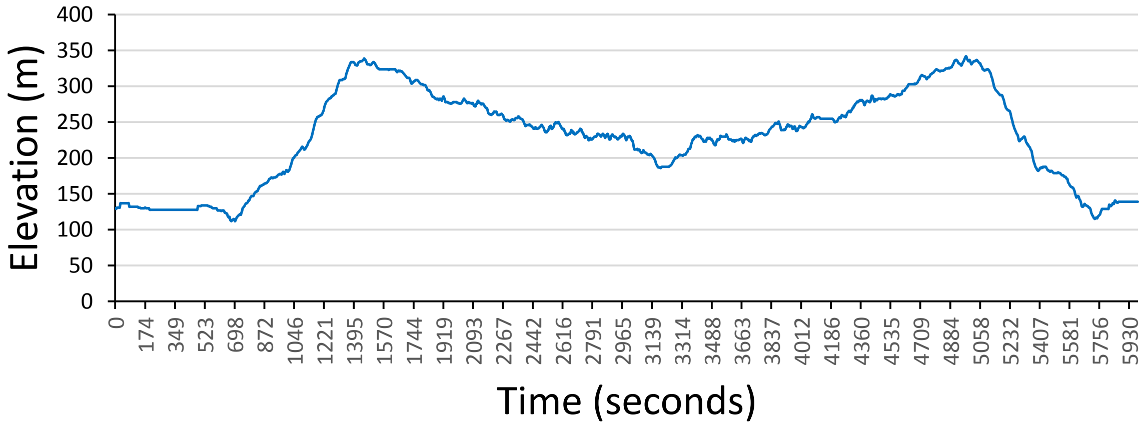


Figure 69 50 mile monitoring cycle – Elevation - Midlothian to Galashiels

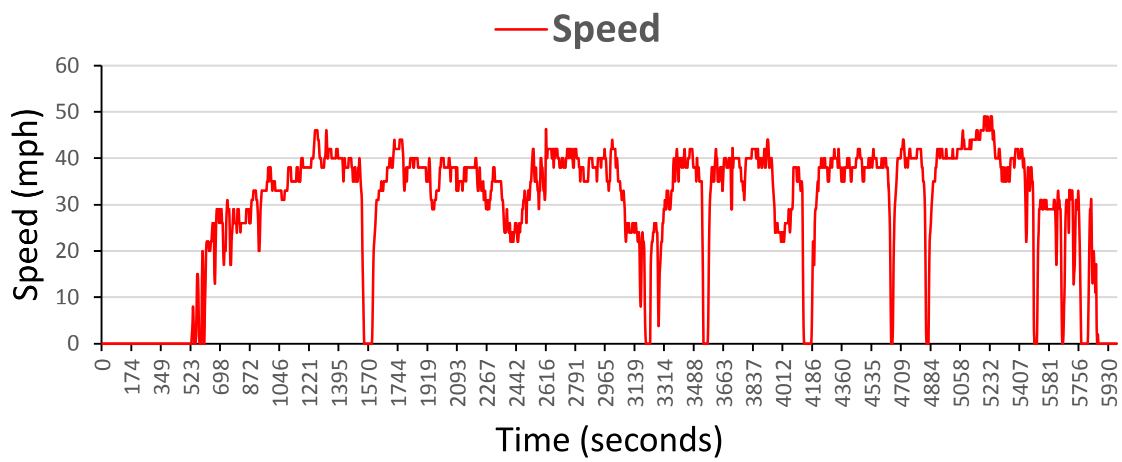


Figure 70 **50 mile monitoring cycle – Speed - Midlothian to Galashiels**

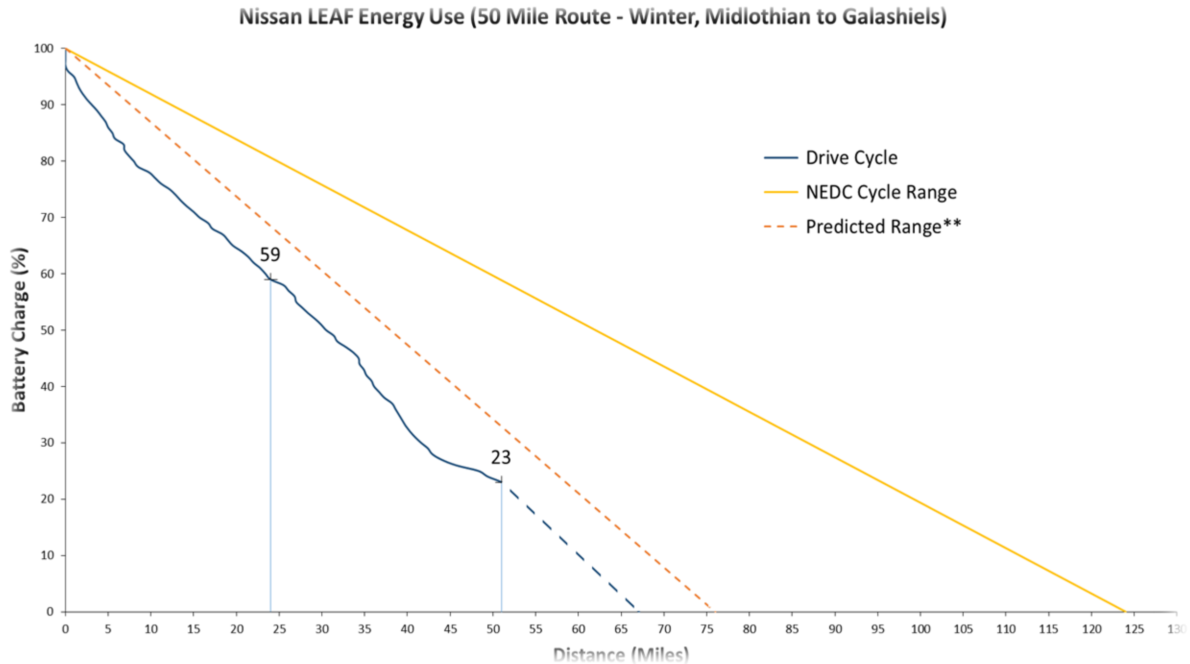


Figure 71 **50 mile experimental journey – energy actual**

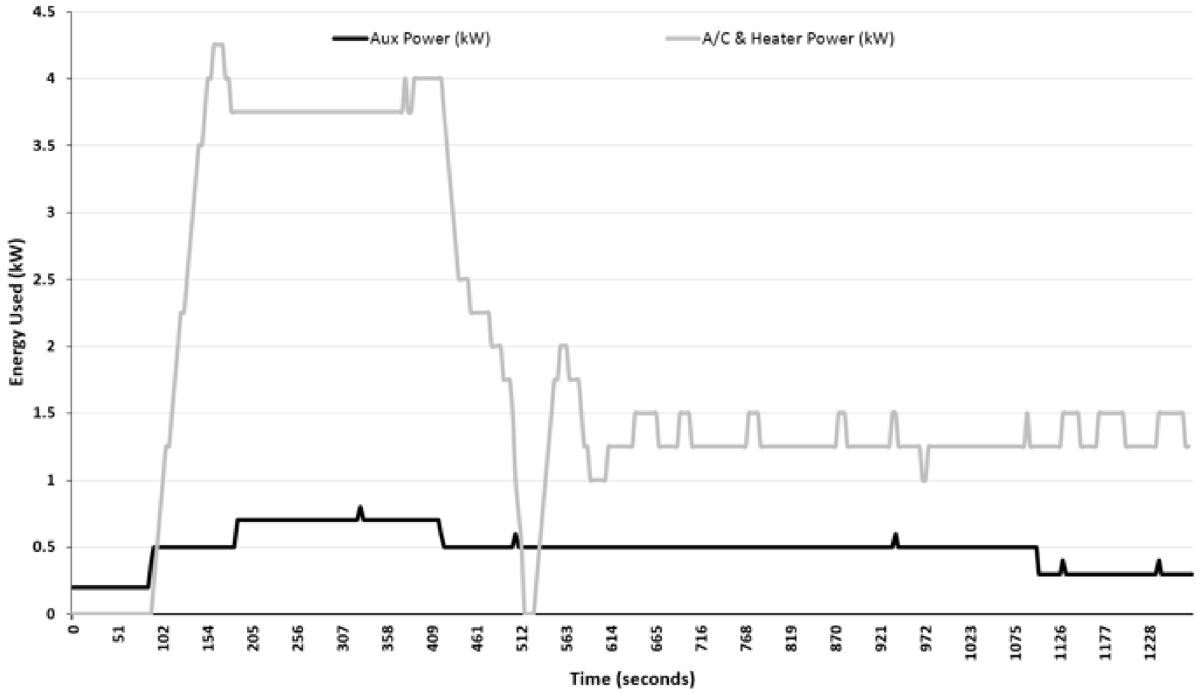


Figure 72 A/C, heater and Aux demand – initial 30 minutes of the journey

The winter test the weather was dry and clear with external air temperature of 2°C the vehicle required defrosting prior to driving. When interrogated at the data port the electronic control unit memory indicated that the battery temperature was 0°C.

The Nissan LEAF like other electric vehicle manufacturers incorporate a high voltage battery heater so as to avoid frost damage to this unit this too will require its own vehicle battery energy as a power source. The evaluation of thermal comfort inside is of importance as this will reduce driver stress and fatigue and has been studied in great detail by (Alahmer et al. 2011). The authors present study understands that whilst maximising range is important so is maintaining a comfortable cabin temperature.

The auxiliary energy values on figure 72 are the heating and air conditioning energy demands required to defrost the Nissan LEAF vehicle, this was in excess of 3.75kW for approximately 6 minutes, and the energy peaked at 4.25kW on initial demand all of which had an adverse effect on the vehicle range when compared with the summer trials.

The lower trace value on figure 72 indicates the consumption of auxiliary energy required to provide energy for the headlights and entertainment systems excluding heater system.

Table 18 50 mile Journey Comparisons

Vehicle Type	Summer						Winter					
	Max Range in miles (NEDC cycle)* Acclaimed mileage given by manufacturer	Estimated Range in miles as indicated while driving the BEV (displayed on the vehicle dash board)	Actual Trip Miles to depletion	Energy Efficiency miles per kWh	% Difference		Max Range in miles (NEDC cycle) Acclaimed mileage given by manufacturer	Estimated Range in miles as indicated while driving the BEV (displayed on the vehicle dash board)	Actual Trip Miles To depletion	Energy Efficiency miles per kWh	% Difference	
					Actual v. Estimated	Actual v NEDC					Actual v. Estimated	Actual v NEDC
Nissan LEAF	124.00	93.0	81.1	3.68	-12.80%	-34.60%	124.00	75.0	76.5	3.66	+2.00%	-38.31%
Renault Kangoo ZE	106.00	70.0	68.3	3.2	-2.43%	-35.57%	106.00	70.0	59.3	3.0	-15.29%	-44.06%
Nissan eNV200 Unladen	105.00	n/a	n/a	n/a	n/a	n/a	105.00	70.0	68.0	3.57	-2.86%	-35.24%
Nissan eNV200 Laden (500kg)	105.00	n/a	n/a	n/a	n/a	n/a	105.00	86.0	68.0	3.72	-17.14%	-35.24%

*Manufacturer's quoted maximum available range on NEDC cycle details:

(Nissan UK 2016; Renault UK 2015; Barlow et al. 2009)

All routes carried out in Drive Mode 'D', and without enabling 'ECO' mode.
Summer trips undertaken without heating, air conditioning, or other auxiliary systems being active.
Winter trips carried out with heating and air conditioning on, set to 20°C, plus all other available auxiliary systems (such as lights and entertainment system) switched on to replicate the actual drive of a typical user during their commute.
Table 18 shows the NEDC, anticipated and actual distances travelled for the chosen vehicle and all journeys were single occupancy so it is predicted that this will be the 'best' case monitoring analogy, the Nissan eNV200 was under test in both the un-laden and the laden condition.
From the 50 mile journey comparisons as shown in table 18 it was found that there was a significant difference between the manufacturers given distance data and the distance actually achievable. The actual distance travelled was less than the dashboard displayed value which when combined gave the user concerns with the achievable range and the possibility of failing to reach the destination. Furthermore, due to the reduced temperature the achievable distance was reduced further when operated in the winter months and gave rise to potential worry should there be the need to detour or other unforeseen circumstances.
The most demanding situation was when the vehicle was utilised in winter and was in the laden condition, in this situation the vehicle had the greatest percentage difference between actual and estimated range.
This journey was successful through the experimental period and this information was shared with the vehicle drivers so that all users had the knowledge that under all conditions the journey was achievable but added range restrictions were introduced with the reduction in temperature and when laden.

5.5 Emotions and determinants of the BEV user

Table 18 does reflect a decreased range capability in winter and also it was found that winter conditions seem to result in an unjustified decrease in use and a substantial share of battery capacity is redundant. This mobility research found that this was not due to the technical constraints of the vehicles but concerns of the drivers using the EVs in those conditions. A study by (Morrissey et al. 2016) showed that the charging behaviours of EV users vary depending on the location of the charging infrastructure and the known reliance on them, this behaviour will require to be conditioned to maximise the efforts of the local authorities.

The Theory of Planned Behaviour (TPB) is extended with emotional reactions towards the electric vehicle and vehicle driving in general. Emotions and the attitude towards the electric vehicle are the strongest determinants of usage intention. Reflective emotions towards vehicle driving and perceived behavioural control factors also play a significant role. Differences in the relative importance of the determinants of usage intention based on environmental concern, behaviour and social values are also considered within this decision. In general, people who are more inclined to use an electric vehicle are less driven by emotions towards the electric vehicle and more by reflective emotions towards vehicle driving, and take more perceived behavioural concerns into account.

(Smith 2008) focuses on the factors affecting the usage intention of electric vehicles, a newly developed product that can lead to a fundamental change in sustainable mobility behaviour. What will make or break the successful introduction of electric mobility in the real world is consumer acceptance (Verhoef et al. 2008).

Therefore, insights into the motivations and barriers of this acceptance, especially by early adopter market segments, are important for a successful introduction of the electric vehicle. Additionally, for the electric vehicle adoption, *the place where one lives* may be important. Living in an urban area can be an opportunity for electric vehicle driving, as driving in the city often implies short trips, which reduces the problem of the range and anxiety of an electric car. But on the other hand, users may have restricted charging facilities at home due to location and infrastructure.

5.5.1 User predictions

If the daily driving requirement distance is less than 60miles in most applications this will be within the capacity of a BEV, however drivers become ‘uncomfortable’ if the remaining driving range becomes less than 30miles. Public accessible rapid chargers will relieve the drivers’ range anxiety even if the driver can rely on it without having to use it.

This was found in a case study by the Tokyo Electric Power Company when they introduced a trial EV with a capacity of 80km in 2007. The vehicle’s daily driving distance is in the region of 40km allowing for the EV to easily cover the local area before recharge was required.

Although the driver had been informed that the vehicles battery capacity was more than sufficient to cover 80km, due to worries that he would run out of power, the driver was hesitant to take advantage of this information (CHAdeMO 2007).

To relieve this anxiety, the company installed a quick charger, car usage dramatically increased with the monthly driving distance exceeding 1400km, which was more distance than normally covered by conventional vehicles in the same area. Of notable mention is that the driver hardly used the quick charger. If so, why did the driving distance suddenly increase to the extent that it did? It was all psychological. In other words, the driver, knowing that he could charge up the car's battery at any time gave him peace of mind resulting in longer (and probably more relaxed) drives.

Hence, the author discovered that quick chargers contribute to both the charging efficiency and increasing driving distances. However, even if the chargers are actually not used, the nearby installation of quick chargers provides drivers with a feeling of comfort which induces users to maximize EV usage.

It is imperative that charging systems in the early stages minimise the total cost in the required infrastructure and as a charging system develops then it is a natural progression to fit quick chargers to replace the normal AC outlets.

The illustration previously given (figure 65) indicates that the home or office, using low power is most suitable where the public require the fast high power version as time is the most important factor within this range of user. Anegawa states that these do compliment themselves in an infrastructure that allows for maximum efficiency (Anegawa 2010b).

Not all electric cars are the same and there is an '*accepted*' range of around 60-90 miles. Up to this range battery packs albeit costly are compact and manageable in size and weight. Vehicles with this range are already produced today at '*affordable'* prices and do not need a dramatic technology break through. Nevertheless, in the public and popular media there is a sense that such vehicles are not an adequate replacement for traditional internal combustion engine (ICE) powered car's long range, fast refuelling and high performance.

Such a view ignores the potential of small BEV's to deliver adequately and economically on the actual mobility requirements of the majority of the population.

This economic and sustainable transport however does come with the expectation of route planning and the user must partially focus on an accurate charging strategy that will suit the individuals' needs. This approach must be acceptable to each user and should not become an onerous task.

5.6 Modelling and simulation

The **VE**hicle **D**ynamics and **E**nergy **C**onsumption (VEDEC) simulation software has been developed which is capable of calculating power and energy requirements for any vehicle during driving. The software also computes energy savings that are achievable from regenerative braking system when compared directly with the energy requirements of the same vehicle without the system. Simulations take detailed account of energy consumed during level cruise, acceleration and gradient-climbing modes. For the purpose of auditing the latter driving mode, topography data may be keyed-in using topography maps or directly logged using an onboard altimeter. The energy analysis work is largely based on the work of (Rubin & Davidson 2001).

5.6.1 Experimental and simulation results

For the simulation study motor efficiency was accounted for as a prerequisite value. The current market models utilise induction motors and their efficiency can be as high as 96% at full load, though 94% is more common. Efficiency for a lightly load or no-loaded induction motor is poor because most of the current is involved with maintaining magnetising flux. As the torque load is increased, more current is consumed in generating torque, while current associated with magnetising remains fixed.

For the test procedures the software was set at 95% for motor efficiency and 60% for regeneration efficiency.

The principle theory is conservation of energy and several analytical and experimental data such as rolling resistance, aerodynamic drag, and mechanical efficiency of power transmission for the general driving performance of the BEV on this route which will be conducted by the daily driver.

Regenerative charging of the BEV will be monitored with respect to the change of operating conditions of a model vehicle such as inclined angle of road and vehicle speed, the chosen route will encompass all of this as well as rural and urban driving.

The test BEV was driven on four routes that involved different driving styles. The vehicle was driven from a known charge point and on each departure the high voltage battery energy level was at 100% state of charge. The vehicle was driven to its destination point and the energy reduction was recorded and the vehicle was put on charge. Distance, time, time on charge and when plugged-in to the charge point the energy was recorded along with the time taken to recharge the vehicles battery pack.

This was conducted for the following data monitoring routes:

- Urban
- Extra-urban
- Rural

The results were compared with the simulation software and conclusions were drawn from the accuracy of the software and which route gave a higher degree of accuracy than the others in this trial.

5.6.2 Friction coefficient

The value of the rolling friction coefficient between the tyre and the road did have a significant impact on the measured simulation results. Variations of this coefficient were altered to determine the simulation changes and the effect that it had on energy modelling. Tyre and vehicle manufacturers will be required to ensure that their BEV tyre will comply with an ultra-low rolling friction factor coupled with significant grip (traction) for vehicle and occupant safety under all road conditions.

Equation 5 was used to determine the friction coefficient for the simulation experimental work.

Equation 5 Friction coefficient

Friction coefficient equation stated as:

$$\mu = \left[\frac{E}{\Delta d} - \frac{1}{4} CdA\rho\left(V_f^2 + V_i^2\right)\right] \cdot \frac{1}{mg}$$

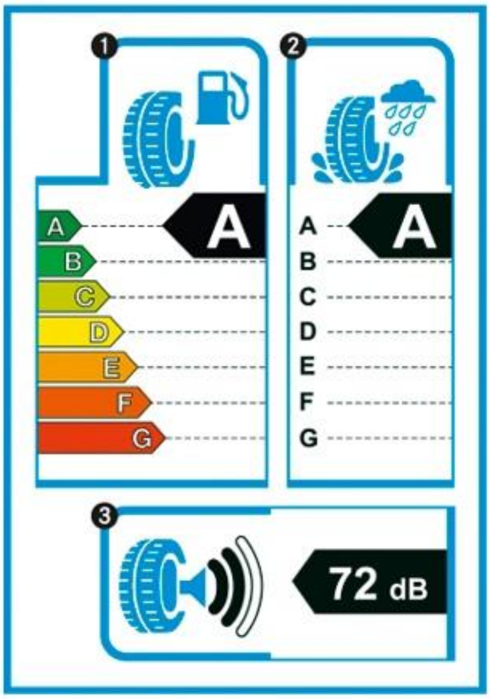
$$\mu = \left[\frac{720000}{1000} - \frac{1}{4} \cdot 0.272 \cdot 2.754 \cdot 1.2(22.35^2 + 22.35^2)\right] \cdot \frac{1}{1875 \cdot 9.81} = 0.0269$$

(Muneer et al. 2008)

Term nomenclature:

Cd	coefficient of drag
A	frontal area
ρ	air density
m	mass
g	gravity
V_f	velocity final
V_i	velocity initial
E	energy
Δd	distance

Tyre rolling friction will influence the overall experimental results as a high coefficient friction tyre will require greater energy to rotate and therefore give a reduction in overall distance travelled due to the increased effort.
The rolling friction factors used in the experiments were between 0.025 and 0.03 dependant on tyre pressure and road surface material. Through calculation as in equation 5 the value for this vehicle type with occupants was 0.0269.
Due to the BEV's limited range they are sensitive to the effects of high rolling resistance so all manufacturers will specify a tyre with the lowest friction coefficient whilst commanding vehicle safety and low noise.



(Automobile Association 2013)

Figure 73 Tyre performance rating standards

Figure 73 illustrates a typical BEV tyre rating (point 1, 2 and 3).

1. Premium tyre and lowest rolling resistance for greatest economy
2. Safe wet road holding and will allow maximum breaking on a wet surface
3. Tyre rolling noise indication (76db is the set industry standard)

5.7 Scope of usage intention

To measure the driving patterns experienced in the city of Edinburgh, the author carried out a study with the use of data logging equipment into a test vehicle, in this case a Nissan LEAF model. Measurements of elements such as distance travelled, speed, rate of acceleration, rate of deceleration, and difference in altitude to determine incline rates and time for journey were recorded.

These data were then transferred to computer for analysis and development of driving patterns along the main commuter routes into the city centre.

For the kinetic energy recovery system, the most important phase to focus upon is the deceleration phase, as this determines the amount of potential energy that can be extracted. Three routes were identified as experimental test routes and the scope was to determine factors that were unique to that route from known parameters. A route was planned and the BEV driven to the point of destination. The scope of intention is therefore, a representative plot of driving behaviour within a given city or a region and is characterised by speed and acceleration.

There is an increasing need to simulate driving cycles for a particular area of study. Within this research the author utilised a software tool using actual experimental inputs that accurately represent real driving behaviour within that location.

The mobility activity was determined for this particular journey and is illustrated in figures 74 and 77. These findings will have a significant effect on the range capabilities of the vehicle as acceleration periods are energy depleting and short deceleration periods with greater acceleration periods will reduce the possibility of any regenerative energy recovery.

The software was developed using fundamental dynamics equations and written within the VBA environment of Microsoft Excel software. The difference between computed and measured net traction energy ranged between +7.9% and -4.5%. In this respect Figures 76, 79 and 81 may be referred.

5.7.1 Data acquisition – urban

This route utilised one of the primary arteries into the city of Edinburgh from the south and due to the nature of this route there was multiple stop-start situations at junctions and all speeds were determined by the traffic flow.

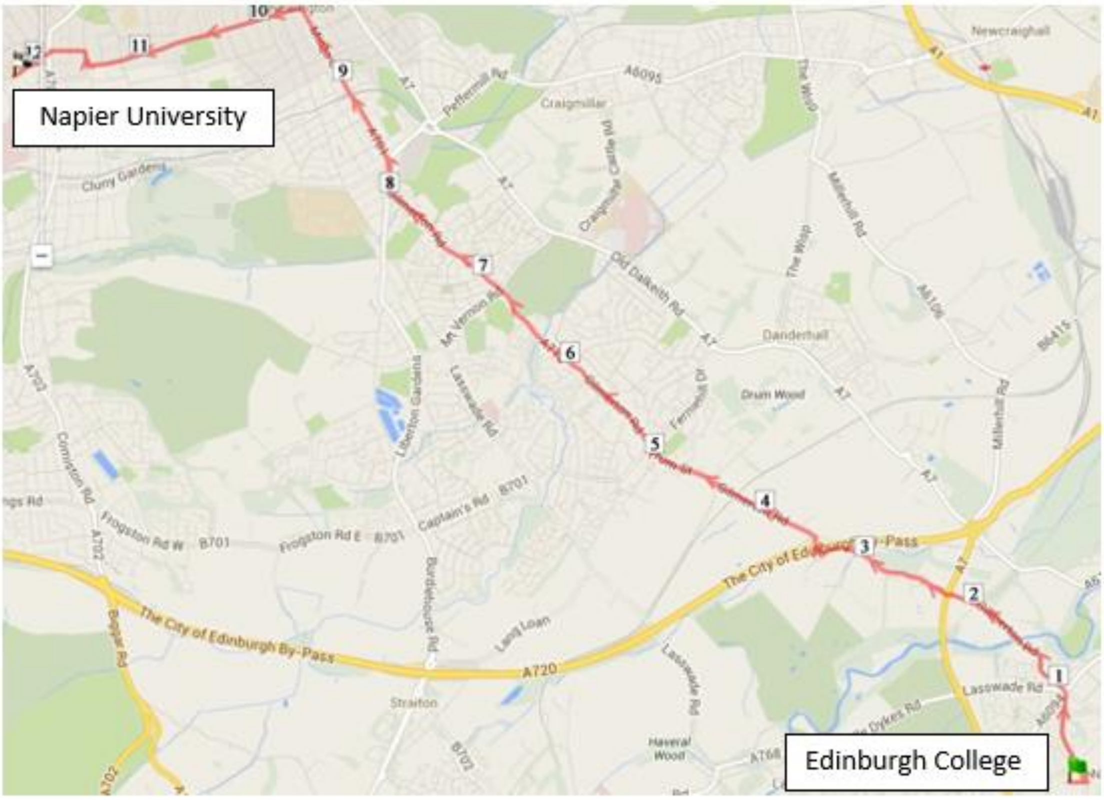


Figure 74 Midlothian to Napier – town route

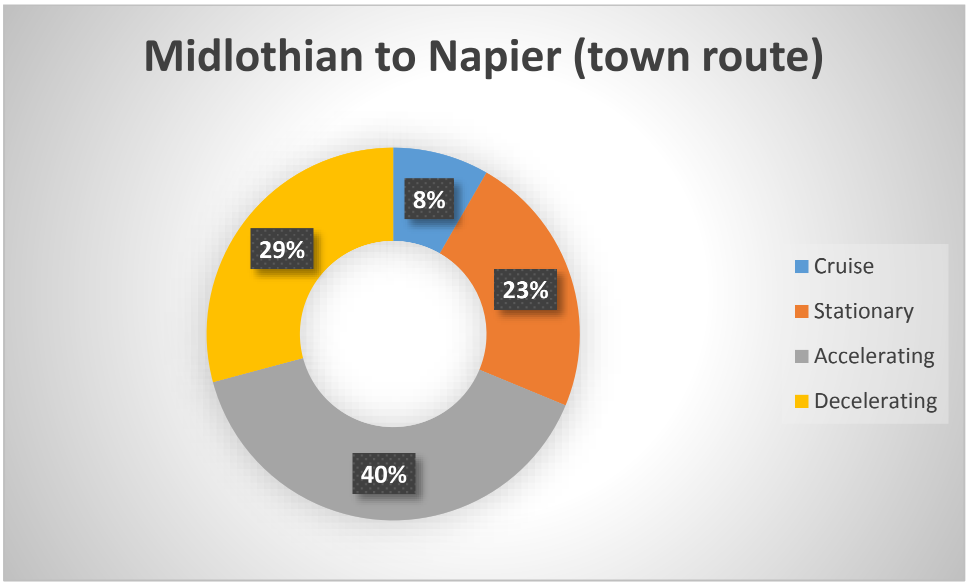


Figure 75 Midlothian to Napier mobility activity

Figure 75 indicates the mobility characteristics when the vehicle was utilised within restricted urban conditions. In initial experiments the author attempted modelling with 30 second intervals and subsequently the speed was recorded also at 30 second intervals but this gave a high degree of inaccuracy as with this type of mobility and the 30 second time frames there can be significant data missing which would render the output inaccurate. For the finalised experimental testing the dash board speed was recorded at one second intervals for the entire journey and this data was the input into the software. The resultant output was accurate as no data was lost when modelled using this reduced time frame. Figure 76 gives an overview of the energy used in simulation and the comparison with the actual value for this 12.1km journey.

	SIMULATION		ACTUAL	
E used	2.672	kWh		kWh
E regen	0.342	kWh		kWh
E tot	2.331	kWh	2.160	kWh
Avge speed	22.75	mph		
Total dist	12161.70	m		
E Accuracy	107.90	diff.	0.171	kwh

actual time (s)	1196
actual dist (m)	11909
actual av. Speed (mph)	22.27
sim time (s)	1196
sim dist (m)	12162
sim av. Speed (mph)	22.75
sim dist accuracy (%)	102.1
sim speed accuracy (%)	102.1

Figure 76 Urban mobility energy, distance & speed - overview

As can be seen in figure 76 the modelled energy usage comparison is within 8% of the actual energy used, and the modelled speed is within 3% of the actual speed as displayed on the vehicle dashboard. It is understood that the energy meter standards for APT street posts are: Active (kWh) = **BS EN 50470-3** (Class B ± 1%). This gives confidence that the simulation software and derived values are the basis of a reliable data set.

100% = 1:1 relationship

The comparison of the simulated speed and distance indicates a 2.1% over estimation between the estimated and the measured data.

5.7.2 Data acquisition – extra urban

This route utilised one of the primary arteries into the city of Edinburgh from the east and due to the partially rural nature of this route evidenced a higher percentage of ‘cruise’ until the experiment reached built-up areas and then all speeds were determined by the traffic flow.

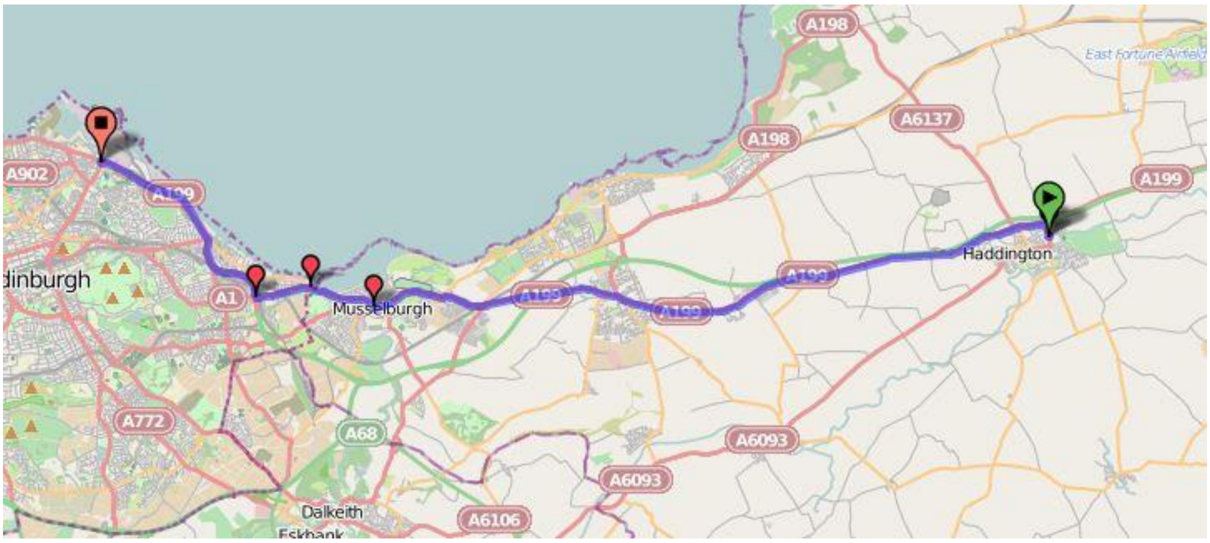


Figure 77 Extra urban route

Figures 78 and 80 indicate the type of mobility activity when utilising the primary and alternative routes into Edinburgh. The results obtained from the one second tests illustrated longer periods of cruise and on both routes chosen gave similar periods of acceleration and deceleration. Both of these routes were chosen because they are standard routes that will be taken by the commuter on a daily basis. The software simulation gave between 95 and 97% accuracy in determining the total energy usage for the journey.

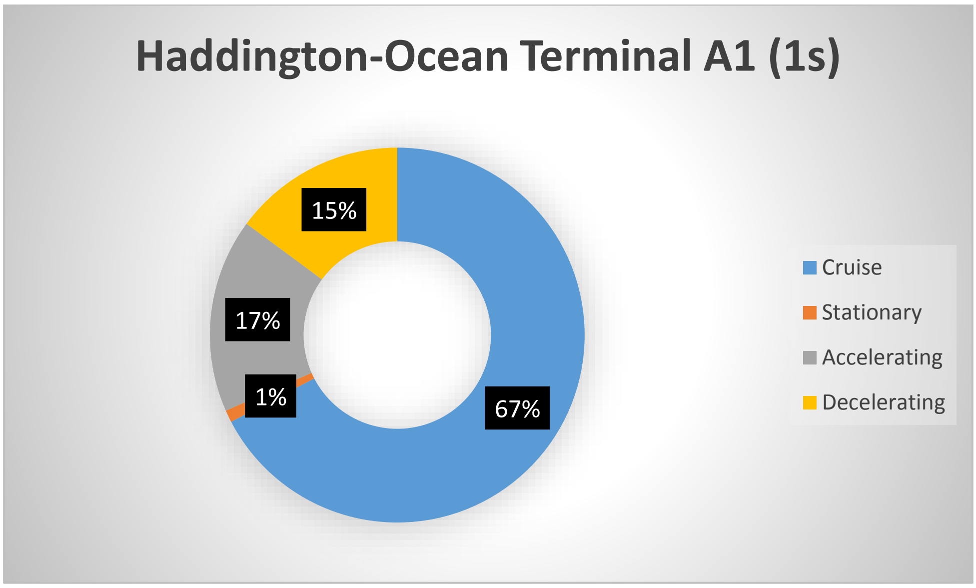


Figure 78 Haddington to Ocean terminal mobility activity – primary route

Due to the dual-carriageway nature of this primary route higher more consistent speeds were achieved and this resulted in a significant 67% cruise section.

The prolonged section of higher speed activity resulted in greater energy use although the journey time was approximately 25% reduced when compared to the alternative route. Modelled energy use for this route was within 5% of the actual energy depletion.

	SIMULATION		ACTUAL	
E used	6.732	kWh		kWh
E regen	0.315	kWh		kWh
E tot	6.416	kWh	6.72	kWh
Avge speed	37.53	mph		
Total dist	29008.39	m		
E Accuracy	95.48	diff.	-0.304	kwh
actual time (s)		1729		
actual dist (m)		30095		
actual av. Speed (mph)		38.94		
sim time (s)		1729		
sim dist (m)		29008		
sim av. Speed (mph)		37.53		
sim dist accuracy (%)		96.4		
sim speed accuracy (%)		96.4		

Figure 79 Extra urban A1 route – overview

The alternative route for this analysis can be seen in figure 78. This route is slightly shorter in distance but due to the urban sections, this test encountered traffic congestion and slower road speeds.

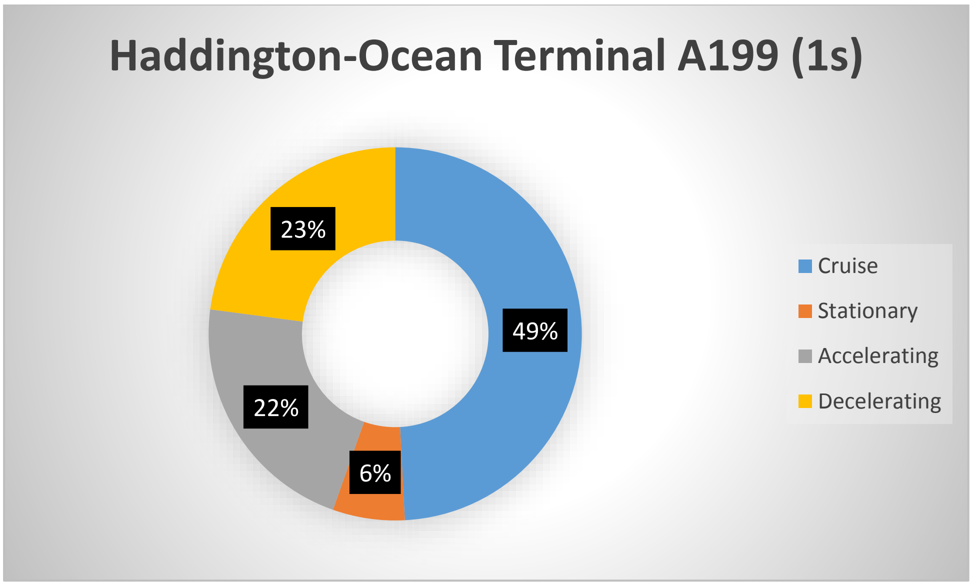


Figure 80 Haddington to Ocean terminal mobility activity – alternative route

	SIMULATION		ACTUAL	
E used	5.638	kWh		kWh
E regen	0.490	kWh		kWh
E tot	5.148	kWh	5.28	kWh
Avge speed	25.40	mph		
Total dist	27040.70	m		
E Accuracy	97.50	diff.	-0.132	kwh

actual time (s)	2381
actual dist (m)	27835.7
actual av. Speed (mph)	26.15
sim time (s)	2381
sim dist (m)	27041
sim av. Speed (mph)	25.40
sim dist accuracy (%)	97.1
sim speed accuracy (%)	97.1

Figure 81 Extra urban A199 route - overview

This alternative route gave the greatest consistency when modelled. The simulated energy was within 3% of the actual energy consumed to conduct this route.

As can be seen all of these routes did bring into question the distance error which the author was aware of. This will be discussed as part of this study in section 5.7.3 to determine the recording tolerance between proprietary software and the vehicle itself.

5.7.3 Comparison between measured and computed distance travelled

Table 19 illustrates the known accuracy of the route distances taken from proprietary sources when compared with the vehicle own dashboard. The dashboard accuracy can also be questioned however the author can state that for UK legislative purposes any speedometer/odometer must be accurate to within -0->+10% of the displayed value (Hansard & Whitty 2001).

This is an EU directive that states that speedometers must 'over' read and they are not allowed to 'under' read the value for example if the cars velocity is actually 30MPH then the speedometer must read 30MPH or over up to 10%. The speedometer will become less accurate as the road tyres wear giving them a smaller rolling circumference.

Under the test conditions both GBmapometer and Google maps gave similar results to each other with less than 2% discrepancy when compared to the vehicle manufacturers' results taken from the dashboard.

The tolerance threshold from Google maps and GBmapometer varies dependant on the map scale in line with the Terrestrial Reference System (TRS) as laid down by Ordnance Survey (Crown Copyright 2016). The software model results were deemed confident as they were within 1% of the two proprietary route mapping tools when tests were taken across six independently devised test routes.

Table 19 Distance travelled comparison and error

Test Number	Vehicle Odometer Reading (converted to m)	GBmapometer		Google maps		Simulation	
		Distance (m)	Conformity (%)	Distance (m)	Conformity (%)	Distance (m)	Conformity (%)
1	27842.0	27440	98.6	27358.8	98.3	28031.74	99.3
2	29766.5	29590	99.4	29611.9	99.5	30872.73	96.4
3	11909.0	12350	96.4	11748.2	98.6	12161.70	97.9
4	12231.0	12340	99.1	11748.2	96.1	12147.66	99.3
5	30095.0	29680	98.6	29611.9	98.4	29008.39	96.4
6	27835.7	27390	98.4	27358.8	98.3	27040.70	97.1
Total			**98.4**		**98.2**		**97.7**

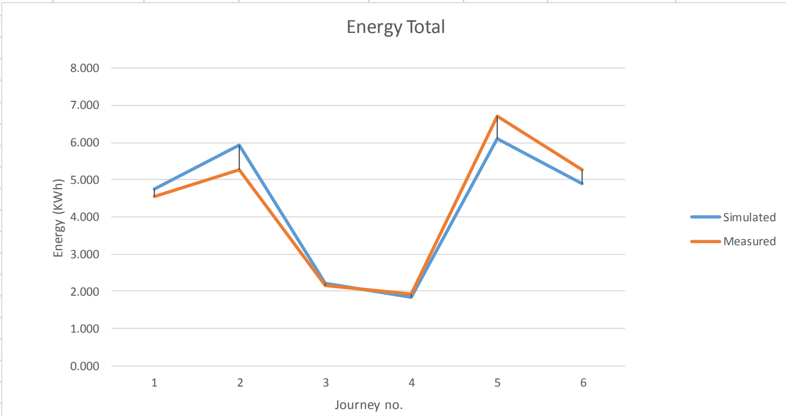
The EXCEL (visual basic for applications) VBA program uses the speed, altitude, and time samples data, as well as the vehicle manufacturer's data and data pertaining to the energy recovery system. From that it determines the amount of energy available during differing combinations of events such as acceleration, cruise, deceleration, and stoppages, as well as the road conditions: ascending, level, or descending.

Table 20 Overview of experimental parameters

Route	Distance (m) Simulated	Distance (m) GPS actual.	Distance (m) Accuracy(%).	Av. Speed (mph) Simulated	Av. Speed (mph) GPS actual.	Av. Speed (mph) Accuracy(%).	E used (Kwh) Simulated	E used (Kwh) Measured Charge.	E used (Kwh) Accuracy(%).	Notes
Hadd-ot a199	28431.7	27842.0	102.1	24.94	24.42	102.1	4.759	4.560	104.4	
Hadd-ot a1	30872.7	29766.5	103.7	42.63	40.23	106.0	5.925	5.280	112.2	
mid-nap town	12161.7	11909.0	102.1	22.75	22.27	102.1	2.209	2.160	102.3	
nap-mid town	11877.7	12231.0	97.1	22.61	23.29	97.1	1.832	1.920	95.4	
Ot-Hadd A1	29008.4	30095.0	96.4	37.53	38.94	96.4	6.110	6.720	90.9	
Ot-Hadd A199	27040.7	27835.7	97.1	25.40	26.15	97.1	4.892	5.280	92.6	
TOTAL			99.8			100.1			99.6	

Quick Adjust	
Rolling Friction Factor	0.026
Motor Efficiency	95%
Regenerative Efficiency	60%

Motor Eff. Regen. Eff RFF



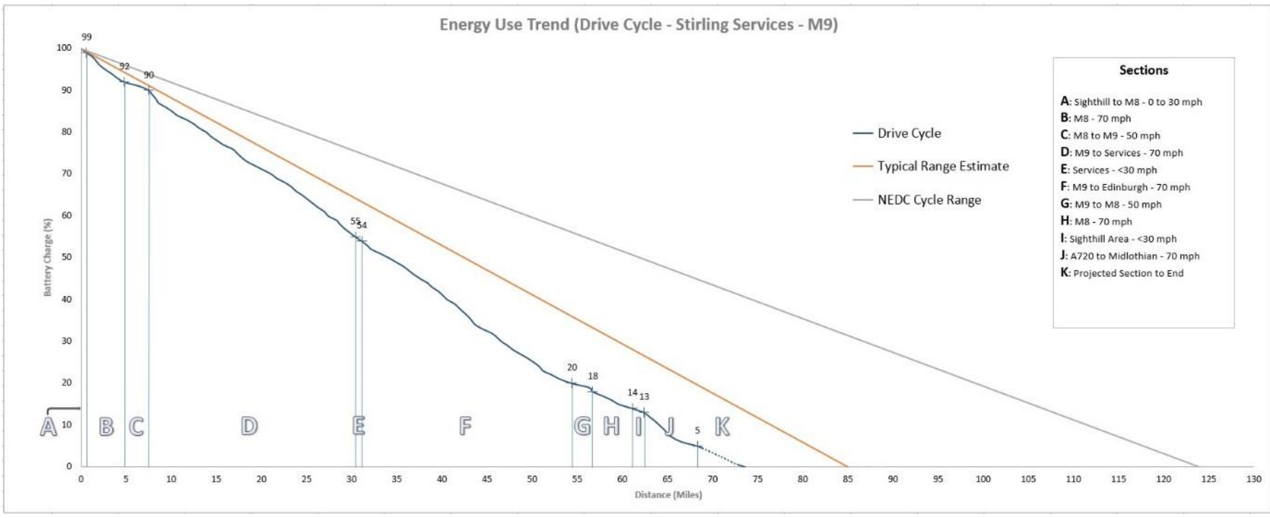


Figure 82 Midlothian to Stirling services – energy discharge

Sighthill/Midlothian campuses to Moto Services, Pirnhall, Stirling, central Scotland: Summer testing done. No heating or auxiliary systems were used. Start point was Sighthill campus and end point Midlothian campus.

Winter testing done on same route, start point was Midlothian campus. End point should have been the Sighthill campus.

The vehicle was driven in gear selector mode D and the driver did not operate the ‘economy’ feature (ECO).

Comparative results were indicated as 73.6 miles completed in summer and 71.6 miles in winter conditions.

5.8 Conclusion

Vehicle mobility of any vibrant city environment is a dynamic entity which is continuously changing and evolving. Knowledge of the mobility, which describes the exact driving patterns of the city in question, is of paramount importance to the formulation of traffic management policies and in forecasting vehicular emissions. Determining the total energy used in this context cannot provide a true representation of actual traffic conditions and, as such, it is not reasonable to expect that emissions calculations that are built on these cycles to yield accurate estimates of emissions as each route under test displayed differing results dependent on the route chosen.

The BEV performance evaluation, the traction motor operational control with distance of travelling and driving cycle patterns have been considered. The focus of this study has been to analyse the impact of the market share of BEVs (with different technologies) in terms of energy consumption in the area Edinburgh region. The Vehicle Dynamics and Energy Consumption simulation tool has been used for modelling energy consumption. For the kinetic energy recovery system, the most important phase to focus upon is the deceleration phase, as this determines the amount of potential energy that can be extracted. For the mobility routes under test the deceleration phase takes up to 29% of the urban journey, which is greater than the extra urban at 15% and 23% dependant on which route was chosen. The steady state cruising is found to be quite low at only 8% of the overall urban journey, primarily because of the charging altitude of roads within the City of Edinburgh. However, the extra urban journey had between 49% and 67% steady state cruising.

With the wide use of automobiles manufactured with built-in kinetic energy recovery systems, significant overall reductions in the production of CO_2 being released in Edinburgh City and throughout the UK could be made through widespread adoption of the BEV.

Chapter 6 Drive Cycle and Economic Performance

6.0 Overview

Not all electric cars are the same and there is an '*accepted*' range of around 60-90 miles. Up to this range battery packs albeit costly are compact and manageable in size and weight. Vehicles with this range are already produced today at '*affordable'* prices and do not need dramatic technology breakthroughs. Nevertheless, in the public and popular media there is a sense that such vehicles are not an adequate replacement for traditional Internal Combustion Engine (ICE) powered car's long range, fast refuelling and high performance. Such a view ignores the potential of small BEV's to deliver adequately and economically on the actual mobility requirements of the majority of the population.

It has been reported 66% of trips were less than 5 miles and 95% of trips were less than 25 miles by (Dept. Transport 2016) and that in the United Kingdom the average car journey is only 8 miles long and the average speed is only 24 mph. This suggests that the capabilities of most current cars are vastly in excess of their actual requirement. This is well proven and is easily explained by evaluation and comparison of the price list of a typical car manufacturer's range.

For each vehicle evaluated (BEV and ICE) there was several control strategies, including electrical dominant and combined cycles, in real world conditions to see if this can fulfil a role to replace the ICE on the given route.

A conventional vehicle will be compared to use as a baseline. The trade-off between fuel consumption and charge cost will be evaluated.

This drive cycle is a comparative indication of range measured under very specific conditions as described within this chapter.

Exactly as with petrol and diesel cars, this study is a comparison of values when the BEV is driven under real conditions and comparing the NEDC (New European Driving Cycle) range with the dashboard indicated range, this range will vary according to speed, driving style, the terrain of the road and the use of air conditioning and heating. If the vehicle is driven in temperate conditions, then the range could more realistically be approximated to a 30% reduced distance for an average suburban trip.

If the vehicle is driven in extreme winter conditions, then the range could more realistically be reduced by 50% for an average suburban trip when compared with the NEDC figures.

This study will address the 'range anxiety' discussion that is often voiced when offering the BEV as an alternative to the conventional fuel vehicle.

6.1 Introduction

The purpose of this drive cycle research work is to give the BEV (Battery Electric Vehicle) user an indication of greater accuracy to the realistic range that the vehicle can travel without encountering a depleted battery and resulting in vehicle electrical system failure. This drive cycle is mainly used by manufacturers for the type approval of light vehicles within the European countries. The current NEDC can best be compared to the combined mpg figure for petrol and diesel cars.

This mobility research work is to give the BEV user an indication of practicality and range that the vehicle can travel under two completely different drive cycles without encountering a depleted battery and resulting in vehicle electrical system failure. This study will also recognise the Carbon Intensity and costs incurred in two areas of the UK government; England and Scotland. This experimental information will go towards the viability of the BEV in any given geographical location.

This work deals with the viability of the BEV when used in the urban commute and an estimation of the vehicle operating cost, fuel consumption, emissions and energy analysis for long range mobility. The operating cost also includes the time cost for the user and the vehicle occupants.

Table 21 gives an indication of the developments of vehicle performance characteristics over a 37 year period with the technological developments in design and performance.

Table 21 Technological vehicle developments

	1977 2.1D Peugeot 504	1984 1.6D Ford Fiesta	2012 Mitsubushi i-MiEV	2014 Nissan LEAF Acenta
Best MPG	33	74	112 equivalent	169 equivalent
CO_2 (g/km)	222.6	127	0	0
Horsepower	59	54	66	109
Torque	82	70	145	254
Weight	1210	835	1070	1493
0-60	23 seconds	19 seconds	11 seconds	9.7 seconds
Top Speed	83	<90	81 (Limited)	93 (Limited)
Price	n/a	£15,000*	£23,499	£18,490

6.2 A comparative range approach using the Real World Drive Cycles and the Battery Electric Vehicle

6.2.1 Legislative range testing

The NEDC test is a standard European measurement of emissions and consumption based on a rolling road test. It is the same standard for petrol and diesel engines as it is for Battery Electric Vehicle. It is a recognised and objective way to measure the performance gaps between competition models and changes in specification.

The car is on a rolling road, undertaking the same urban cycle (ECE-15 cycle) three times, then the extra-urban cycle once. The average of these 4 cycles decides the NEDC range (Barlow et al. 2009).

This test is conducted within a laboratory at 20-30° C on a flat rolling road where no pre-warming is allowed and all air conditioning and electrical equipment is switched off. An electrical machine simulates wind resistance and vehicle inertia. This drive cycle, it is a very specific drive cycle (figure 21) with periods of acceleration and constant deceleration and speed in effect bears little comparison to the real world drive cycle (figure 22) that has been conducted within our tests routes. The Department for Transport agree that this drive cycle has little relation to a real driving patterns on the road (Barlow et al. 2009).

6.2.2 The Test Vehicle

Nissan LEAF 2014 model

LEAF is an acronym for: **L**eading **E**nvironmentally friendly **A**ffordable **F**amily car.

The vehicle used for this experiment was the 2014 model compact five door Nissan LEAF electric car with specification as table 22, which has Kinetic Energy Recovery Systems (KERS). This vehicle has an all-electric energy recovery system to replace energy into the traction battery when braking, under over-run conditions this will come into effect under deceleration or downhill conditions which will benefit the user so as to allow maximum vehicle driving distance.

How much energy the KERS can replace back to the battery will depend on the driver behaviour, traffic flow, speed attained and the topographical route taken for the vehicle journey so different routes were chosen to offer a mix of road networks.

Kinetic energy recovery systems (KERS) for regeneration when coupled to an electric motor for traction is possibly the best solution presently available to dramatically improve the available energy while providing better performances within strict budget constraints. (Boretti 2013) states that different KERS may be built purely electric, purely mechanical, or hybrid mechanical/electric differing for round trip efficiency, packaging, weights, costs and requirement of further research and development.

This chapter will complete an investigation into experimental analysis of the energy flow to and from the battery of a latest Nissan LEAF when used with the real world drive cycle. This analysis provides a state-of-the-art benchmark of the propulsion and regenerative braking efficiencies of electric vehicles with off-the-shelf technologies. While the propulsion efficiency approaches 95%, the round trip regenerative braking efficiency reaches the 70%, values previously achieved only with purely mechanical systems, few percentage points below the round trip efficiencies of todays' best mechanical system.
Nissan LEAF see Figure 27 has the specification as given by the manufacturers in table 22.

Table 22 Product information as given by the manufacturers

Physical dimensions	Compact hatchback	4.45 m long	1.77 m wide	1.55 m height			
Battery, charging and performance	80 kW (109 HP) peak	280 Nm maximum torque	Lithium ion, 24 kWh, standard charge in 6 hours (100%)	Quick charge in 30 minutes (80%)	17.3 kWh / 100 km consumption	175 km range (108 miles)	Max Speed of 145 km/h (90 mph)
Price & market entry	36.990 Euro VAT included	Market entry 2012					

6.2.3 The current approach to range prediction

Current approaches use battery information (State of charge, state of health and temperature) combined with recent consumption to predict range. New approaches are suggesting two possible methods for improving this. Firstly, developing a more user centred approach based upon regular trips and previous driving style. This approach also wants to use increased amounts of data such as elevation, external temperature, route, road conditions etc. so rather than giving a mileage range it would give a destination range based on history, current data and previous trips/driving style. The other approach is to look more at how battery health and losses through the repeated charging cycle and battery degradation can have an effect on the range calculation and trying to model this more accurately.
The work conducted by (Oliva et al. 2013) states that the driver can only rely on the dashboard information as displayed and this remaining driving range due to many sources of uncertainty is difficult to accurately predict. The driving style, the road conditions and the surrounding traffic are some of these uncertain factors.

This further supports the paper by (Ceraolo & Pede 2001) relates to algorithms based on battery discharge rate and temperature to discuss the residual range. The residual range (RR) estimate is inherently a two-stage process. First, the residual battery energy has to be estimated then the residual range estimates comes from the combination of the residual battery energy estimate and some estimate of the vehicle efficiency, i.e., the distance covered per battery kilowatt hour

The actual drive cycle battery algorithm will require a more computing science based approach based upon both the residual battery capacity providing a real time map based on most popular user route from driver history to estimate where you can get based on previous energy consumption for that route. This will necessitate further study which will have to consider the global positioning of the vehicle so as to determine the route taken whilst building up a driver profile along with consideration of external parameters such as weather conditions, road traffic and time of the day as stated by (Ferreira et al. 2012). Simulation results from (Potarusov et al. 2010) clearly show an increased energy requirement at low temperature resulting in a reduction of the vehicles' driving range. It is necessary to analyse the energy usage and range of a battery electric vehicle, using real life data over simulation where possible.

6.2.4 Presently developed real world drive cycles

This paper investigates the energy consumption of a battery electric vehicle under real world drive cycles on differing journeys and weather conditions.

This real life drive cycle study showed the impact of ambient temperature and compares Summer and Winter temperature conditions to determine the additional energy needed to heat the interior resulting in a higher specific energy usage and a reduction in useable vehicle travel.

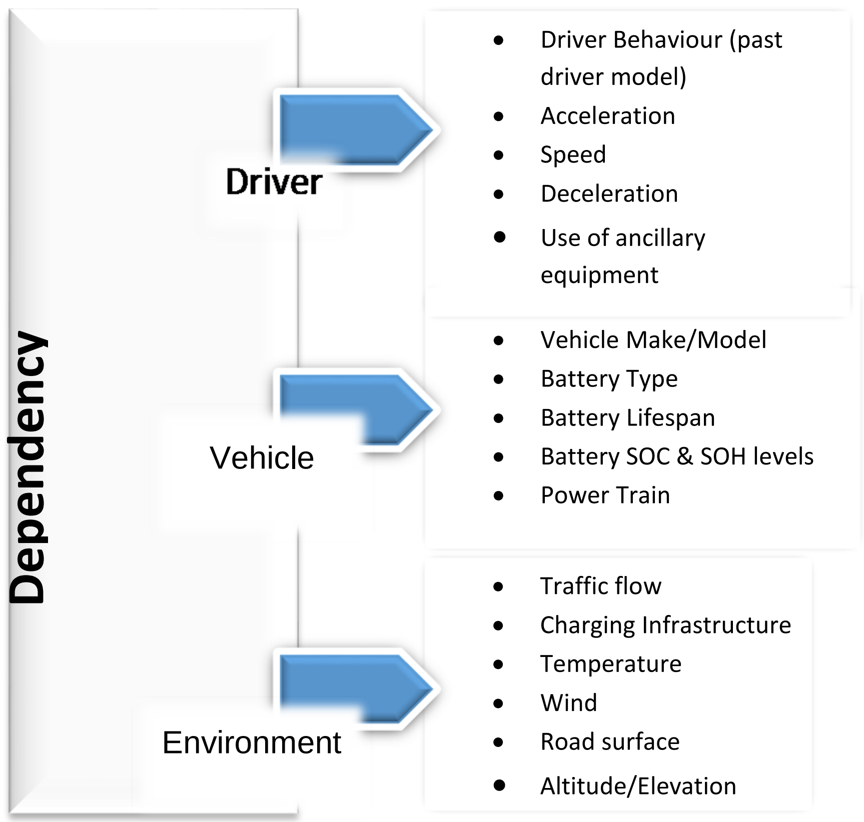
This paper introduces an estimation method, in which twelve factors are considered, including vehicle current location, remaining battery energy, road network, elevation topology, road grade, vehicle travel speed, ambient temperature, interior temperature, status of on-board electric devices and the demand on auxiliary energy.

6.2.5 Range prediction

The range prediction calculation is based on past driving data, collected from the vehicle, the user and the environment. Aftermarket tracking equipment is fitted to the vehicle and will give data in relation to the driver's requirements as well as storing times, GPS coordinates and driver behaviour such as excessive braking, acceleration and cornering forces. From the GPS coordinates it is easy to calculate travel distances and from the hardware interrogating the vehicle Electronic Control Unit and CANBUS data via the diagnostic port such as state of charge levels and temperature of the high voltage battery can be determined. Driver profile is based on recording this data at time of departure and will be aligned with past data analysis and historical evidence of driver behaviour all of these will be inputs to act as a 16 point 'Data Set' approach to estimate the electric vehicle range. The data set approach will model the regression activities to find the best fitting estimation based on current State of Charge level, past driver behaviour (previous SOC level, weather information and temperature, average speed, traffic information).

This drive cycle experiment will target certain routes and road networks to give the electric vehicle user confidence that the vehicle will be able to achieve the distance expected under real driving conditions and advise of any discrepancy in the data being relayed back to the driver.

This discrepancy will be measured so as to give the driver a real world data set that is realistic when taking into account the inputs as indicated in figure 83. It is essential to record all dependency parameters as indicated in figure 83 as changes here will have an effect on the potential distance that can be travelled.



(Milligan & Muneer 2015)

Figure 83 The required 16 point Data Set for the experimental range prediction

6.3 Drive cycle experimental work

The experimental work conducted within this research agrees with (Boretti 2013) where discussion of analysis of the energy flow to and from the battery of a latest Nissan LEAF covering the Urban Dynamometer Driving Schedule (UDDS). This analysis provides a state-of-the-art benchmark of the propulsion and regenerative braking efficiencies of electric vehicles with off-the-shelve technologies.

While the propulsion efficiency approaches 90%, the round trip regenerative braking efficiency reaches the 70%, values previously achieved only with purely mechanical systems and gives the Nissan LEAF car a very efficient regeneration system without have a negative effect on the driving experience for the car user and its passengers. This regeneration system will have a bearing on the experimental results obtained and allowing the altitude change to have an effect on the energy present to propel the vehicle further for the given route, however this cannot be done in isolation alone as the behaviour of the driver will have a significant affect to utilising the vehicles potential range and there are no two drivers alike therefore making this an ever-changing variable.

To ensure that all driving conditions were met it was decided to conduct the real world tests on routes that vehicle users will encounter such as Rural, Urban, Extra Urban and Intercity journeys. And to obtain greater accuracy the tests were conducted across different seasons, here experimental findings were determined for the summer and winter months, this allowed data analysis of the Air Conditioning and Heater consumption as well as the auxiliary energy usage so as to allow thorough vehicle defrosting prior to the test drive and maintaining an inside vehicle temperature of 20°C for the comfort of the driver conducting the test.

6.3.1 Methodology

This section critically analysis two objectives. Information and data was collected to determine comparisons between dashboard discrepancies and to determine reliability of the manufacturers figures. One was to evaluate the accuracy of the computer algorithm in car display when compared to the accuracy of the NEDC figures which all car manufacturers must comply with. The other was to accurately measure the discrepancy in the dashboard displayed value when the vehicle is used over differing weather conditions.

For the car purchaser and user, the NEDC value will be the value that the manufacturer claims and this will go towards the decision of the buyer at time of vehicle purchase. This information will also determine the strategic positioning of the charging system infrastructure throughout the nations road network, as this positioning must be based on the 16 point data set to calculate the actual range achievable by the vehicles.

Tests were conducted and data collected in the summer months when the air temperature was between 16 and 20° C and again in the winter months when the air temperature was between -2 and 2° C this information prove to be invaluable as the distance the vehicle could be driven was reduced as the temperature decreased. Interior cabin temperatures were set to 20°C in the summer trials and cooling ventilation conditions were utilised in the winter months.

In accordance with the journey taken auxiliary energy was used for equipment such as heated seats and in car entertainment as the driver deemed to be acceptable for the journey as there is nothing to gain by trying to conserve all auxiliary energies as this is not likely to happen when the vehicle is being used in conditions such as the daily commute. Under the test conditions the radio, heater (set at 20°C) and heated seats were used if applicable as this will be the normal condition when used by the commuter.

Figure 84 In-car display – suggested distance the vehicle can travel shown on right hand side instrument.

The in-car dashboard display is all the driver can get as an indication of what distance is available, as its information will be used similar to a fuel gauge in an internal combustion engine conventional car, this display accuracy will be essential to the vehicles' range in journey planning see figure 84. Prior to any journey the user must check that the previous user has put the returned vehicle on-charge on termination of that journey. Under ideal conditions the battery electric vehicle will have a full charge on commencement of the journey thus giving it maximum range capabilities. The electric vehicles that were under test here have got in the region of <100mile range when fully charged and this is approximately ¼ the range of a conventional fuel car when full of fossil fuel so this requires a change of human behaviour so to remove the risk of range issues and battery depletion.

The Nissan LEAF test car had full charge as indicated by the dash board display prior to the start of each experiment, this was 'real time' analysis and as the cars were driven the energy reduction was recorded as the vehicle was moving towards its destination.

Recording stopped when the car had been driven to near critical or actual battery depletion which was beyond when the car was warning the driver of imminent electrical system failure on the dashboard display. Prior to the start of each journey the vehicle was fully charged as indicated by 100% useable energy displayed on the dashboard and checking that the charge supply had stopped from the charging post indicating that further charging was not possible. This was all verified by interrogating the vehicles Electronic Control Unit and CANBUS via the diagnostic port using a hardware plug-in to determine the charge of the high voltage traction battery state, this experiment gave a lower value of 97% for the SOC (State of Charge) when fully charged and not 100% as expected. The hardware plug-in values are shown in Figure 85 and this indicates a maximum available energy capacity of 22kWh.

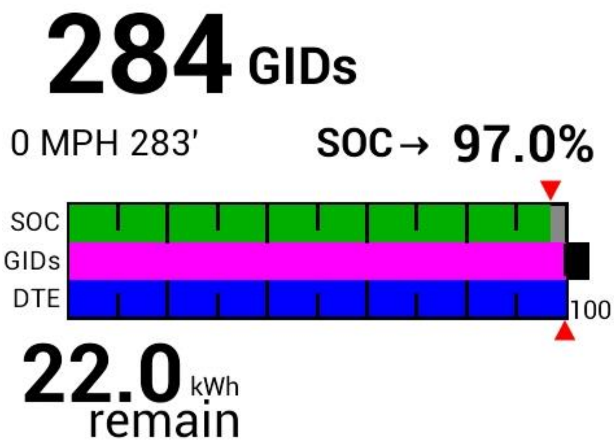


Figure 85 High Voltage Traction Battery information from CANBUS port

GIDs = Value representing state of charge of the battery. 1 GID is equivalent to 75-78Wh of available energy and in-keeping with the traction battery energy capabilities. This was correctly calculated at the experimental stage as repeated tests indicated a fully charged HV battery indicated 22kWh and 284 GIDs.

The figure 85 screenshot was indicative of the values stored within the cars ECU (Electronic Control Unit). This was a fully charged car and the available energy was 2kWh less than the manufacturers stated capacity of 24kWh. This would indicate that a fully charged battery is displaying 100% to the driver however the ECU is recording a lower value.

This test was repeated over many Nissan LEAF cars and over many timeframes and the values of figure 85 were constantly repeated and the maximum value that could be attained was 22kWh, giving 2kWh margin for safe battery control and removing the risk of overcharging irrespective of the charging source that the car is plugged into.

6.3.2 Vehicle and seasonal drive cycles

The drive cycle data is gathered live for the experiment using the vehicles own ECU (Electronic Control Unit) memory and the CANBUS diagnostic port using a LUJII ELM327 V1.5 mini-wireless OBD2 diagnostic scan tool that has been retro-fitted. This equipment will record off-line, store and display battery management system information pertinent to the SOH (State of Health), Temperature, SOC (State of Charge), number of fast charges, rapid charges and auxiliary power usage to operate systems.

The purpose of this analysis is to determine the drive cycle information which is gathered from journeys taken at random and the vehicle is not being driven to any specific drive patterns nor route. It is journeys that have been encountered within the daily usage of the battery electric vehicle a sample has been taken to illicit four different drive cycles and with all journeys a typical commuter driver was driving not a test driver. All of these cycles were employing the ‘car chasing’ technique and following the traffic conditions so the car speed was governed by road conditions legislative constraints and the speed of the vehicle in front. It was not necessary to plan the journey to certain times of the day as this would not be expected when using a conventional vehicle nor was the route taken all the information given was that the car had to get from point A to point B without detailed route planning. The journeys driven utilised the following road types:

a) Urban cycle
b) Rural cycle
c) Mixed combined (extra urban) cycle
d) Intercity cycle

For the four given drive cycles, data was collected from the summer months for the routes and again for the winter months and comparisons were examined in relation to the energy discharge rate and the route and distance travelled.

The following table 23 indicates the discrepancy in actual distance travelled as ratified by google maps when compared with the computational dashboard value as displayed to the driver and the range inaccuracies when compared with the NEDC value. To accurately determine if there was a difference in results due to climatic conditions this experimental test approach was taken over two seasons and the variance recorded by live data recording in the vehicle.

The percentage difference was recorded and compared across all routes and both seasons. It can be seen from table 23 that the vehicle was lees energy efficient and had the greatest percentage difference when used in the winter months.

Table 23 Nissan LEAF Range Comparisons

Route	Summer						Winter					
	Max Range in miles (NEDC cycle) Acclaimed mileage given by manufacturer	Estimated Range in miles as indicated while driving the BEV (displayed on the vehicle dash board)	Actual Trip Miles	Energy Efficiency miles per kWh	% Difference		Max Range in miles (NEDC cycle) Acclaimed mileage given by manufacturer	Estimated Range in miles as indicated while driving the BEV (displayed on the vehicle dash board)	Actual Trip Miles	Energy Efficiency miles per kWh	% Difference	
					Actual v. Estimated	Actual v NEDC					Actual v. Estimated	Actual v NEDC
1 - Rural	124.00	93.0	81.1	3.68	-12.80%	-34.60%	124.00	75.0	76.5	3.66	+2.00%	-38.31%
2 - Extra Urban	124.00	93.0	84.0	3.50	-9.68%	-25.00%	124.00	83.0	69.2	3.47	-16.63%	-44.19%
3 - Intercity	124.00	85.0	73.6	3.34	-13.41%	-31.45%	124.00	92.0	71.6	3.30	-22.17%	-42.26%
4 - Urban	124.00	93.0	89.0	4.04	-4.30%	-28.23%	124.00	86.0	71.0	3.70	-17.44%	-42.75%

Manufacturer's quoted maximum available range is **124** miles on NEDC cycle as expressed by (Nissan 2015; Barlow et al. 2009).
All routes carried out in drive gear mode 'D', and without 'ECO' mode.
Winter trips carried out with heating and air conditioning plus all other available auxiliary systems (such as lights and entertainment system) switched on.
Summer trips carried out with no heating, air conditioning, or other auxiliary systems active.
Winter trips carried out with heating, air conditioning on and interior temperature set to 20° C.

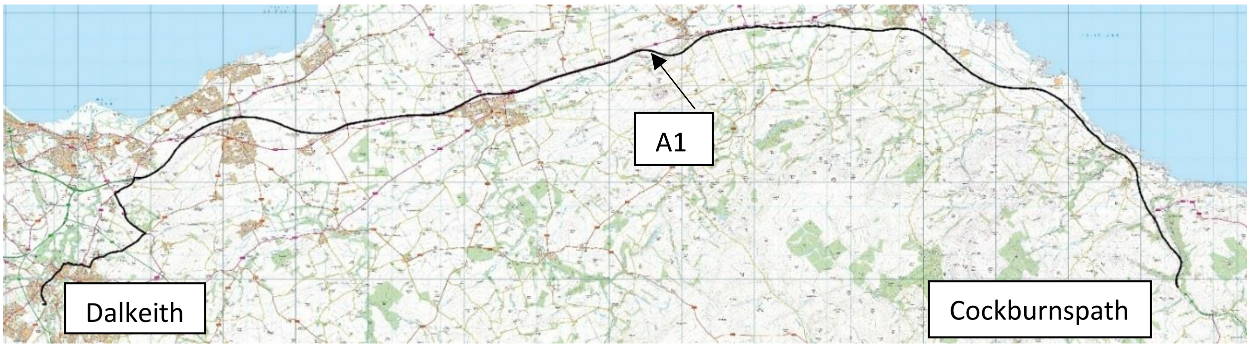


Figure 86 Extra Urban drive cycle route

The extra urban route chosen was from Dalkeith, Midlothian, Scotland driving east of the City of Edinburgh to the main A1 dual carriageway. This route encompasses mixed driving styles and speeds and the test was conducted over sections of 30 – 40mph urban roads and national speed limit 50-60 mph roads and 60 – 70mph dual carriageway roads.
The route analysis Figure 86 was taken from a section of A1 road in an easterly direction from the City of Edinburgh; from Midlothian, Dalkeith to Cockburnspath, south east of Dunbar in the Scottish Borders region where the vehicle was then driven back along the same route for the return journey.

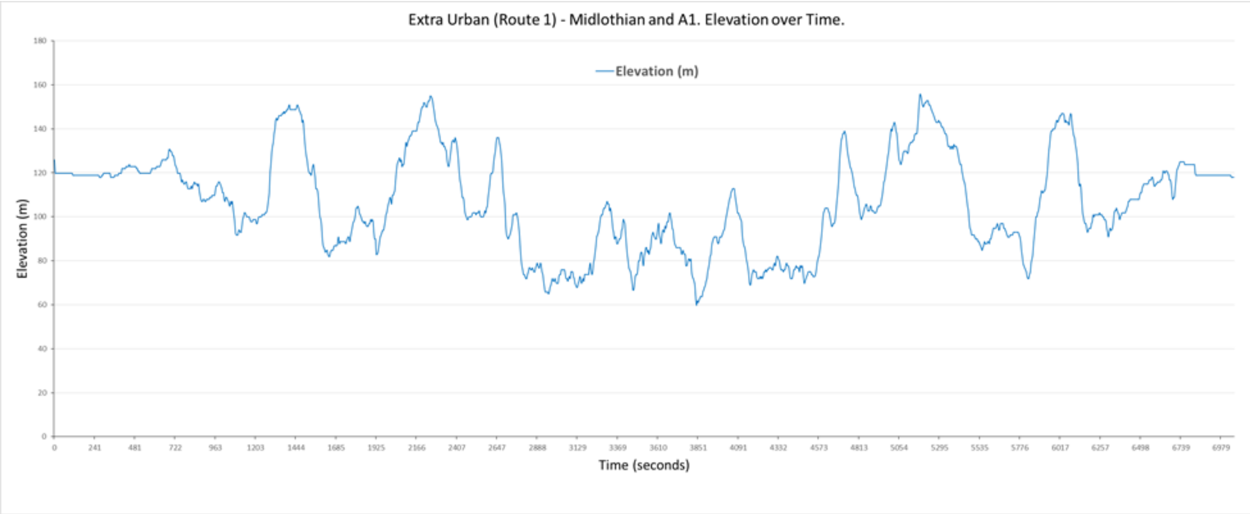


Figure 87 Extra urban - elevation

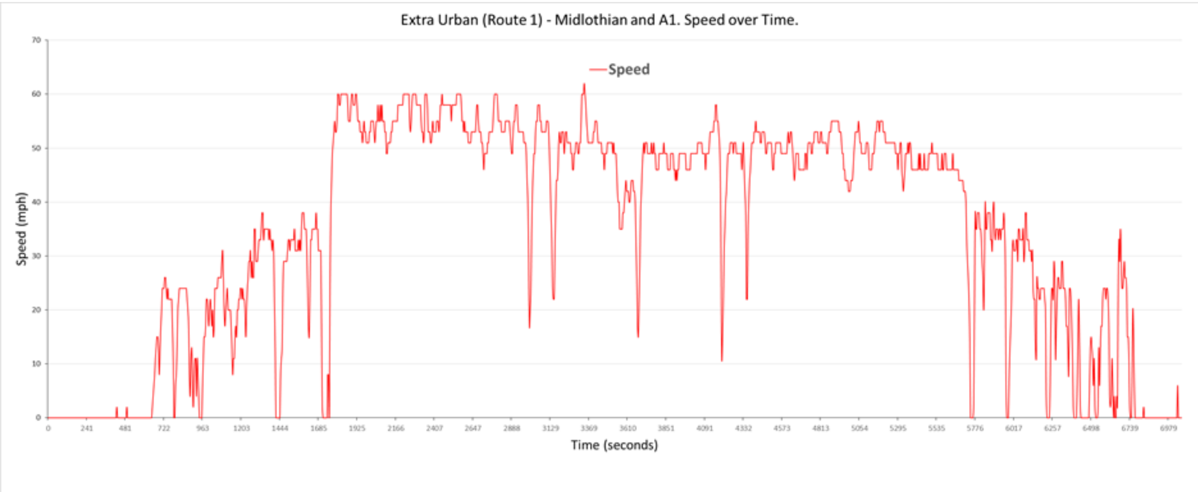


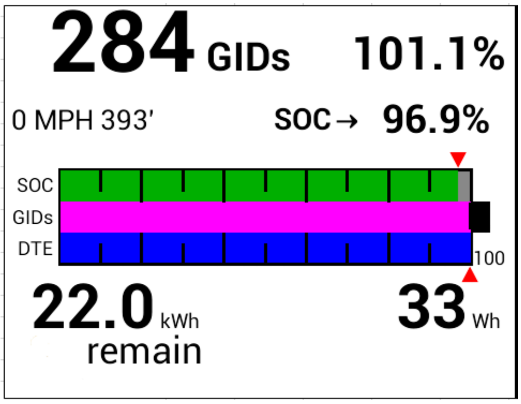
Figure 88 Extra urban - speed

The extra urban drive cycle route with the drive characteristics indicated comparing speed over time. It can be clearly seen that there are significant periods when the car is maintaining a speed in the region of 50-60mph at the duel carriageway section and there will be negligible energy recovery over this time period. Figure 88 above encompasses the total (return) drive cycle and the only periods where regeneration is applicable is the start and at the end of the test.

Indication from the hardware plug-in Table 24 (left) below gives values pertaining to the battery condition both before and after the experiment Table 25 (right) indicates fully charged with maximum battery energy available and the 33Wh is the energy that has been used out

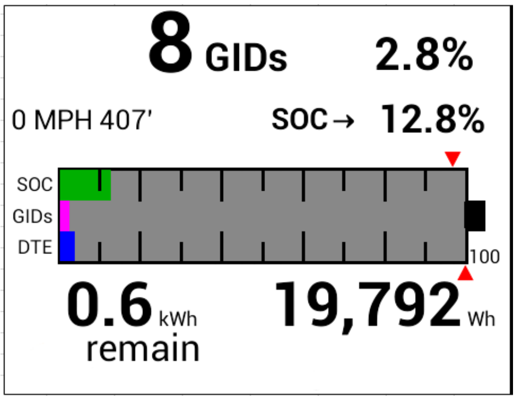
of the available 22kWh available as can be seen after the vehicle has completed the experiment 19,792Wh has been used thus only leaving 0.6kWh remaining.
The battery after the test is very close to depletion and will required to be recharged fully prior to the next drive cycle operation.

Table 24 battery analysis – start



Battery condition at test start

Table 25 battery analysis - end



Battery condition at test end

The extra urban drive and discharge cycle is shown below in Figure 89.

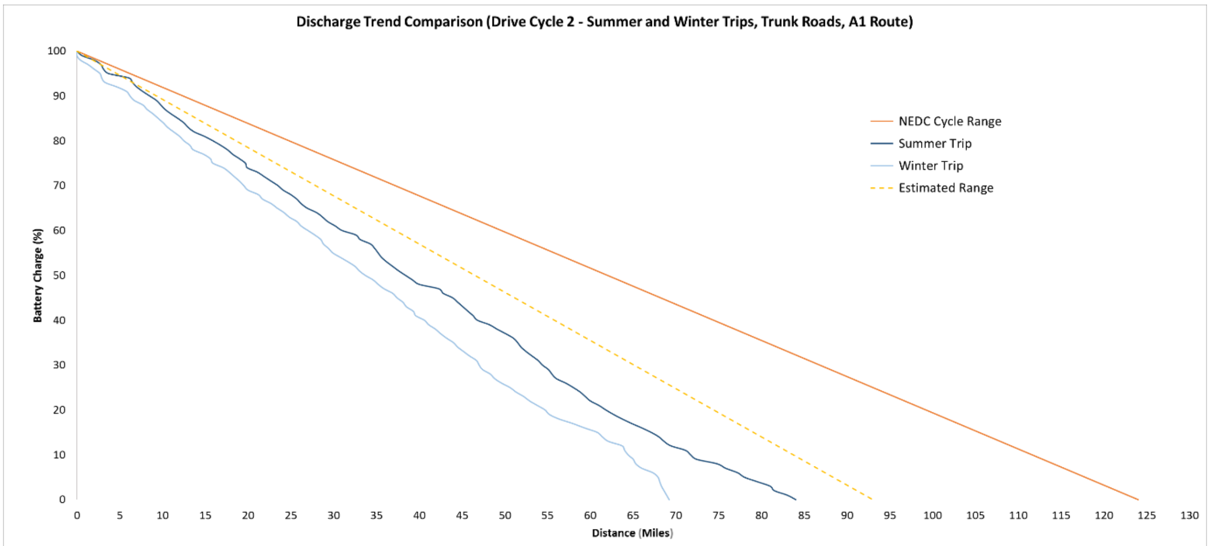


Figure 89 Summer and winter – discharge actual

Indicates the experimental variance in the suggested and available distance that can be travelled, as can be seen the dashboard display algorithm is indicating 94 miles available to the user.

In the summer months the vehicle has available energy to allow 84 miles but in the winter months only 69 miles are available. This is an 18% average reduction in range which may have an adverse effect on the driver and vehicle reaching their destination. The climatic conditions (wind, rain and temperature) are the only variables here as the vehicle was driven by the same driver and all controls were set for the tests.

The greater the demands of the auxiliary power required for interior heating the more of an adverse effect this will have on the vehicles' 'distance to empty'.

These results have come from the vehicle being used in day-to-day commute conditions and the results show a marked decrease in potential range due to the reduced temperature conditions and associated demands on the energy from the high voltage battery pack. This range deficiency was also recognised in the work of (Farrington & Rugh 2000) where the impact of auxiliary loads was discussed.

Additional energy is being used to supply the auxiliary heating and air conditioning that is required to maintain the inside car temperature set at 20° C (see figure 90) this along with inaccuracies in the dashboard display algorithm give the driver a different (lower) range achievable to what is being displayed and to the NEDC manufacturer values. For user confidence the dashboard display algorithm must be reworked to give a higher degree of accuracy to keep the distance in line with what can actually be achieved when being driven by the user.

It should not be omitted to state in the findings that the BEV has got a 12 volt battery which will power the lights and auxiliary devices and a 350+ volt high voltage traction battery to give traction to the road wheels and give auxiliary heating. This high voltage battery must maintain the 12 volt battery charge at the same time as supplying all of the other vehicle needs so accurate recording and display values is of paramount importance as is drain and balancing.

Chart of the auxiliary energy consumption:

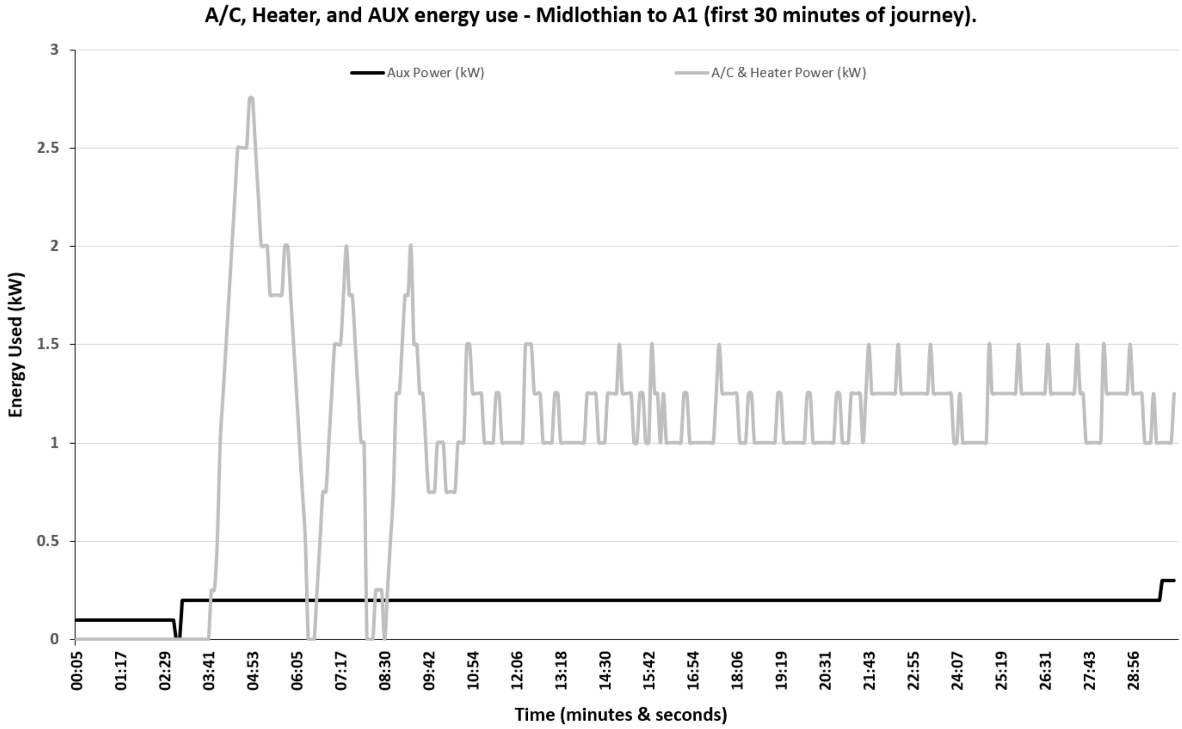


Figure 90 A/C, heater and Aux demand

The figure 90 indicates the energy consumed by the auxiliary battery to maintain the inside cabin temperature at an acceptable 18° to 20° C when the exterior temperature on the winter test was between 4° and 6° C. It has to be remembered that this vehicle does not have an alternator to allow battery recharging so any recharging of the auxiliary battery will be through energy transfer from the HV traction battery.

6.4 Carbon intensity and energy analysis of urban and long range intercity battery electric vehicle mobility

6.4.1 Overview

Industrialisation and transportation create pollutants through the combustion of fossil fuels. In the UK a quarter of all CO_2 emissions come from Transport and approximately 90% of this comes from road vehicles. According to the UK Government, at the end of 2013, there were 35 million vehicles licenced for use on the roads in the UK. Over 4,300 new, Ultra-low emission vehicles (ULEV) were registered for the first time, a 25% increase in ULEV sales from the previous year. Looking at the overall automobile market electric cars registered in the UK accounted for approximately 1% of the total car sales in 2015 (Office for Low Emission Vehicles 2015).

The population of the city of Edinburgh has been forecast to increase by 28.2% from 482,640 for the year 2012 to 618,978 in 2037 (National Records of Scotland 2015a). In 2012 the statistical predictions according to the National Records of Scotland indicate that the city's population is expected to increase at more than three times the rate for Scotland as a whole. To support this growth, it will involve a transportation approach change and change in the attitude of people and companies will be required. The city authorities will have to address the overpopulation of vehicles in the city commute.

(M. Knez et al. 2014) assert that the level of CO_2 emissions can be reduced by adaptation of transport technologies, peoples' driving habits and changing driving policy.

The city authorities can implement these changes to control the approach to transportation in four ways:

- Regulation and taxes
- Environmentally friendly vehicles
- Change of the transport regime
- Location and servicing of new housing/infrastructure

The implementation of the electric vehicle in the across city commute can address all three of these points if the supply of energy from the grid can support the demand in a sustainable and environmentally clean nature thus removing the burden and pollution from fossil fuelled power stations.

The mix of energy sources used to produce electricity for use within Scotland is significantly different to the mix as used in the rest of the UK. The different sources used to create the energy mix over a thirteen-year period are lessening the demand on fossil fuel as a medium and now has a significant renewable energy component to support the demand since 2002 (Edenhofer et al. 2011).

This trend will include wave, tidal, solar and wind (on-shore and off-shore) generating technologies which now produces a substantial share of the potential energy sources available due to their flexibility and the increased efficiency with the development improvements of the hardware.

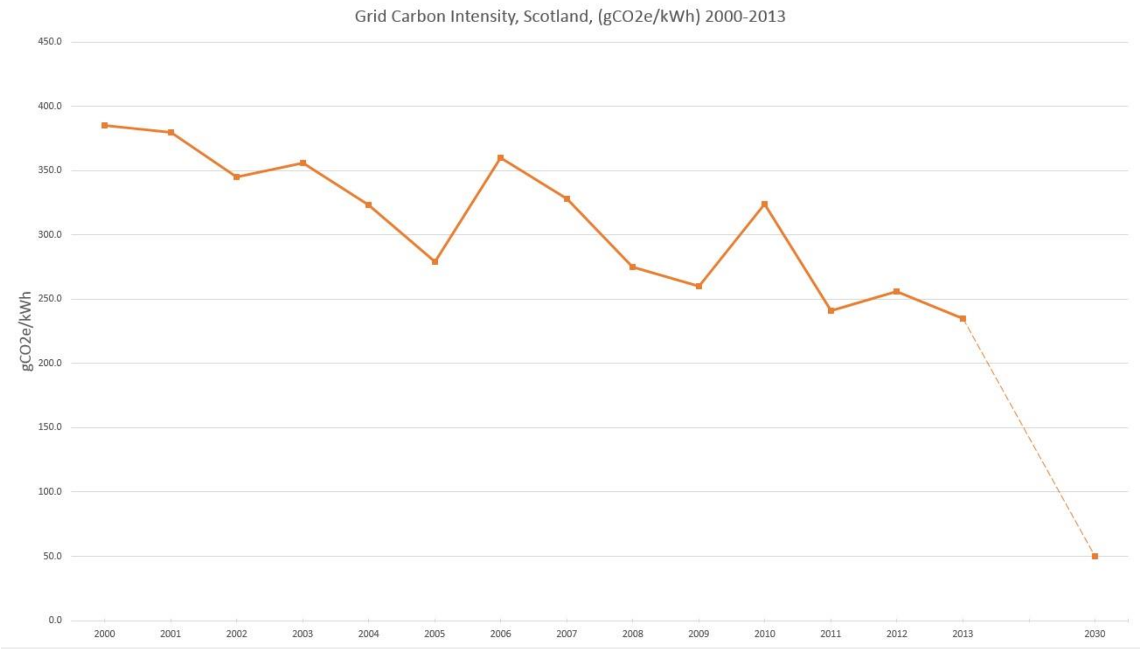
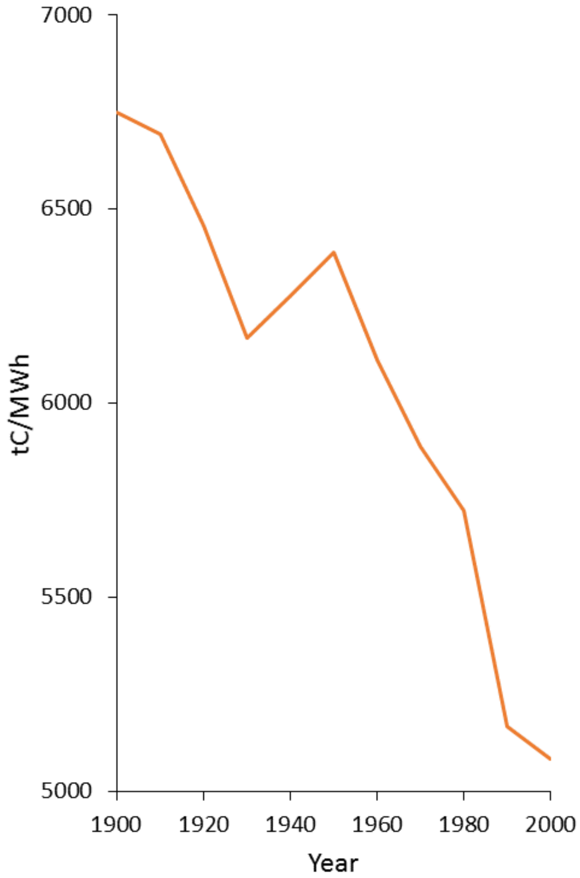


Figure 91 Scotland Grid Carbon Intensity 2000 – 2013

The grid carbon intensity has been reducing year on year, the 2013 values being 250gCO_2e/kWh but future expectation is that UK government legislation will lower this further to 50gCO_2e/kWh by 2030 as indicated in figure 91. This low value will negate the use of fossil fuelled power generation as the primary source to the increasing energy needs.
The fall of grid carbon is in accordance with the energy source mix being used and will be determined by the fuel type being in the highest demand at that time.
As can be seen in Figure 91, the overall energy demand is decreasing therefore, to meet the output target the amount of renewable energy is on the increase. The trend line for Carbon intensity across Scotland is falling proportionally and is reflected in-line with the decarbonisation of the world’s energy supply shown in Figure 92.



(Smil 2006)

Figure 92 Decarbonisation of the world’s energy supply

6.4.2 Commuting distances

Edinburgh College for the across campus commute will primarily utilise the evening or off-peak charging strategy so as to utilise the lowest tariff rate currently at seven pence per kWh which will negate the high demand scenario encountered with day time charging which will compound the existing demand drawn from the grid to the College.

The aim of this section is to look at the cost, emission reduction and energy consumption when the BEV is used for short- and long distance commute. Evaluation was conducted on two routes for the multi-mode simulation and drive mode analysis. The modes under examination were acceleration, deceleration, cruise, ascent and decent and they have been validated using experimental data to determine the regeneration efficiency of the electric vehicles under test.

This session of testing will take the BEV into test conditions across an urban situation and an intercity situation which is out with the accepted and recognised driving condition as indicated by many travel surveys.

One survey of nearly 750,000 US drivers from (Bloomfield 2012) indicated that 95% of drivers travel less than 40 miles to work and that the average daily commute is 13.6 miles. Within this US study more than 60% single trip distance samples taken were under 6 miles.

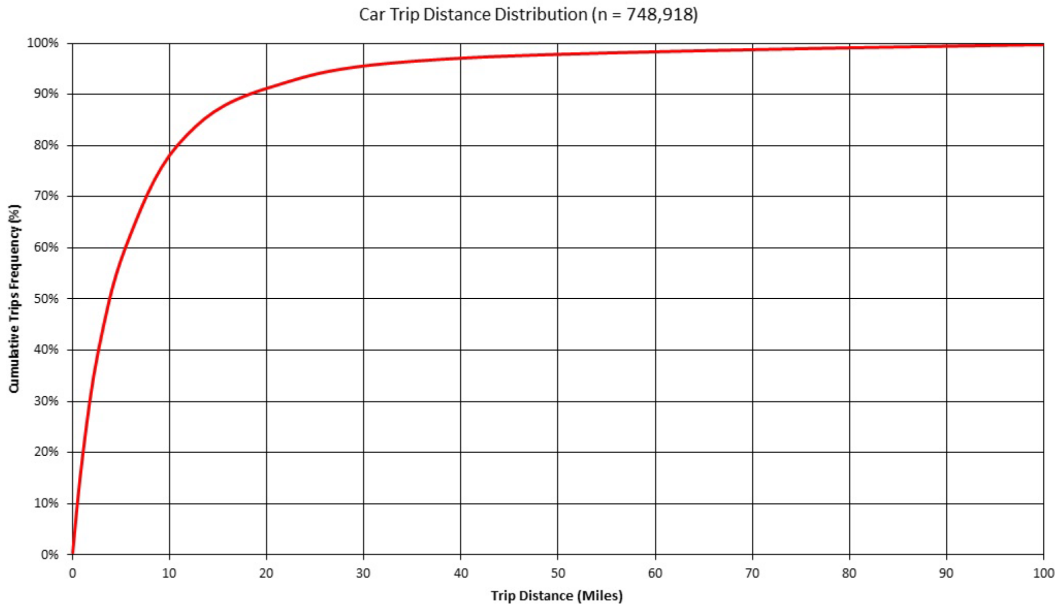


Figure 93 Average distance travelled – United States

This distribution of trips indicate that a BEV could easily replace the ICE vehicle for a significant percentage of journeys.

Another survey indicated that the individual journey length in the UK is 8.6 miles and the average total daily distance travelled is 25 miles. In Europe, more than 80% of Europeans drive less than 63 miles in a typical day (SMMT 2016). This shows that a significant number of journeys could easily be made using a BEV.

Cumulative frequency by journey distance plots for car driver journeys taken from the 2014 Scottish Household Survey representative of individual journeys made by 9720 (<1.5% of the US study) randomly selected drivers from Scottish households is shown in figure 94 and these gave results that are also in line and comparative with the other travel surveys.

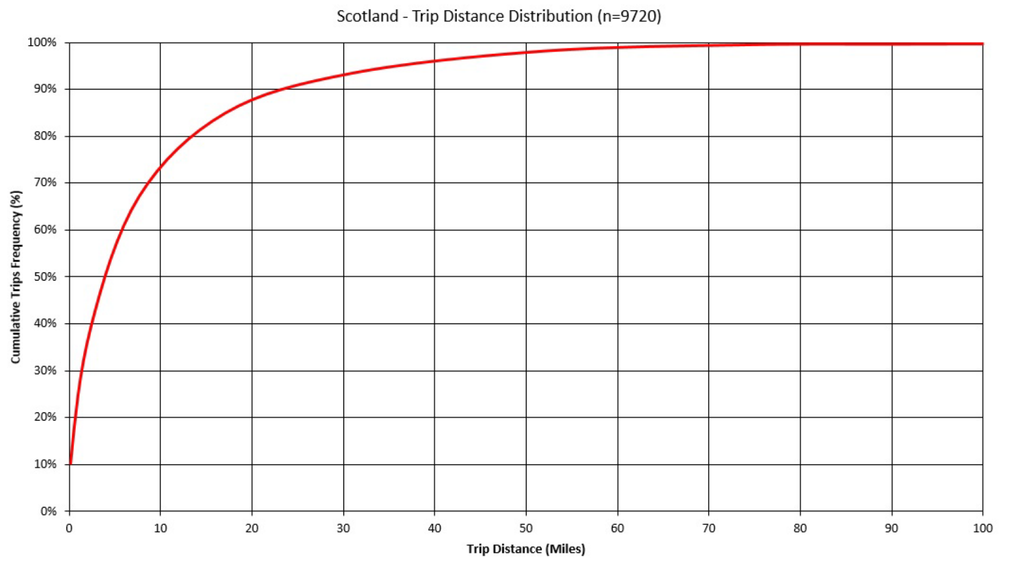


Figure 94 Average distance travelled - Scotland

From the BEV usage for a four-year period a sample was taken with 22376 cumulative trips from the Edinburgh College fleet and this was indicative of the US, UK and Scotland travel surveys that exist. These international and national surveys can be verified independently by actual measured results indicated in figure 95, taken by Edinburgh College in January 2016 as an average trip distance of 5.16 miles has been recorded.

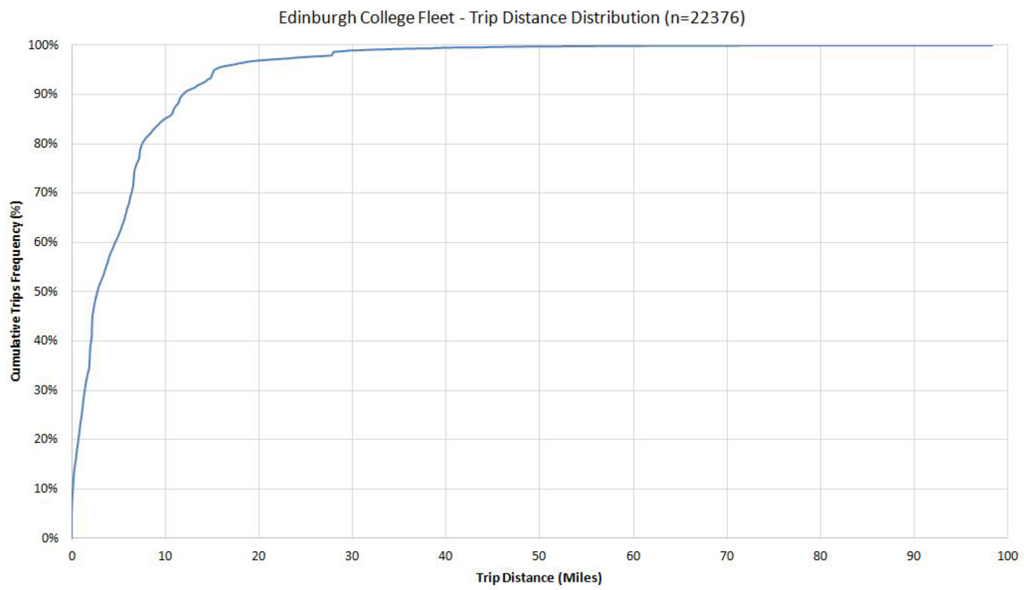


Figure 95 Average distance travelled – Edinburgh College Fleet

All of these travel cumulative totals are indicating the same range determents and gives a strong case for the adaptation of electric vehicles for the majority of road journeys and as can be seen 85% of all of the experimental data indicated in this study donates a journey length of less than 10 miles.

The Edinburgh College study was primarily using the campus single location chargers to charge the vehicles. The strategy was to recharge the BEV's on a daily basis was usually carried out when the vehicle was parked at the Campuses at the end of the day. This is a suitable strategy for urban travel and the across campus drive cycle but for long range mobility the BEV user will be completely reliant on the current transport infrastructure.

As recognised by a study on charge timings by (Neubauer et al. 2012) this will take the charging strategy from the normal single location workplace charging to requiring charging at different urban locations and utilising a 'just-in-time' strategy for the intercity journey and relying on a working infrastructure which is available for use on arrival. Multiple charge stations may be required so as to remove local overcrowding.

Following (Lemoine et al. 2008) assumptions with respect to charging losses, vehicle recharging is approximately 83% efficient—increasing the battery's state of charge by 1 kWh requires 1.2 kWh from the electrical outlet. If this scenario is scaled up supporting and robust infrastructure will have to be in place from the outset to ensure reliability from the infrastructure.

Due to the nature of the business activity all cars will be returned to a Campus at the end of the working day. On their Campus return they will be subject to a 'right away' charge strategy. This work and data collection supports the studies conducted by (Neubauer et al. 2012) where it is recognised that there are three types of charge strategy to support their use patterns.

6.4.3 Discussion

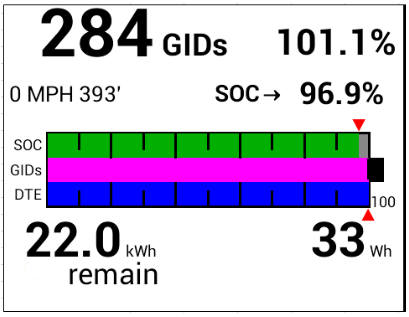
Experimental work was undertaken in order to analyse the data obtained when the BEV was used in a multiple journey data set across the City of Edinburgh, Scotland, and when the vehicle was driven to conduct long range analysis in a 1000 mile journey. In this article an experimental evaluation of an electric vehicle has been undertaken. The Nissan LEAF BEV has been used for this task with the 'car chasing' technique employed to measure the driving cycle. The speed and energy use were recorded for the vehicle that was driven along the principal arteries of the City of Edinburgh, Scotland. In a separate activity vehicle driving tests were also undertaken to determine the energy consumption and CO_2 and NO_X expelled in long range intercity mobility.

The Nissan LEAF BEV like every other car on sale in the EU, cars must undergo official fuel economy testing under the New European Driving Cycle regulations. The NEDC test lasts just 13 minutes which is too short to obtain real-world data. Instead, the laboratory-obtained figures are then used to calculate total fuel efficiency and range.

A set of laboratory tests used to determine fuel economy for city, extra-urban and both combined, the NEDC tests don't take account of weather conditions, how full the car is with luggage or passengers, and most importantly, individual driving styles. The NEDC does not forecast the RR (residual range) and cannot predict if the present driving style will be maintained. As indicated by (Ceraolo & Pede 2001) the faster the trip the lower the available range and the electric vehicle user will have to plan for the trip and will want to know what the distance the vehicle will be able to cover, starting now.

The vehicle used for the experiment was a pure electric BEV (battery electric vehicle) Nissan LEAF 2014 model which has a 24kWh Li-Ion battery. The Lithium-ion battery cells in the test LEAF, consists of a graphite anode and a lithium metal oxide cathode and an electrolyte of a lithium salt and an organic solvent.

The car was installed with data recording equipment that will monitor and record speed, distance, time, location and forces (acceleration and deceleration). The vehicle had monitoring and recording hardware fitted so as to allow interrogation of the BEV ECU (electronic control unit) to determine the HV battery status and working conditions. At the commencement of the experiment the dashboard display gave indication of a fully charged traction battery. The recording equipment indicated as at Figure 96; that although the battery was at 100% SOC (state of charge) the available energy to power the vehicle was 22kWh.



GIDS = Value representing state of charge of the battery. 1 GID is equivalent to 75-78Wh of available energy therefore this statement is correct and in keeping with the traction battery energy capabilities.

Figure 96 High voltage battery conditions at start of all experimentation

This test was repeated over many Nissan LEAF model year 2013, 2014 and 2015 cars and over multiple timeframes and the values of figure 96 were constantly repeated and the maximum value that could be attained was 22kWh, giving 2kWh margin for safe battery control and removing the dangerous risk of overcharging the Li-ion cells irrespective of the charging source that the car is plugged into. For the endurance of the battery and to remove the possibility of completely depleting the battery pack and will not put the battery chemistry DoD (depth of discharge) into a state where it will become difficult to recharge and the life expectancy will be massively reduced.

The Nissan LEAF was fitted with a data recording system as well as hardware to record the High Voltage (HV) Battery parameters.

The data recording and the hardware equipment was set to monitor and record the following parameters so as to critically analyse the journey.

The tool utilised the CANBUS diagnostic port using a LUJII ELM327 V1.5 mini-wireless OBD2 diagnostic scan tool. Measurement accuracy is stated from the company as +/- 1% full scale at 25°C.

The manufacturer states it is Restriction of Hazardous Substances (RoHS) compliant has and supports all legislated OBD-2 protocols:

ISO 15765-4 (CAN)
ISO 14230-4 (Keyword Protocol 2000)
ISO 9141-2 (Asian, European, Chrysler vehicles)
SAE J1850 VPW (GM vehicles)
SAE J1850 PWM (Ford vehicles)

(Obd & Datasheet n.d.)

1. Speed
2. Time
3. GPS location
4. Distance
5. Frequency events/trips
6. Distance to battery depletion
7. Harsh braking
8. Harsh acceleration
9. Harsh cornering
10. Battery state of charge
11. Available energy capacity
12. Frequency start/stop

It was determined that throughout all of the experimental testing there were no adverse acceleration, cornering or braking conditions recorded and that all speeds were in accordance with the legislative limit.

6.4.4 Edinburgh College inter-campus commute

Edinburgh College has four sites located within Edinburgh and the Lothian Region, Scotland as shown in Figure 97. Due to the campus locations the BEV is an effective low emission mode of transport that is suitable for the across City commute.

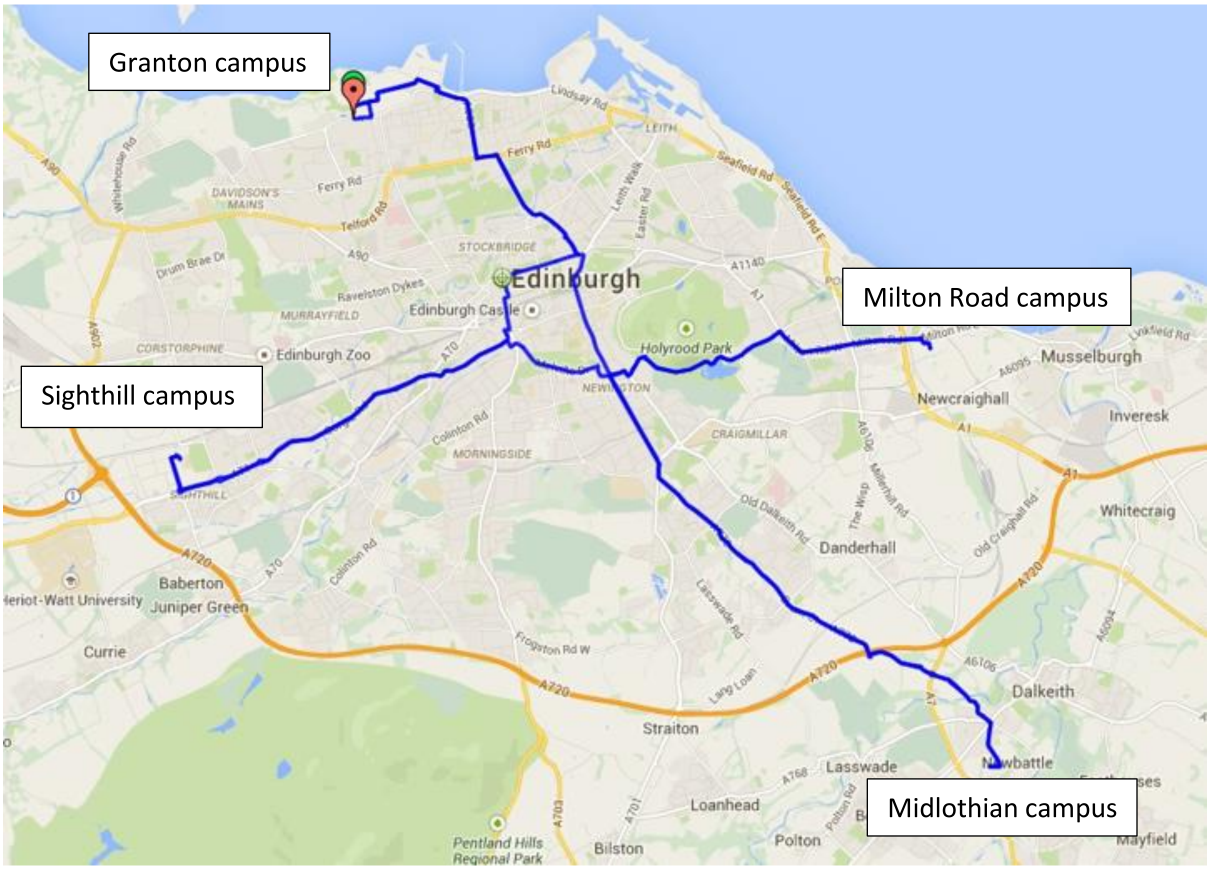


Figure 97 Edinburgh College campus locations

The inter-campus commute has to be achieved at differing times of the day encountering different driving conditions and throughout the complete academic session. Experimental testing was conducted to determine if the BEV can fully service all campuses as a means of inter-campus travel at any time in the year as a requirement to the staff throughout the day and the night.

In this drive cycle method, it is not expected that the driver should adapt his or her drive patterns to the limited range of the vehicle but it may require the use of quick charging to compensate for the restricted range available.

Chargers are located within each of the Campus grounds and there are other publically accessible chargers available within easy reach of the commuter undertaking this journey. A real world drive cycle was conducted in both summer and winter seasons to see if all Campuses could be within the reach of the BEV without the need for plug-in time as often the cars are just participating in multi-drop use – stopping for less than 2 minutes and therefore the plug-in time would have a negligible effect on the battery chemistry state of charge and therefore this analysis would be the worst case situation for the BEV and driver.

The route was split into four experimental sections:

Section A: Granton campus to Midlothian campus (travel distance 13.1 miles)

Section B: Midlothian campus to Milton Road campus (travel distance 6.6 miles)

Section C: Milton Road campus to Sighthill campus (travel distance 9.3 miles)

Section D: Sighthill campus to Granton campus (travel distance 5.9 miles)

The commute was across the City of Edinburgh to each Edinburgh College Campus location and then repeated which is the ultimate ideal range that can be achieved. This will give any user the confidence required to complete this journey under any road and weather condition. The Campus locations are not equidistant but the route taken will be the most direct. Each journey will have differing road and traffic conditions and each section will require different driving styles which will change to suit the surrounding requirements.

The drive cycle was conducted within two seasons in the year, taking into account the warmer ambient summer temperature and the colder winter temperature. This is an important aspect as it will evidence any difference in BEV performance across the same route accounting for the external differences such as temperature change, wind and rain. An important factor will be the need for extra interior cabin temperature for the driver to be comfortable and safe for the journey.

This extra heating will ultimately come from the transfer of energy from the High Voltage (HV) traction battery to the heater system thus removing energy that would otherwise drive the vehicle.

The continual demand on heating and auxiliary systems has indicated a measurable loss of the available energy. This has been calculated a 2% energy reduction for every 15 minutes to maintain the interior cabin temperature at 21° C. This result was recorded with the vehicle stationary and the exterior temperature was 5º C. It can be predicted that greater energy will be used to support these systems when the vehicle is moving due to wind chill and the increase auxiliary load.

Summer Drive Cycle:

Figure 98 depicts the discharge curve across all of the journey sections, the energy available in the summer is sufficient to complete return journeys between Campuses and as shown in discharge table 26 the reduction in energy is indicated for the route.

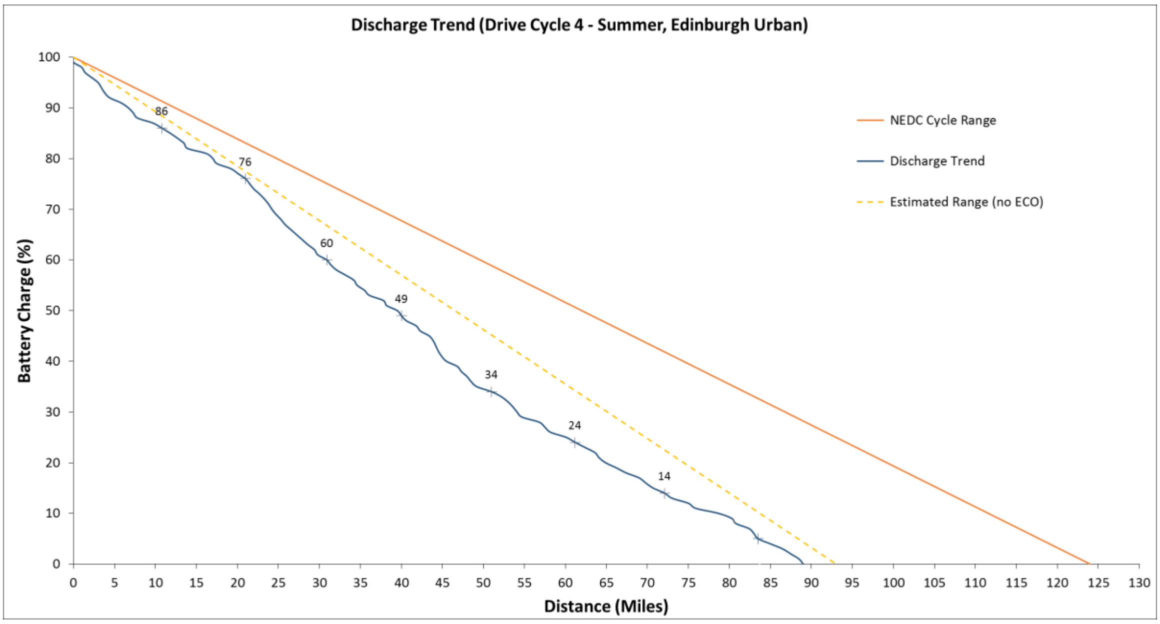


Figure 98 Summer - experimental drive cycle – discharge actual

The actual discharge curve for the summer drive cycle gave a reduced range by 8% from the dashboard prediction and a significant 30% reduction from the manufacturer's given figures as taken from the New European Drive Cycle (NEDC).

Table 26 Discharge summer split per Section

100-86% charge section A: Granton campus to Midlothian campus (1st visit)
86-76% charge section B: Midlothian campus to Milton Road campus (1st visit)
76-60% charge section C: Milton Road campus to Sighthill campus (1st visit)
60-49% charge section D: Sighthill campus to Granton campus (1st visit)
49-34% charge section E: Granton campus to Midlothian campus (2nd visit)
34-24% charge section F: Midlothian campus to Milton Road campus (2nd visit)
24-14% charge section G: Milton Road campus to Sighthill campus (2nd visit)
14-5% charge section H: Sighthill campus to Granton campus (2nd visit)
5-0% charge section I: Projected figures to depleted battery

The ambient and battery temperatures were taken both at the start and at the end of the drive cycle Table 27. The available energy was measured both at the start and at the end confirming that at the end of the four inter-campus commute the battery was close to depletion is shown in Table 28.

Table 27 Summer Temperatures

External Temps (°C):

Start of Trip = 10.0°
End of Trip = 12.0°

Battery Temps:

Start of Trip = 9.5°
End of Trip = 12.1°

Table 28 Battery capacity

Available kWh at start = 21.9

Available kWh at end = 1

Energy Used = 20.011kWh

Energy efficiency = **3.70** miles per kWh

This energy consumption was confirmed by hardware installed interrogating the BEV's electronic control unit at the start of the experiment and at the end Figures 99 and 100 for summer and Figures 102 and 103 for the winter season. The end parameters indicate close to full depletion of the usable available energy.

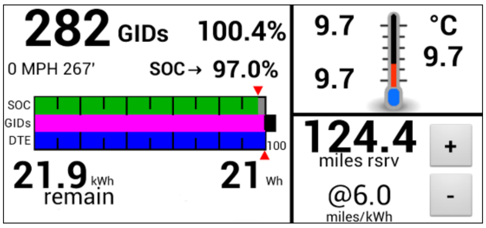


Figure 99 Initial energy available

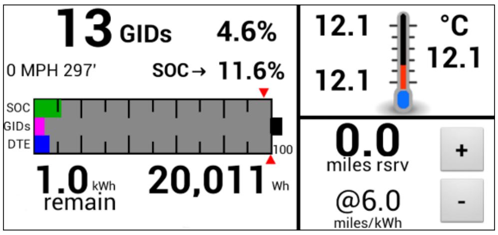


Figure 100 Final energy available

Winter drive cycle:
The aim was to accept the drivers behaviour and 'normal conditions' were set to get a typical approach to the vehicle user. When this drive cycle was conducted in the colder winter months when it was necessary to heat the passenger compartment to between 20°C and 22°C to make the journey safe and comfortable.
This drive cycle experiment as shown in figure 101 indicated a reduction of the available range to an actual 65 miles which was approximately 22% less than the dashboard display and nearly 50% less than the manufacturers NEDC stated figures of 125 miles.

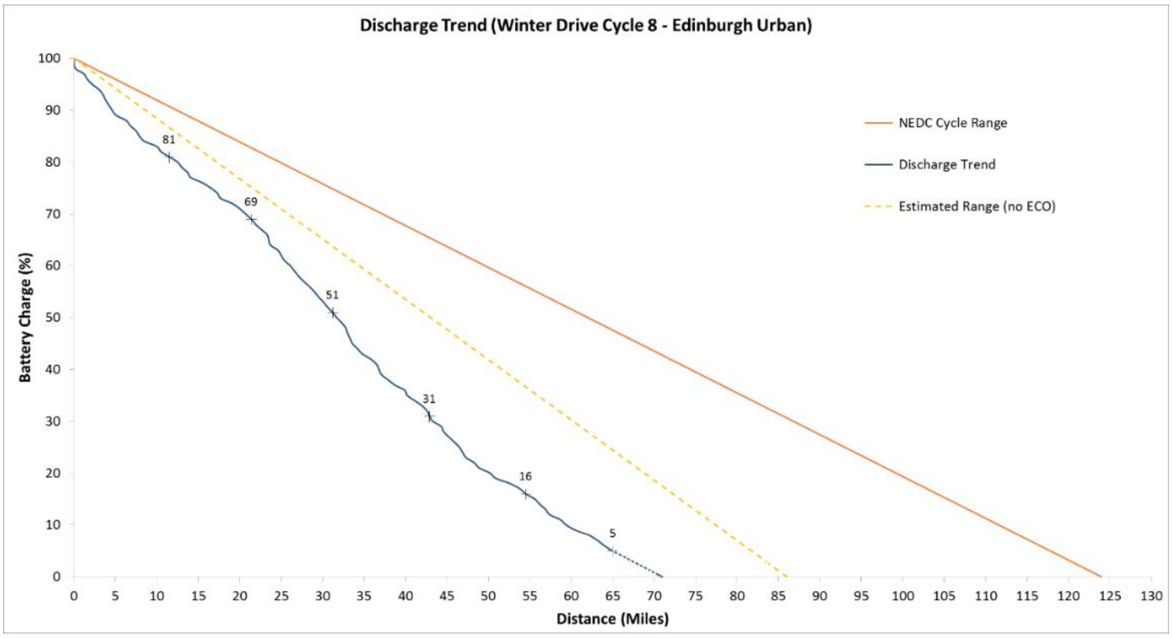


Figure 101 Winter - experimental drive cycle – discharge actual

Table 29 indicates that there were return journeys that could not be achieved and this would necessitate BEV charging to be made available when an ‘all campus’ return journey was required.

The winter drive cycle could not be fully completed due to depleted battery prior to the end of the experiment.

Table 29 Discharge winter split per Section

100-81% charge section A: Granton campus to Midlothian campus (1st visit)
81-69% charge section B: Midlothian campus to Milton Road campus (1st visit)
69-51% charge section C: Milton Road campus to Sighthill campus (1st visit)
51-31% charge section D: Sighthill campus to Granton campus (1st visit)
31-16% charge section E: Granton campus to Midlothian campus (2nd visit)
16-5% charge section F: Midlothian campus to Milton Road campus (2nd visit)
5-0% charge section I: Projected figures to depleted battery
Milton Road campus to Sighthill campus (2nd visit) – not achieved
Sighthill campus to Granton campus (2nd visit) – not achieved

Table 30 Winter Temperatures

External Temps (°C):

Start of Trip = 2.0°
End of Trip = -1.0°

Battery Temps:

Start of Trip = 3.8°
End of Trip = 9.6°

Table 31 Battery capacity

Available kWh at start = 22.0
Available kWh at end = 1.2
Energy Used = 20.454 kWh

Energy efficiency = **3.47** miles per kWh

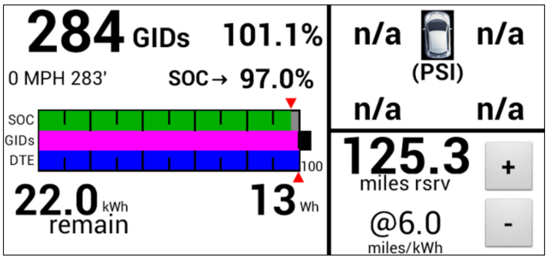


Figure 102 Initial energy available

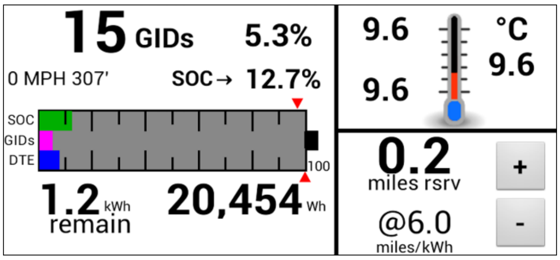


Figure 103 Final energy available

The results in Table 31 were recorded and as a result of the extra energy being consumed to heat the passenger compartment and full completion of the inter-campus journeys were not achieved. This heater power peaked at 3kW and was automatically controlled by the interior vehicle temperature sensor, the temperature was set to 20°C as the set point and the system feedback cycled the variable until the desired temperature was achieved. This is shown in Figure 104.

The auxiliary systems such as lights, radio, battery management and vehicle control systems consumed a constant 200W and the and the A/C and heater system consumed between 0 and 3000W of power to maintain the constant passenger compartment temperature due to the vehicle interior heat losses sustained in this commute.

The following actual measured results were calculated to make a comparison of the losses accrued in heating and auxiliary systems consumed against the total energy available.

Auxiliary energy used in the first hour of commute was 723Wh.

A/C and heating energy used in the first hour on commute was 2,146Wh.

This gave the combined additional energy used in the first hour of commute as 2.869kWh which is 13% of the overall total available energy.

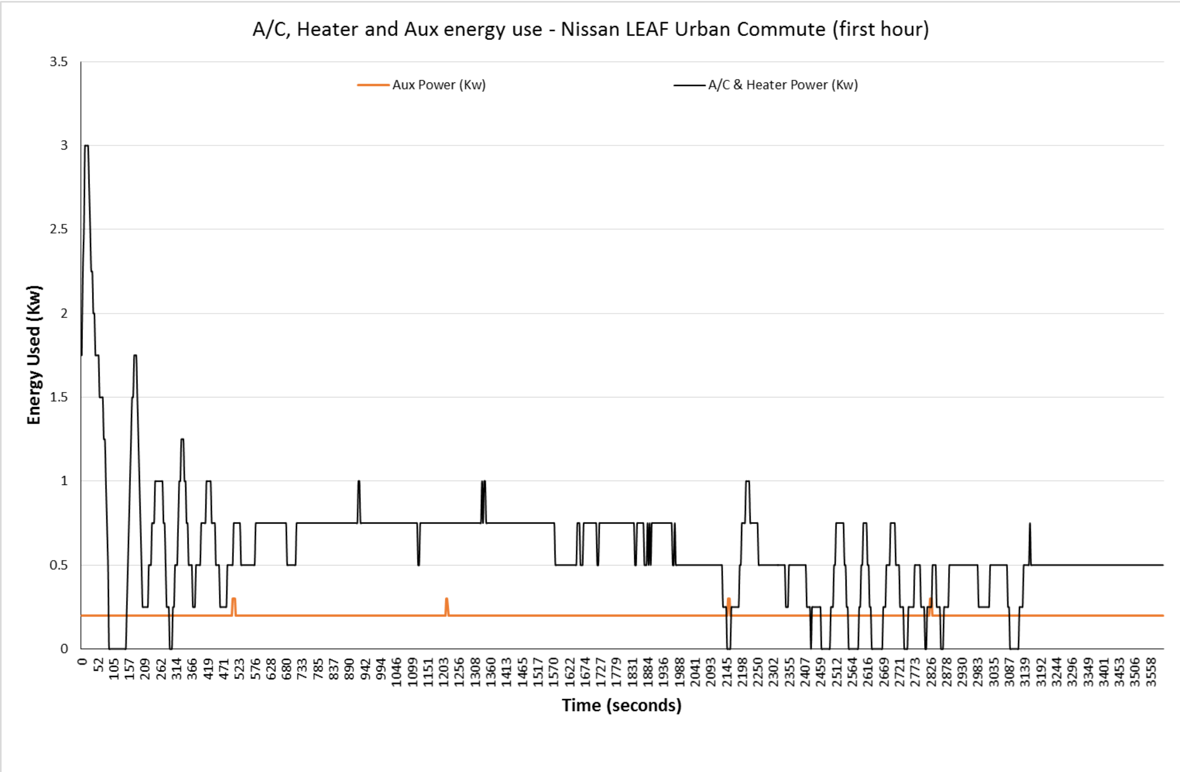


Figure 104 A/C and auxiliary energy use

6.4.5 Drive cycle analysis

As is indicated from both Figure 100 summer and Figure 103 winter experiments the BEV range has been affected by the change in ambient temperature more energy will be utilised in cabin heating this compounded with wind, rain and additional auxiliary equipment being used in the winter which had the effect of reducing the distance that can be travelled.

All sections of the experiment were conducted with the same driver however it is also noted that the slope of each discharge curve is not consistent from each of the sections driven.

All sections driven are different depicting the varying road conditions and the traffic encountered in the City of Edinburgh. The greatest differing sections are A and C, where section A is not a steep as section C, these are displaying differing driving styles required to achieve the journey which is having a greater depletion effect on the battery range this supports the studies conducted by (Neubauer et al. 2012).

Figures 105 and 106 illustrate Section ‘A’ speed and elevation charts, these routes are across south east Edinburgh, Granton campus to Midlothian campus with an average speed less than 20 MPH and 14 stop/start occurrences. The acceleration is progressive which is indicative with this drive cycle route and the vehicle motion whilst decelerating will induce energy regeneration back to the traction battery.

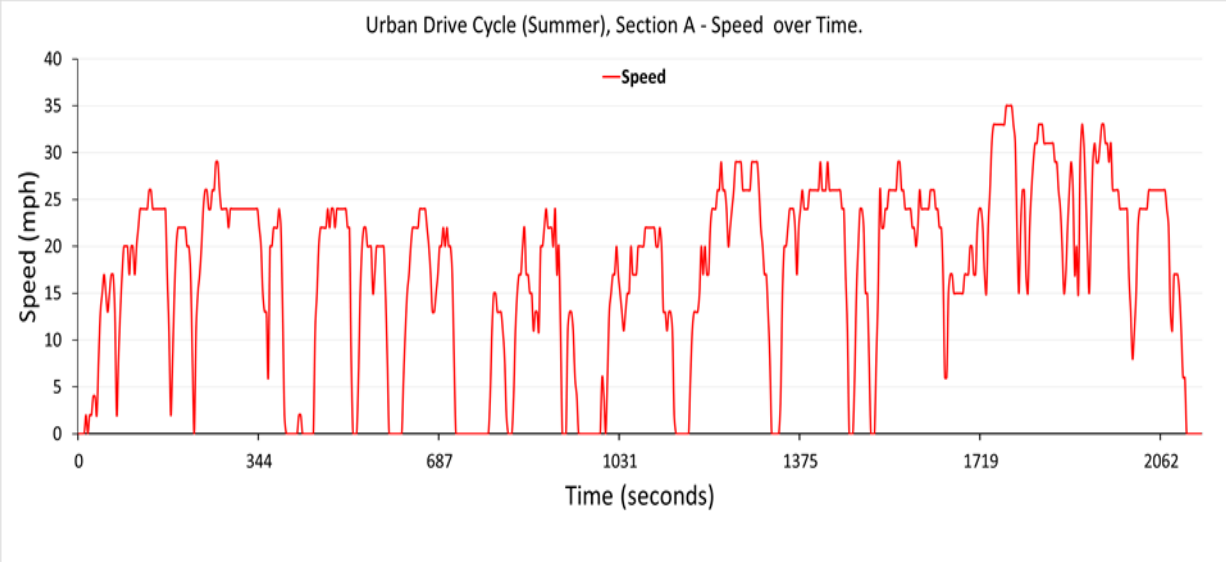


Figure 105 Section A drive cycle - speed

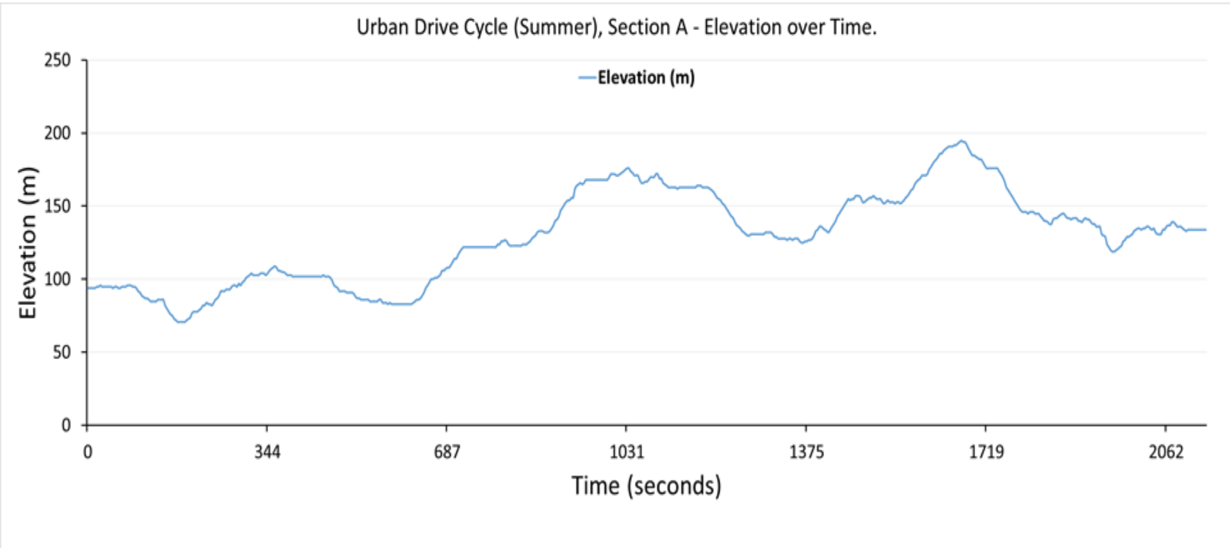


Figure 106 Section A drive cycle - elevation

Section C Milton Road to Sighthill campus drive cycle shown in figure 107 and 108 has a significant steeper slope to the discharge curve. This indicates much faster acceleration to gain road speed in order to maintain flow with the surrounding city traffic, it is still an average of 20 MPH but with 24 stop/starts. The frequency of this experiment was conducted 10 times to give the results as indicated to calculate the coefficient of variation see table 32.

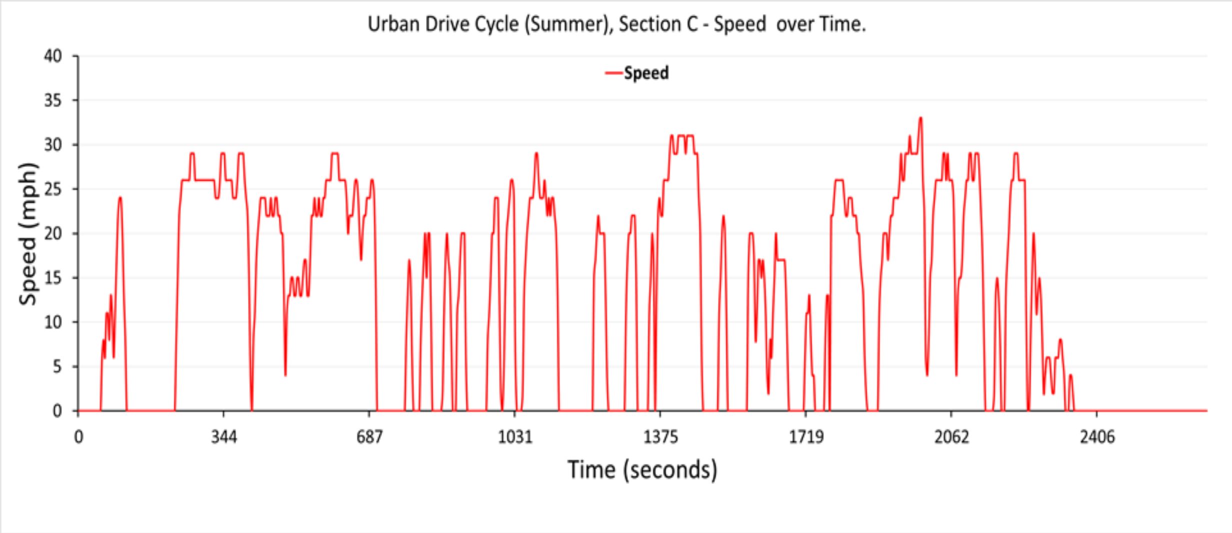


Figure 107 Section C drive cycle – speed

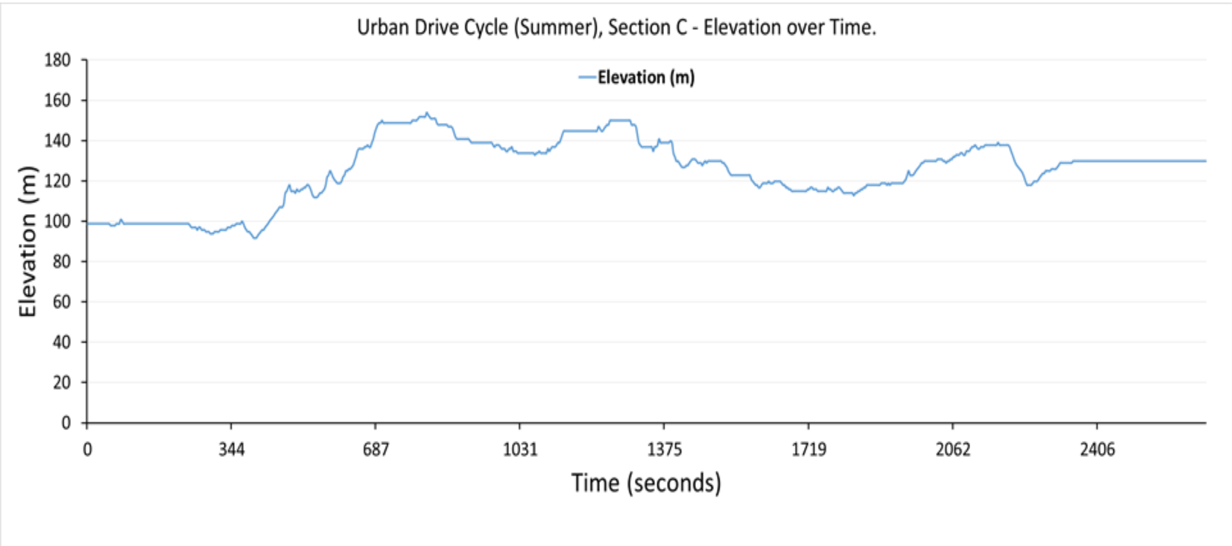


Figure 108 Section C drive cycle - elevation

High discharge current required to accelerate the BEV due to the drive cycle conditions is indicated in the experiment and this is evidenced by standard deviation calculations to determine the variance as results show in Table 32. The regeneration efficiency will be reduced as there is a high number of events where the speed drops below the 'regeneration cut-off' so here there will not be any regenerative charging possible.

Coefficient of variation was calculated to illustrate the rate of change that was present in the section drive cycles. Section C gave the highest rate of change for both acceleration and significantly higher when in the deceleration mode.

Equation 6 Standard deviation

Standard deviation equation

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

(MTSU 2008)

Term nomenclature:

n number of data points

χ_i each of the values of the data

Σ sum of

Table 32 Inter-Campus Journeys Standard Deviation

	Average acceleration	Standard Deviation	Coefficient of variation	Average deceleration	Standard Deviation	Coefficient of variation
Section A	0.50	0.33	0.66	-0.53	0.35	0.66
Section B	0.46	0.29	0.63	-0.65	0.40	0.61
Section C	**0.55**	**0.41**	**0.74**	**-0.52**	**0.49**	**0.94**
Section D	0.48	0.26	0.54	-0.55	0.37	0.67

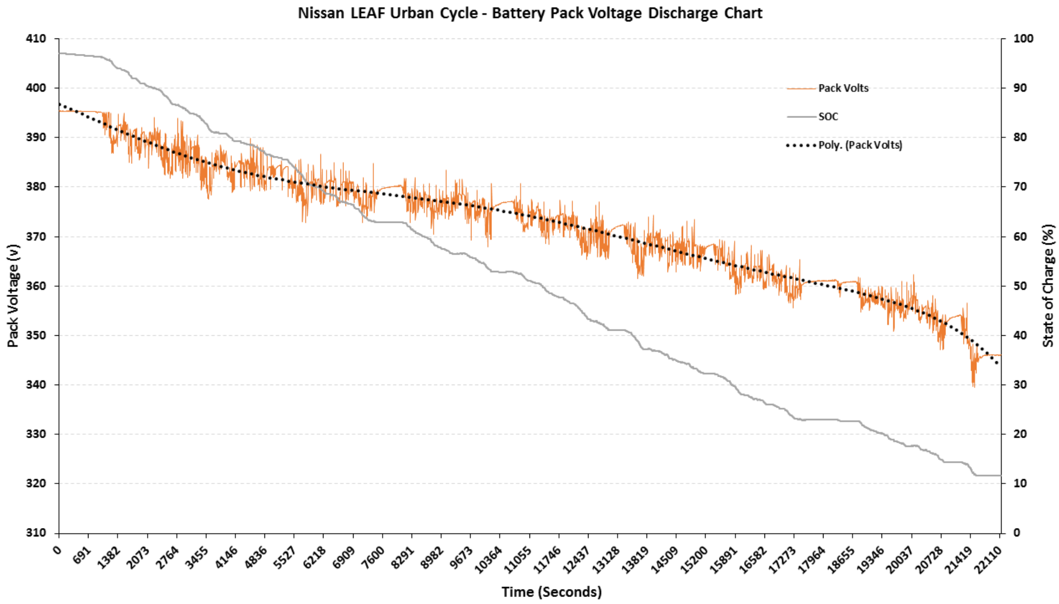


Figure 109 Battery pack voltage discharge curve for the urban drive cycle

The battery pack voltage discharge is shown in Figure 109 for the urban commute. This is taken over the entire journey until the HV battery pack was close to depletion. The voltage drop was measured at 63.88v between 100% state of charge and 0% SOC.

Table 33 State of charge equivalent - Nissan

(NB. Actual figures derived from ECU interrogation)

Nissan LEAF				
SOC		Pack Volts	kWh	
Indicated	Actual	Actual	Indicated	Actual
100%	97.1%	395.42	24	22
75%	75%	380.93	18	16.5
50%	50%	372.77	12	11
25%	25%	358.56	6	5.5
0%	11.6%	346.08	0	2.552

Table 34 State of charge equivalent – Mitsubishi

Mitsubishi i-MiEV		
SOC (indicated)	Pack Volts	kWh
100%	360	16
75%	349	12
50%	338	8
25%	327	4
0%	316	0

Nissan LEAF indicated values on table 33 are those provided by the vehicle driver display. Actual values are those derived from hardware installed through the vehicle CANBUS.
Nissan LEAF battery capacity is quoted by Nissan as 24kWh. Actual useable capacity is 22 kWh at 100% max charge as indicated by control unit interrogation.
At 100% charge as indicated by the vehicle display, control unit interrogation indicates that the pack is 97.1% SOC.
At complete discharge as indicated by the vehicle, interrogation indicates that the pack still has approximately 12% capacity in reserve.

The vehicle display stops showing range available at around 5% (indicated) battery charge, and also stops displaying the remaining battery percentage. This is designed to encourage drivers to seek recharge during normal use, and allow a ‘reserve’ for them to be able to do so but this is approaching depletion.

Mitsubishi i-MiEV full discharge voltage is based on reading of 320 volts for 90% discharged battery pack according to installed hardware. The vehicle indicators displayed 0% charge, and zero range remaining (see table 34).

Table 35 Seasonal Comparisons - overview

Urban Route: Edinburgh	Summer				Winter			
	% of Battery Used	Average Speed (mph)	Estimated Energy Use*	Notes	% of Battery Used	Average Speed (mph)	Estimated Energy Use*	Notes
Section A: Granton Campus to Midlothian	14%	20.4	3.08kWh	Mostly uphill. Active stop/go traffic	19%	19.3	4.18kWh	Uphill section. Active stop/go traffic.
Section B: Midlothian Campus to Milton Road	10%	20.3	2.20kWh	Mostly downhill. Less stopping.	12%	22.0	2.64kWh	Downhill. Less stop/go. Higher average speed.
Section C: Milton Road Campus to Sighthill	16%	19.6	3.52kWh	Active stop/go and sharp acceleration.	18%	20.0	3.96kWh	Sharp acceleration and deceleration
Section D: Sighthill Campus to Granton	11%	17.9	2.42kWh	40+mph roads, then stop/go & downhill.	20%	20.3	4.40kWh	Mainly downhill, but extra heating increased kWh use**

* based on percentage of battery power used, assuming 100% charge representing 22kWh available from Nissan LEAF battery pack.
** Section D (winter) also included a brief stop, so vehicle consumed extra energy in reheating when journey commenced again.

Additional Notes:

All routes carried out in a 2014, 2nd Generation Nissan LEAF 'Acenta', using Drive Mode 'D', and without 'ECO' mode.

Winter trips carried out with heating and air conditioning plus all other available auxiliary systems (such as lights and entertainment system) switched on. Set to 20°C.

Summer trips carried out with no heating, air conditioning, or other auxiliary systems activated.

6.4.6 Intercity mobility and economics

As part of the BEV research a vehicle was driven on a 1000 mile return journey which would remove the vehicle from the local known charge point infrastructure and make the driver become fully reliant on the installed infrastructure. A significant problem is finding the shortest path for a BEV when it has a limited battery capacity, therefore it must stop and recharge at certain locations.

The driving range limit and the lack of charging infrastructure are the two main characteristics of EVs at the current adoption stage.

If the number of chargers is less than what we need, it means that the BEV drivers may have to wait for hours to get a fully charged battery which will discourage the user and eventually influence the market penetration.

Therefore, it is of considerable importance to perform in-depth research on the multi-modal BEV use because the battery technology is a main competitive factor in the EV market.

To identify the energy consumed under practical applications the BEV was driven from Edinburgh Scotland to Bristol England. This was done over multiple days, in multiple sections and it was made possible utilising the 'Ecotricity Electric Highway' Rapid Charger network which is an aligned series of rapid chargers running along the main A701 - M74 – M6 – M5 route from Scotland to South West England illustrated in Figure 110. The Ecotricity electric intercity route was a UK government initiative which started in July 2011 with a single charger but now the network encompasses almost the entire motorway network (Ecotricity 2016).

The positioning of these rapid chargers in of paramount importance to the success, too close together and the cost of the network will be prohibitive and too far apart the journey may not be achieved. As discussed by (Taylor et al. n.d.) it is stated that with current technology vehicles the saving could impact significantly on journeys less of than (100km) 62 miles charge range which is in line with the UK governments strategic aim to site rapid chargers at least 50 mile intervals on the Primary road network (Alba n.d.).

And this work is verified with the previous given parameters as stated within this paper.

The Nissan LEAF BEV was fitted with data recording equipment and this was used to record the 1000 mile return journey and this experiment will be reliant on robust infrastructure support with strategically positioned 50 kW rapid chargers available as well as maximising the available energy and distance from the car capabilities.

The vehicle was driven in accordance to the traffic laws, weather conditions and drivers capabilities.

From GPS location:
Midlothian town centre, Edinburgh, Scotland, UK
Latitude 55.883987
Longitude -3.079659

To GPS location:
Bristol town centre, Bristol, England, UK
Latitude 51.454513
Longitude -2.58791
(Google 2016)

The route taken was the quickest and most direct, this was 380 miles from start to finish which is given by the Automobile Association route planner as a journey of 6hours and 30minutes (Automobile Association 2015).

The route planner time taken is assuming an ICE vehicle. In this BEV experiment the driving time was 8hours and 30minutes, but the total time including all charging and rest stops was 14hours. This 5hours and 30minute difference was the time used in vehicle charging on either a 'fast' or 'rapid' charger and also for allowing the charge post to be cleared by the previous user so making it available. This situation occurred on more than one occasion and the post was not available on demand.

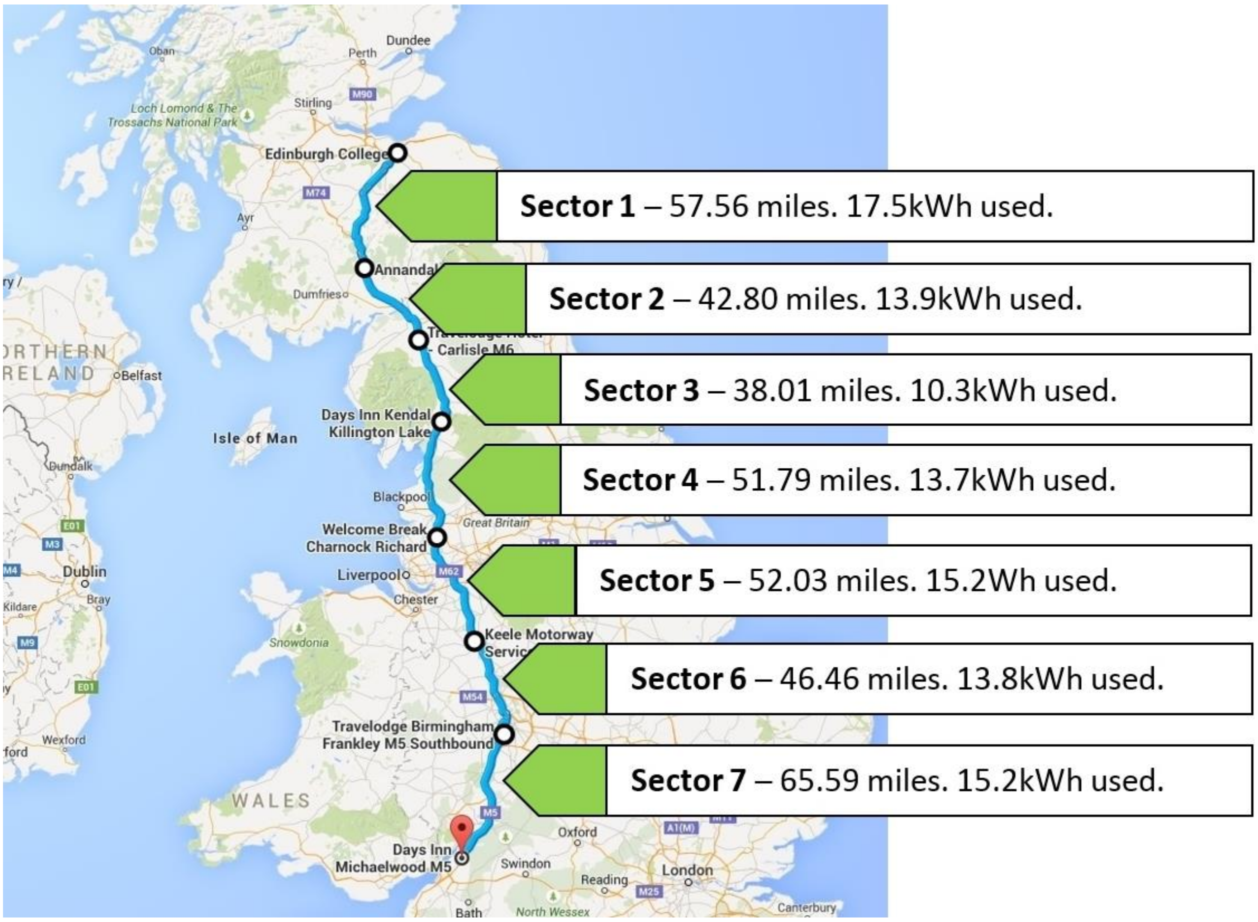


Figure 110 Intercity long range route – Scotland to England

The journey for detailed analysis was split into seven sectors this gave an accurate representation of the sections and due to the terrain and elevation the cost of the trip, fuel costs, emissions and energy consumed could be directly compared to ICE vehicles.

The time factor for the user was also taken into consideration as this type of journey is out with the expected user requirements. The BEV user must consider this factor as an acceptable duration of journey time and compared with an ICE vehicle.

The output of these will have an effect on the practicality of this type of mobility for a long range journey.

The electric vehicle was driven from Edinburgh to Bristol and the distance travelled is shown in Figure 110 between the charge stops. This just-in-time strategy for the charge interval was of paramount importance for a successful journey as the BEV did not have sufficient range in reserve to make the next stop and charge point either due to the extra demand placed on the traction battery on the higher speed sections or on the sections with a greater and constant incline.

Table 36 Charge section data

The charge sections driven gave actual measured data of:

Section 1	3.23 miles/kWh	5.17 km/kWh (poor weather, trunk road plus inclination)
Section 2	3.08 miles/kWh	4.93 km/kWh (Poor weather, 60 MPH section)
Section 3	3.70 miles/kWh	5.92 km/kWh (Poor weather, 50 MPH section, regeneration)
Section 4	3.78 miles/kWh	6.05 km/kWh (55MPH, motorway section)
Section 5	3.42 miles/kWh	5.47 km/kWh (55MPH, motorway section)
Section 6	3.37 miles/kWh	5.39 km/kWh (55MPH, motorway section)
Section 7	4.23 miles/kWh	6.77 km/kWh (Slipstream behind HGV, motorway section)

It was noted that the tractive efficiency varied constantly dependant on road conditions but instantaneous values on road sections gave data between 1.38 miles/kWh and 4.91 miles/kWh.

The BEV was driven at all times within the legislative speed limits and according to the prevailing weather conditions but it was determined within the course of the experimentation drive that the available tractive energy was consumed at a greater rate when the vehicle was driven at a higher speed.

Table 37 CO_2e impact and ICE vehicle comparison per section

1000 Mile Route Comparison (CO_2 Impact).

Day One:	**Distance (miles)**	**Energy Use**	**CO_2e Impact - UK Figures[(1)]**	**CO_2e Impact - Scottish Figures[(2)]**
Section 1: Edinburgh to Roadchef Annandale Water (M74).	57.56	17.5 kWh	8.09 kg	4.11 kg
Section 2: Roadchef Annandale Water (M74) to Moto Carlisle/Southwaite (M6 Southbound)	42.80	13.9 kWh	6.42 kg	3.27 kg
Section 3: Moto Carlisle/Southwaite (M6 Southbound) to Welcome Break Killington Lake (M6 Southbound).	38.01	10.3 kWh	4.76 kg	2.42 kg
Section 4: Welcome Break Killington Lake (M6 Southbound) to Welcome Break Charnock Richard.	51.79	13.7 kWh	6.33 kg	3.22 kg
Section 5: Welcome Break Charnock Richard to Keele Services.	52.03	15.2 kWh	7.02 kg	3.57 kg
Section 6: Keele Services to Moto Frankley	46.46	13.8 kWh	6.38 kg	3.24 kg
Section 7: Moto Frankley to Michaelwood (M5 Northbound).	65.59	15.2 kWh	7.02 kg	3.57 kg
Totals:	**354.24**	**99.6 kWh**	**46.03 kg**	**23.41 kg**[(3)]

	Distance (miles)	**Fuel Used & Cost[(5)]**	**CO_2 Emissions**	**Notes**
Equivalent ICE Comparison[(4)]:	354.24	46.00 ltr £47.84	77.53 kg	2014 Ford Focus 1.6 (Manual)

This long range intercity journey was carried out in a 2014, 2nd Generation Nissan LEAF 'Acenta'. All charging was free to the user and this is current practice at this time however it is under review by the government and it is expected that future studies in this field may show the local authorities requesting a payment for the charger use. The rapid charge complexities and different charge (monetary) methods with no apparent consistency across multiple authorities vary from:

- Rapid charge from £2.00 per session then 9 pence per kWh but with a monthly subscription of £8.00 (Chargemasterplc 2016).
- Rapid charges from 15 pence per kWh – flat rate (Transport Evolved 2016).
- Rapid charges from £5.50 for the first 45 minutes then 15 pence per minute after that with a maximum cost of £12.00 (Transport Evolved 2016).
- Rapid charges from £3.80 for the first hour then £5.00 per hour thereafter (Zap-Map 2016).
- Rapid charge nominal rate of £4.50 per session regardless of time – flat rate, this figure was utilised in the comparison tables this nominal £4.50 rate adopted for this study (Chargemasterplc 2016).

These are publically accessible rapid chargers, costs borne by the user will finance installation, support, infrastructure and the supplying company's profit. As indicated by (Energy Savings Trust 2015) the rapid charger will charge to 80% in approximately one hour whereas according to (UK Power Limited 2015) the domestic user will experience an electricity 'plug-in-tariff' costs between £0.094 and £0.104 per kWh for their electricity but the charge time to 80% will be in the region of six to seven hours.

- Note 1 in Table 37 indicates the CO_2e Impact, these UK Figures are based on UK Grid Carbon Intensity of 462.19g CO_2e/kWh for 2015 as given by the Governments Department for Environment, Food and Rural Affairs (DEFRA 2015).
- Note 2 the Scottish Grid Carbon Intensity of 235g CO_2e/kWh for 2013 is also given in Table 37 this is reported in the paper by (Committee on Climate Change 2015).
- Note 3 the CO_2e impact figures in Table 37 is calculated at nearly a 51% difference between the UK and Scottish values which indicates a clear difference in the carbon intensity between England and Scotland power generation methods which can be evidenced by the greater percentage reliance on renewable technologies in Scotland over than fossil fuel fired power stations primarily using polluting oil, gas and coal.
- Note 4 this journey can be directly compared with the fuel and environmental cost of a current similar sized ICE passenger vehicle the 2014 Ford Focus 1.6 emissions at 136g/km as shown in Table 37. According to (Lane 2015) this similar sized vehicle will give an expected 35mpg under this drive cycle and the financial cost will be nearly £100 for the return journey directly borne by the user and of which 72% is taken by the government as tax.

- Note 5 this petrol cost is variable and market fluctuations will determine the final garage forecourt cost to the user. Table 37, it has been stated (Automobile Association 2015) that the fuel cost had been determined by calculating the December 2015 average UK fuel price of £1.04 per litre (95 Octane Unleaded). This cost has fallen by 9% in the last twelve month period.

It should be noted that the latest fuel price report as indicated by (Automobile Association 2016) that the average UK price of 95 Octane Unleaded has increased to £1.11 per litre.

Table 38 Overview between ICE Vehicle and BEV CO_2 and Cost comparison

1000 Mile Route Comparison (CO_2 impact + monetary cost).

	Distance (miles)	Energy Used	Total Cost of Charges(1)	Cost per Mile	Cost per kWh	CO_2 at Tailpipe	CO_2e Impact of power gen. - UK Figures(2)	CO_2e Impact of power gen. - Scottish Figures(3)
Nissan LEAF	1008.6	269.5 kWh	£72.00 Actual £ 0	£0.07	£3.74 Actual £ 0	nil	124.56 kg	68.08 kg

	Distance (miles)	Amount of Fuel Used	Total Cost of Fuel(5)	Cost per Mile	Cost per Litre	CO_2 at Tailpipe	CO_2e Impact of fuel production - UK Figures(6)	CO_2e Impact of fuel production - Scottish Figures(3)
Equivalent ICE Comparison(4)	1008.6	131.00 litres	£136.24	£0.15	£1.04	220.75 kg	79.90 kg	43.67 kg

Total Carbon Impact for 1000 mile trip (UK Figures)	
Nissan LEAF	**Equivalent ICE Vehicle**
124.56 kg CO_2e	300.65 kg CO_2e

Total Carbon Impact for 1000 mile trip (Scottish Figures)	
Nissan LEAF	**Equivalent ICE Vehicle**
68.08 kg CO_2e	264.42 kg CO_2e

Trip carried out in a 2014, 2nd Generation Nissan LEAF 'Acenta'.

At the time of experiment journey as illustrated in table 38 the following costs and data were utilised to determine the comparative pollution emissions from an internal combustion vehicle.

All six notes refer to Table 38.

(1) Ecotricity 'Electric Highway' charge posts used. All currently free to use so cost assumes 16 logged charges during trip at nominal £4.50 (flat rate per session)

(2) Based on UK Grid Carbon Intensity of **462.19g CO_2e/kWh** for 2015.

Source: (DEFRA 2015)

(3) Based on Scottish Grid Carbon Intensity of **252.6g CO_2e/kWh** for 2013.

Source: (Committee on Climate Change 2015)

(4) 2014 Ford Focus 1.6 emissions at **136g/km. 35mpg**.

Source: (Lane 2016)

(5) Fuel Cost calculated using December average UK fuel price of **£1.04 per litre** (95 Octane Unleaded).

Source: (Experian Catalist 2015)

(6) Approximately 6kWh of energy is used to produce 4.546 litres (1 gallon) of unleaded fuel.

Source: (The Long Tail Pipe 2015)

Therefore, 131.00 litres of unleaded used divided by 4.546 gives the number of gallons. That result, multiplied by 6 kWh, determines the amount of energy used to create 131.00 litres of fuel.

The calculated figure is **172.9 kWh** – the grid CO_2 intensity of which is **79912.7g (79.9kg).**

Add that to the emissions caused by burning the fuel, and the CO_2 impact of an ICE for 1000 miles is **300g/km.**

6.4.7 Analysis of pollutants

Table 39 Overview between ICE Vehicle and BEV CO_2, NO_x and Cost comparison

1000 Mile Route Scotland/England Comparison (CO_2 & NO_x impact + monetary cost).

	Distance (miles)	Energy Used	Total Cost of Charges[(1)]	Cost per Mile	Cost per kWh	CO_2 at Tailpipe	NO_x at Tailpipe	CO_2e Impact of power gen. - Scottish Figures[(2)]	CO_2e Impact of power gen. - English Figures[(2)]	NO_x Impact of power gen. - Scottish Figures[(3)]	NO_x Impact of power gen. - English Figures[(3)]
Nissan LEAF	1008.6	269.5 kWh	£72.00 Actual £ 0	£0.07	£3.74 Actual £0	nil	nil	68.1 kg	121.9 kg	22 g	206 g

	Distance (miles)	Amount of Fuel & Energy Used	Total Cost of Fuel[(4)]	Cost per Mile	Cost per Litre	CO_2 at Tailpipe[(5)]	NO_x at Tailpipe[(6)]	CO_2e Impact of power gen. - Scottish Figures[(2)]	CO_2e Impact of power gen. - English Figures[(3)]	NO_x Impact of power gen. - Scottish Figures[(4)]	NO_x Impact of power gen. - English Figures[(5)]
Equivalent ICE Comparison	1008.6	131.00 litres 172.9 kWh	£136.24	£0.15	£1.04	220.7 kg	48.6 kg	43.7 kg	78.2 kg	14 g	132 g

Table 40 Scottish and English environmental impact

Total Impacts for trip (Scottish Figures)		
	Nissan LEAF	**Equivalent ICE Vehicle**
CO_2*	68.1 kg CO_2e	264.4 kg CO_2e
NO_x**	22 g NO_x	62 g NO_x

Total Impacts for trip (English Figures)		
	Nissan LEAF	**Equivalent ICE Vehicle**
CO_2*	121.9 kg CO_2e	299.0 Kg CO_2e
NO_x**	206 g NO_x	180 g NO_x

Tables 39 and 40 demonstrate the difference in total environmental costs and pollutants when the BEV is used primarily in Scotland or used in England.

As illustrated, when the BEV is driven in England the total pollutants emitted is overall higher due to the power generation method. The Nissan LEAF CO_2 emissions for the test journey were almost twice the level due to the greater reliance on fossil fuel for current power generation. These findings agree with the National Statistics given from Department of energy and climate change in table 41.

Table 41 Energy generation trends – 2015 data

	Scotland	Wales	Northern Ireland	England	UK total
2013					
Coal	20.4%	44.4%	34.0%	38.8%	36.4%
Gas	10.3%	17.3%	45.8%	30.3%	26.7%
Nuclear	34.9%	16.7%	-	17.5%	19.7%
Renewables	32.0%	10.3%	19.5%	11.8%	14.8%
Oil and Other	2.4%	11.3%	0.7%	1.6%	2.4%
2014					
Coal	20.3%	35.7%	28.3%	31.1%	29.7%
Gas	5.4%	24.1%	49.1%	34.3%	29.8%
Nuclear	33.3%	9.3%	-	17.3%	18.8%
Renewables	38.0%	16.3%	22.2%	15.6%	19.1%
Oil and Other	2.9%	14.6%	0.3%	1.7%	2.6%

(Dept of Energy and Climate Change 2015)

6.5 Conclusion

The driver of an electric vehicle requires reliable information with regard to the potential range of the vehicle. This must be taken from a real world data set and this 16 point analysis gives a clear indication of the achievability of distance when compared with previous NEDC and the display as indicated by the vehicle dashboard.

Integrating external data from web and global positioning with battery conditions it has been argued (Enthaler & Gauterin 2013) that the state of charge, state of health and operating temperature supports the internal battery losses may be attributed to incorrect range estimations. That may be a topic for further study. This study at present has indicated that the dash board value of distance remaining and the real life value is inconsistent as it is displaying between 56% and 88% of a difference dependant on the climatic conditions and the route taken.

This study indicates the error present and it is this information the electric vehicle user must be aware of so that the journey can be completed without traction battery depletion. (Enthaler, Achin., Gauterin 2013).

This experiment achieved an accurate representation of available range and gives an indication of the costs incurred both monetary and CO_2 released to atmosphere. The accuracy of the displayed value had significant error when compared with the actual experimental findings and this error margin increased when the vehicle was subject to colder weather conditions or when the vehicle was subject to gradient change when the battery was subject to a higher demand.

One feature of the experimental journeys within this section was that it necessitated a general commuting driver rather than a specialist professional driver. It will be this commuter driver that will experience the BEV as a ‘pool car’ to fulfil their job role and the response variable will be the energy economy of the vehicle irrespective of the climatic conditions.

This section had a focus on the electricity generation methods and the differences between energy generation methods between England and Scotland, and how this plays an important part in a sustainable transport system.

When considering a BEV for the journey it is important to consider the security of the energy supply and carbon free energy sources in the transportation sector to assist global CO_2 overall reduction targets.

These tests were conducted on open public roads and offered a real life data set that reflected the actual performance of the BEV to replace a large proportion of conventional vehicles that are restricted to low-mileage commuting.

This experiment will be an essential part of route planning for situations where the electric vehicle will be used as a 'daily commute' vehicle or when put into a commercial activity and used by a number of drivers all which may have specific driving behaviours.

There has been little research considering that different BEV users have their own tolerance of 'range anxiety' which means that drivers will not always charge their batteries until the batteries are running out. Different drivers will react on range anxiety differently when they arrive at a charging station. So, it is important to consider the range anxiety as a term which differs among the users.

This study of grid, lifecycle, drive cycle and user when conducted together will give a meaningful dataset that ultimately give a higher degree of confidence of the BEV's efficient capabilities to replace the ICE vehicle for the normal daily travel.

Chapter 7 Appraisal Management Systems

7.0 Overview

For an efficient management system, the control systems of business BEV allocation booking will be analysed. This is designed and implemented to ensure that the vehicles are fully utilised and that their use can be a 'planned' event. This will be of great benefit as a vehicle management tool which, with bespoke design and execution will ensure that the vehicles are suitable for the intended journey. This system will complement GPS tracking for fleet control.

This tool will also control the legal aspect and safe conduct of drivers and licence permissions in compliance with the business needs. The author decided to allow a maximum allocation of six penalty points endorsed on the user's licence to promote and install a safe driving cohort.

Users can be added and removed from the system in-line with changing business needs and staff recruitment furthermore the user system activity can be controlled, tracked and monitored as required.

7.1 Introduction

The first models of electric cars that were made available within the UK were Nissan LEAF and Mitsubishi i-MiEV. Now all of the mainstream car manufacturers provide BEVs within their model range.

In 2011 Edinburgh College acquired electric cars for supporting inter-site staff travel. This was followed by Edinburgh Napier University acquiring a Renault Zoe EV. The latter two educational institutions have also installed EV charging points at each of their campuses. The third partner of this study - Maribor University of Slovenia – hosts a Faculty of Logistics which is in the process of setting up an electric vehicle research program. A brief account of the relevant activities of Edinburgh College is provided below.

Edinburgh College are playing a leading role in monitoring 14 BEV's which have been on contract hire 10,000miles per annum over a three year period. There are a total of twenty-four charging points, two located at each campus and the remainder at strategic locations across Scotland where business use has been identified. The BEVs are for staff use only and for corporate College business embedded into the company's fleet travel plan. The College has leased the BEVs since 2011 with the first year operating as a trial period, following full roll out of vehicles to the four main campuses.

Trials are still frequently undertaken to understand the efficiency of the vehicles in serving the operational needs of the staff at the College.

Staff can book an electric vehicle through a simple booking system available on the College's intranet site. Out of the 1,500 staff working at the college, 550 staff have signed up to use these cars and are now approved users. The typical workforce using the vehicles comprises workplace assessors and staff who undertake lectures at various locations. It is compulsory practice that prior to the member of staff requiring access to the system all new registrations undertake training. As identified by (Tinsley 2014) taking the time to train and motivate personnel will aid in developing skills and allow a swifter implementation. This requirement is for new staff and to provide ongoing support to existing staff as car models and layouts change or to establish confidence to infrequent users.

This personnel training saves on organisational resources and minimises operational disruption.

7.2 Range limitations

Limited range is a challenge for BEV users. A frequently discussed phenomenon in this context is range anxiety. There is some evidence suggesting that range anxiety might be a problem only for inexperienced BEV drivers and, therefore, might decrease with practical experience. It has been shown that comfortable range increases with BEV experience over a period of three months (Franke, Cocron, et al. 2012).

It has been realised that comfortable range is likely to increase with longer periods of driving experience. Indeed, in the early trial periods the dashboard displays were constantly being checked and after driving the vehicles from campus to campus which could be a short 10 mile distance were put on charge on arrival (Franke & Krems 2013). This is reinforced by research which indicates that after a few months, it is only possible to attain an acceptable level of competence in a specific domain; whereas, a far longer period of time is needed before an individual is able to develop an optimal level of relevant knowledge and competence (Ericsson 2006).

The battery electric vehicles introduced as 'pool cars' did experience an initial period of uncertainty as all staff were encouraged to fully utilise them as the preferred method to inter campus travel (Franke et al. 2015). A system of training sessions and confidence building was required to support this implementation.

A part-understanding of the technology was required to offer clarity and to reinforce the vehicles capabilities.

All of this became available on the Edinburgh College BEV booking system. A simple to use self-service system that would give the user the ability to book a vehicle and thus removing it from general availability at this time.

7.3 The performance analysis of independently devised user-control system

The system was required to be an easy to use, easy to manage, cloud-based reservation and scheduling system. Developed in-house and based on open source software from http://www.bookedscheduler.com/ this open software allows bespoke booking systems to be developed and is an ideal interface for staff to manage and adapt their own bookings.

7.3.1 Field requirements

Grey fields represent times the cars are available. Red fields show that a vehicle cannot be booked. To start a booking, the user will click on a start time. This generates a pop up screen as shown below where a start time can be set, a recurrence, details added on the nature of the trip, plus any participants.

Clicking 'save' generates an email which can be printed out so that it can be handed over to facilities staff at each campus in exchange for the eCar keys. The booking can also be printed straight from the system. Bookings are editable, and can be transferred to other staff members by administration if necessary.

The system allows reports to be generated for visibility of multiple statistics such as: monthly number of bookings, most bookings per user/group etc.

7.3.2 Data collection methods

As all users must have a College computer systems account, they will access the system and in doing so they are identified with a unique user number and their email name and address is stored against the requested activity. This personal identifier is required as the username to access the booking management system. The user states the time and date that the vehicle is required for and submits this information. An automated response is sent to the applicants email confirming the request has been successful.

All authorised staff can see other bookings but they can only modify their own by accessing the system and following the on-screen instructions.

7.3.3 User interface

The system was required for resource allocation to ensure that all staff had aces to a user identifiable and controlled management system. In the early developing trials of the project any existing users migrated from previous database.

All new users have to register using their email address. Permissions are set by assigning each user a 'group' based on their main home campus. This determines which eCar they are able to take out. Global announcements can be made through the front page (Dashboard) to remind users of holidays etc.

Driving licence checks are in place and vehicle use and charging training is conducted, importantly, the user cannot access the system until these competencies are complete.

7.3.4 Evaluation

Currently, there are fourteen electric vehicles in the system, multiple cars for each campus. User Interface is located on the Edinburgh College homepage on the intranet and is a calendar based system as illustrated below:

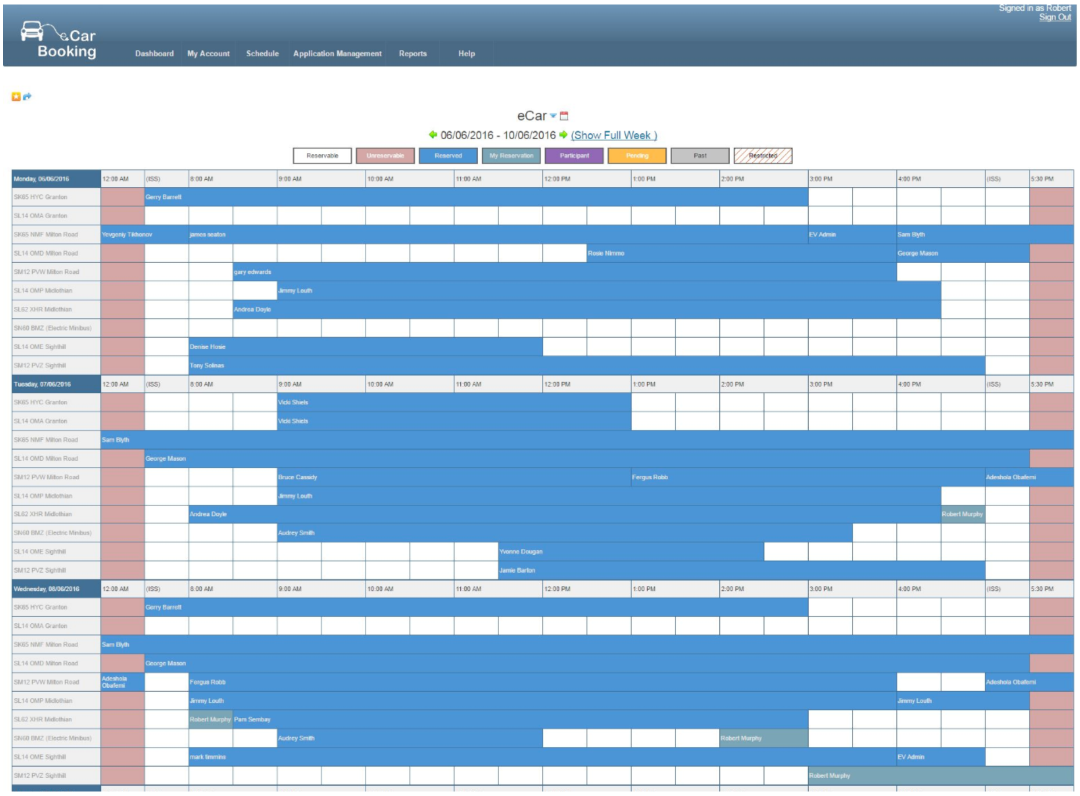


Figure 111 Management system calendar screen

There are currently in excess of 550 individual users, split across four main campus groups. The total number of bookings since the new system went live in 2012 is in excess of 6300 across the entire Edinburgh College fleet.

If passwords are forgotten, a link on the log in page will generate an email with a new password so that the user can log in and reset it. Passwords can also be reset manually over the phone by contacting eCar administration. Users are able to assign themselves a unique username should they wish or they can continue to log in with their email address. Multiple group permissions can be assigned if there is a valid business reason. Most staff do have an individual campus base so should not require this but it can be made available if required.

The system is intuitive and self-policing. When people see on-screen that a vehicle is already out, they cannot book it. If necessary, bookings can be controlled by having each one set to ask for authorisation when it is submitted (feedback).

Table 42 displays the data in table format. The actual monthly data is displayed graphically in figures 113 and 114 which also give an indication of the salient points that occur within the business such as peak travel times and frequency of low activity due to academic student/staff holidays.

The booking system went live in 2012 tables 42 and 43 give a snapshot figures from May for the last four years followed by the annual figures.

Table 42 Individual month illustration

May 2012 – 3 booking
May 2013 – 101 bookings (annual 97% increase)
May 2014 – 114 bookings (annual 12% increase and number of bookable vehicles doubled due to project expansion)
May 2015 – 190 bookings (annual 40% increase plus an additional four bookable vehicles)
May 2016 – 329 bookings (annual 43% increase)

The month of May was chosen due to the high frequency of mobility activity generated by activities in the conclusion to the end of the academic term. May has a higher activity of workplace assessors using vehicles that any other month. Workplace assessors are the greatest users as can be seen in table 45.

Table 43 Annual illustration

2012 – 285 bookings per annum
2013 – 963 bookings per annum
2014 – 1601 bookings per annum
2015 – 2083 bookings per annum
Jan - May 2016 – 1401 bookings to date (projected to be in excess of 3360 per annum)

Table 43 illustrates the increased user frequency over a four-year period and this increase also accounts for all campus locations increasing their available vehicles by either a factor of two or three as the initiative became established.

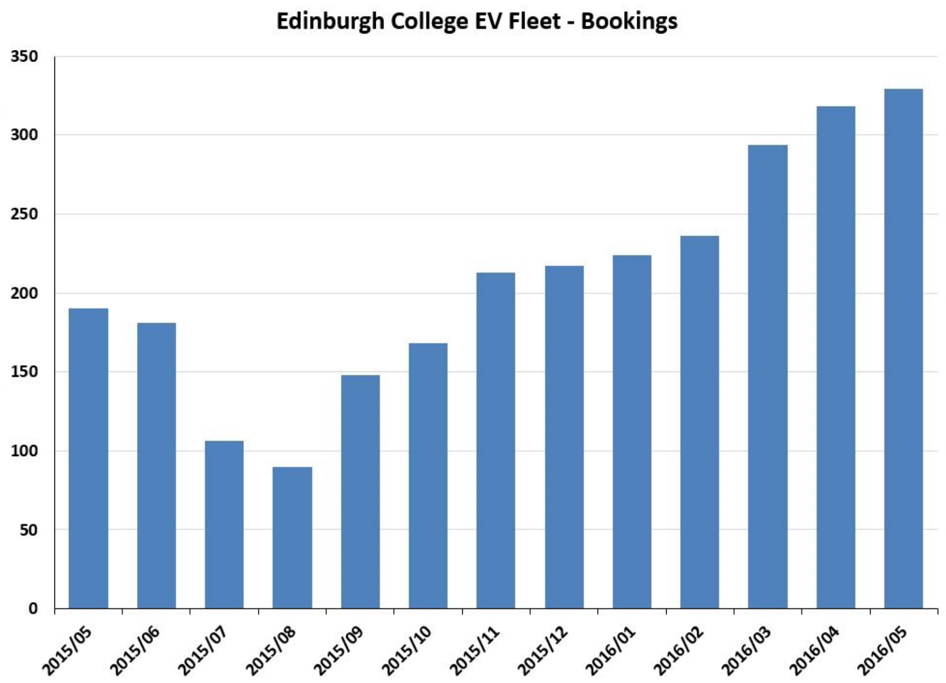


Figure 112 Annual illustration of the management system – May 2015 till May 2016

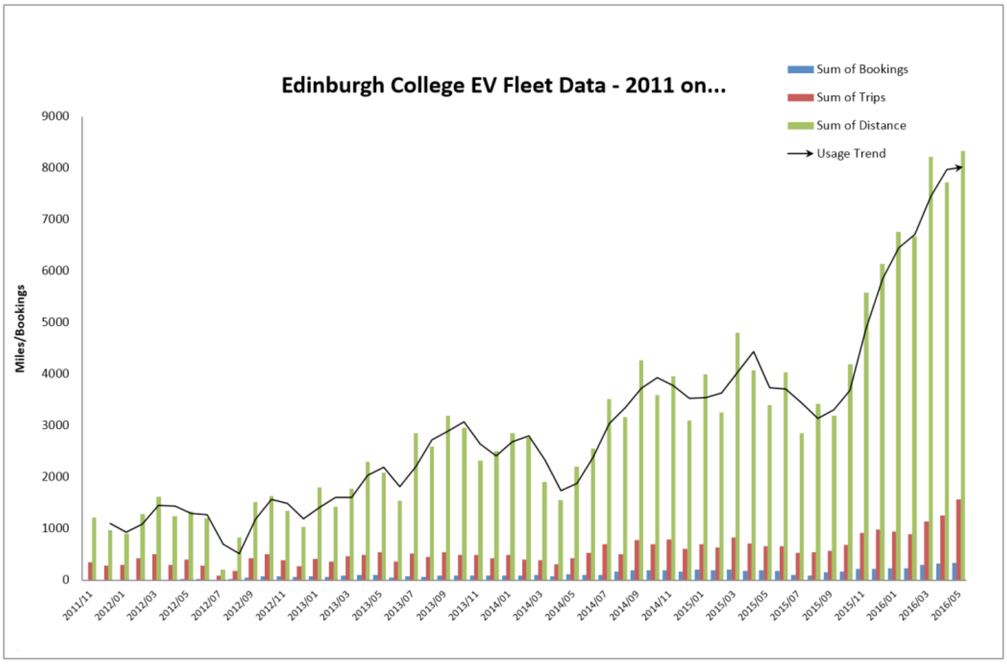


Figure 113 Annual usage trend 2011- 2016

Figure 114 indicates the whole fleet usage trend. This usage pattern is supported by the works of (Pearre et al. 2011) which takes into account all activity and illustrates the increase in frequency as an increased number of users travel further as drivers become more confident in the BEV.

7.4 Fleet vehicles - economic and environmental impact analysis

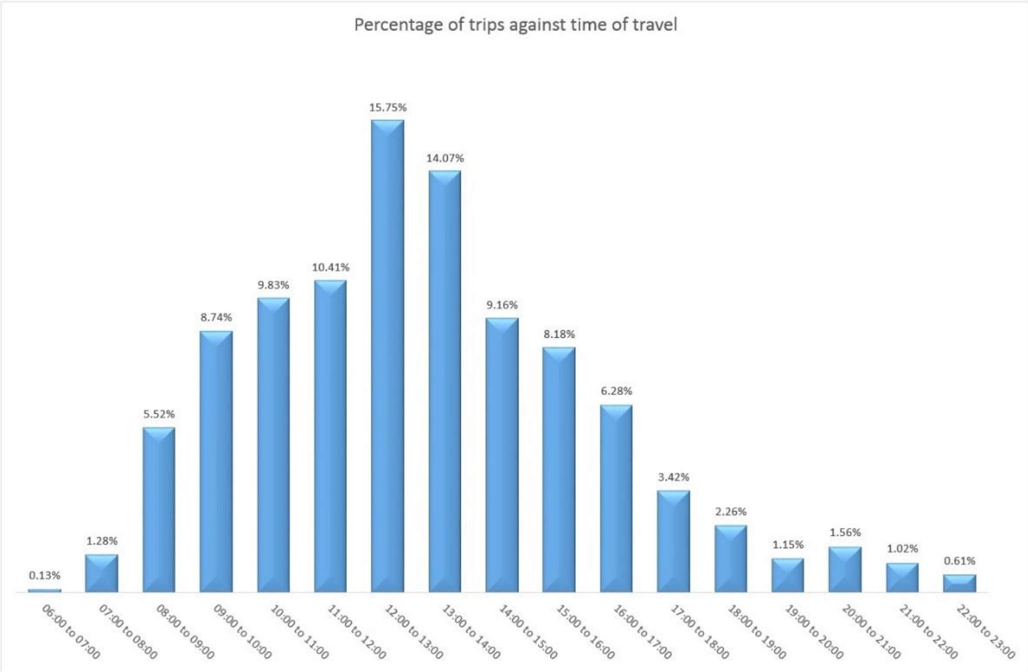


Figure 114 Typical travel times and frequency

Figure 115 and 55 indicate the frequency shift pre and post College merger. The pre-merger period gave rise to discussions around further utilisation of the BEV fleet to the general public out with College opening times as a ‘EV car club’ to generate income. This demand will warrant further study and is recommended as future work in chapter eight.

Currently the Milton Road campus has the highest demand for electric car use, with the Granton campus having the lowest demand. Notwithstanding this, given the nature of activity, the usage of the electric cars at each of the College campuses fluctuates throughout the academic year.

Whilst there is a booking system in place which records journey lengths, their origins and destinations, it was difficult to identify if there have been many occurrences of staff trying to book a car and being unsuccessful due to a lack of availability of cars.

In April 2015 a ‘survey monkey’ (Survey Monkey 2015) was used to identify the acceptance within the College and to determine the users’ perception of key drivers within the project. The anonymous ‘survey monkey’ was offered to all authorised eCar users and consisted of the same eight questions over the two year focus period. The questions were multiple choice and rated the activity out of ten with one being unacceptable and ten being exceptional. The final question was ‘free text’ and this gave the participants an opportunity to offer an expression or state their opinion.

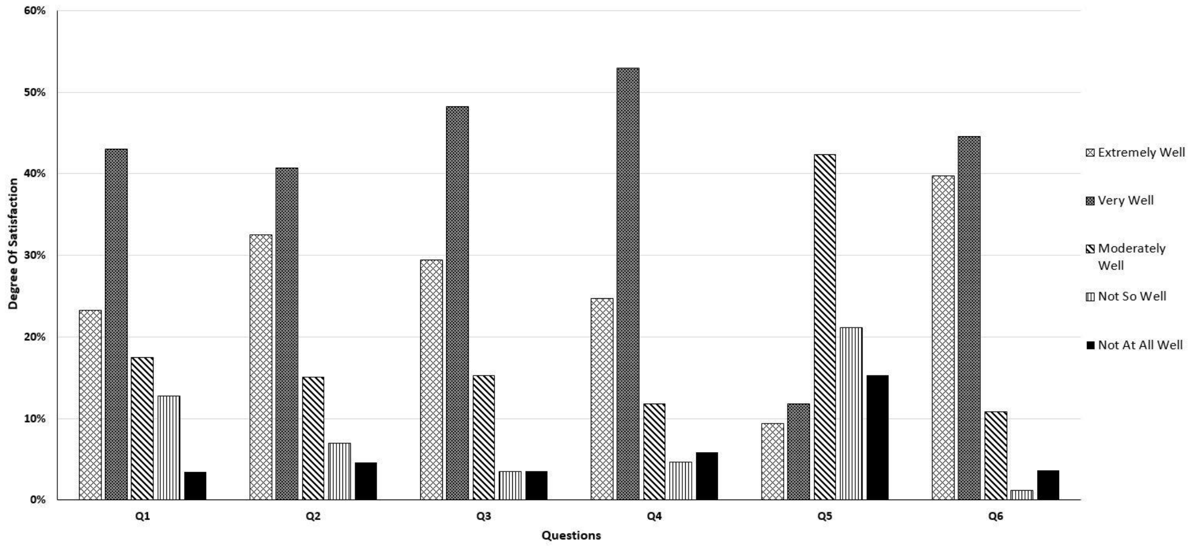


Figure 115 Satisfaction response to survey - overview

Figures 116 to 122 inclusive give an indication of the responses from the individual questions and the differences over a one year period. All respondents indicated a positive experience with one exception. This exception was question 5, with greater staff numbers utilising vehicles there are occasions where vehicles are fully utilised and therefore unavailable.

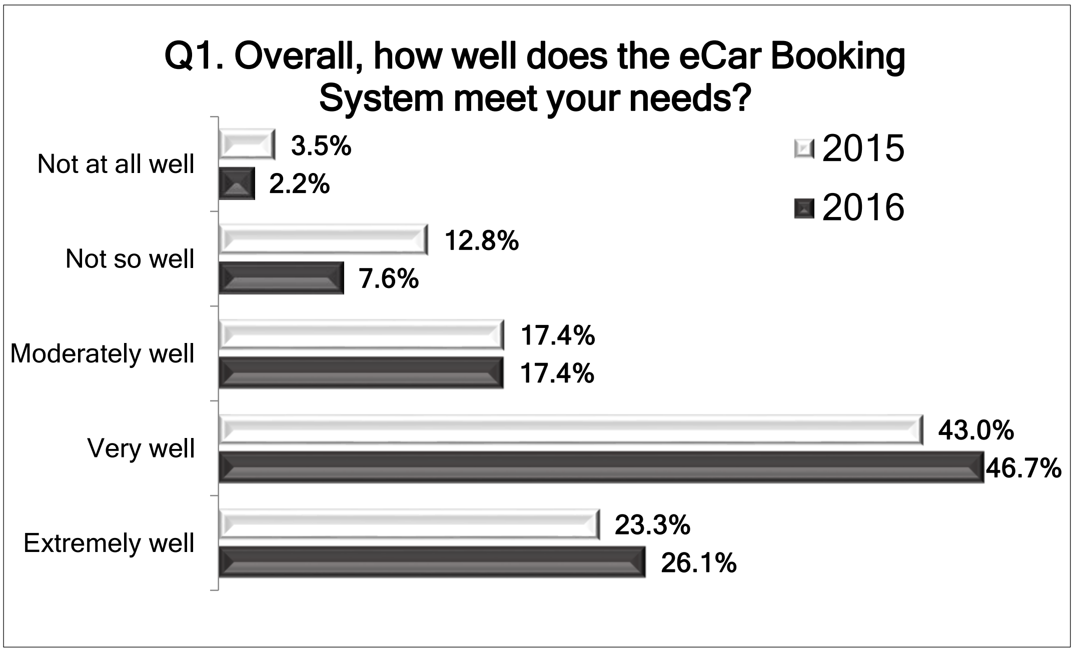


Figure 116 Staff survey and annual comparison – Q1

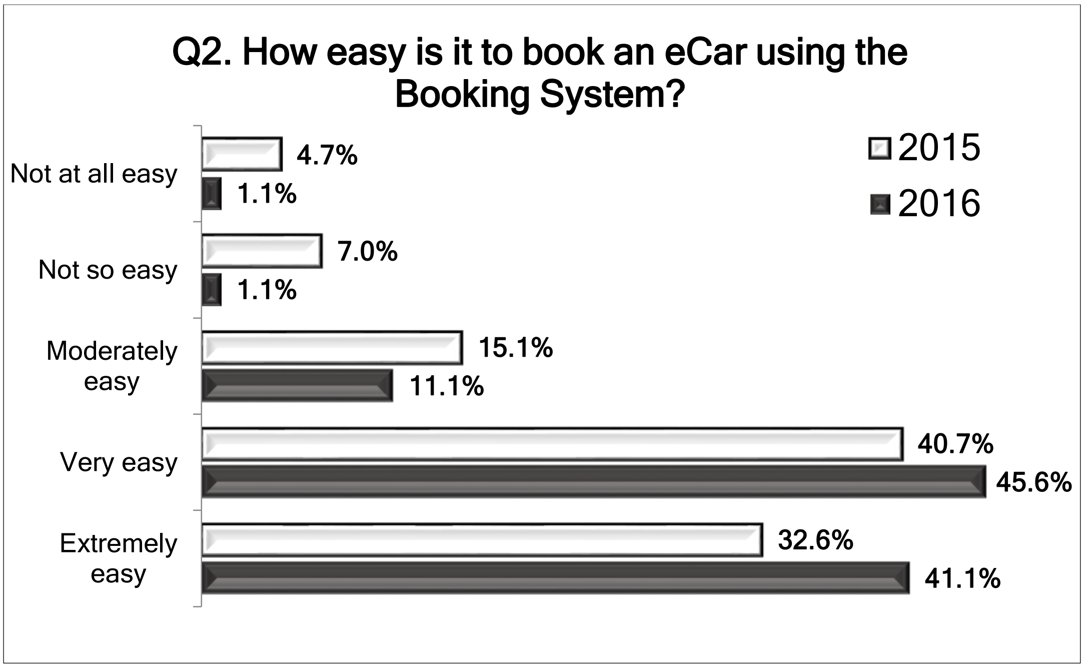


Figure 117 Staff survey and annual comparison – Q2

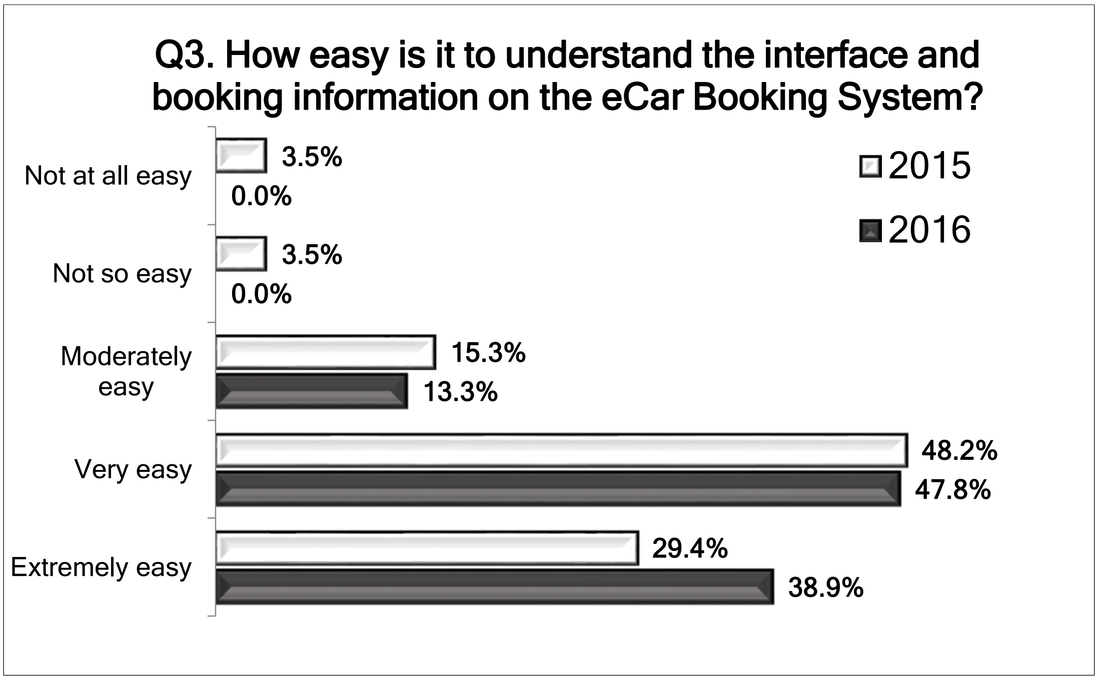


Figure 118 Staff survey and annual comparison – Q3

These responses to question 2 and 3 indicate that staff over time have accepted the interface and the ease of the interaction. This has improved within the year and with the personnel acceptance and user confidence.

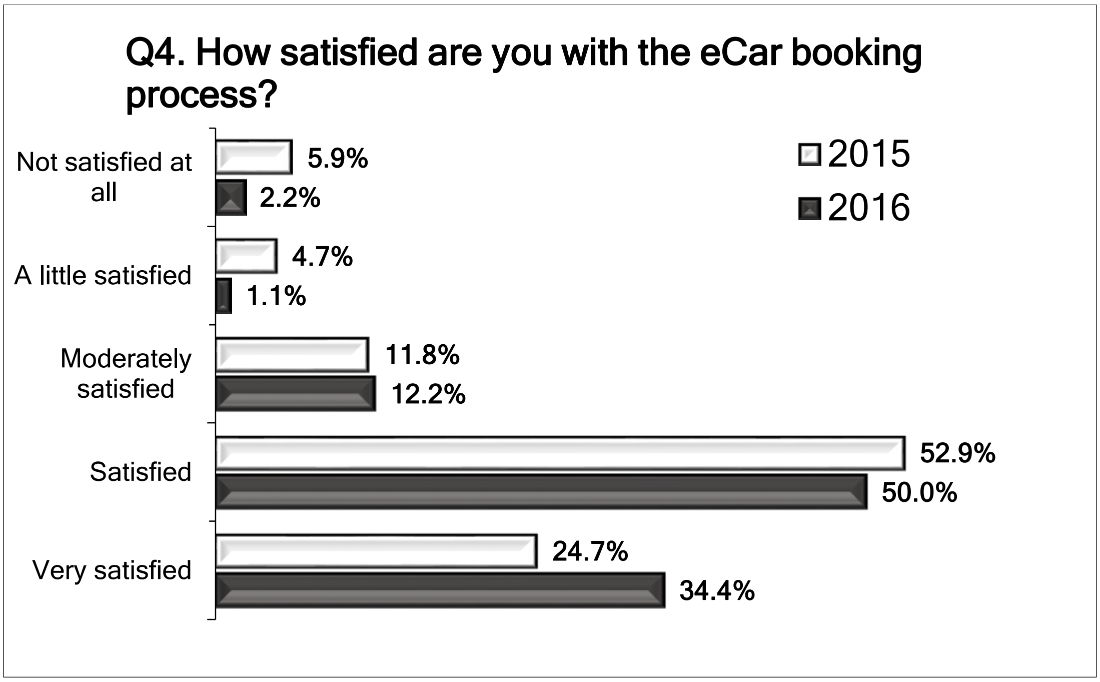


Figure 119 Staff survey and annual comparison – Q4

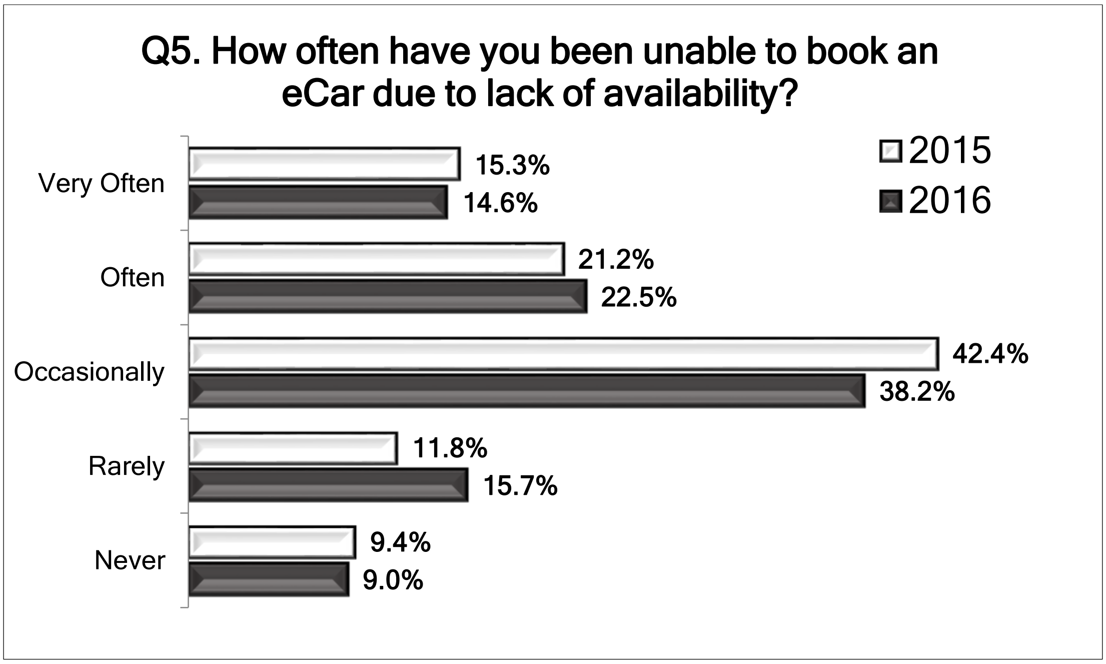


Figure 120 Staff survey and annual comparison – Q5

The responses to questions 4 and 5 indicate that staff are positive about their booking execution and have experienced consistency with lack of car availability over the year period. This 'balance' between availability and surplus vehicles is positive and personnel driven as within this year extra vehicles were made available in-line with demand.

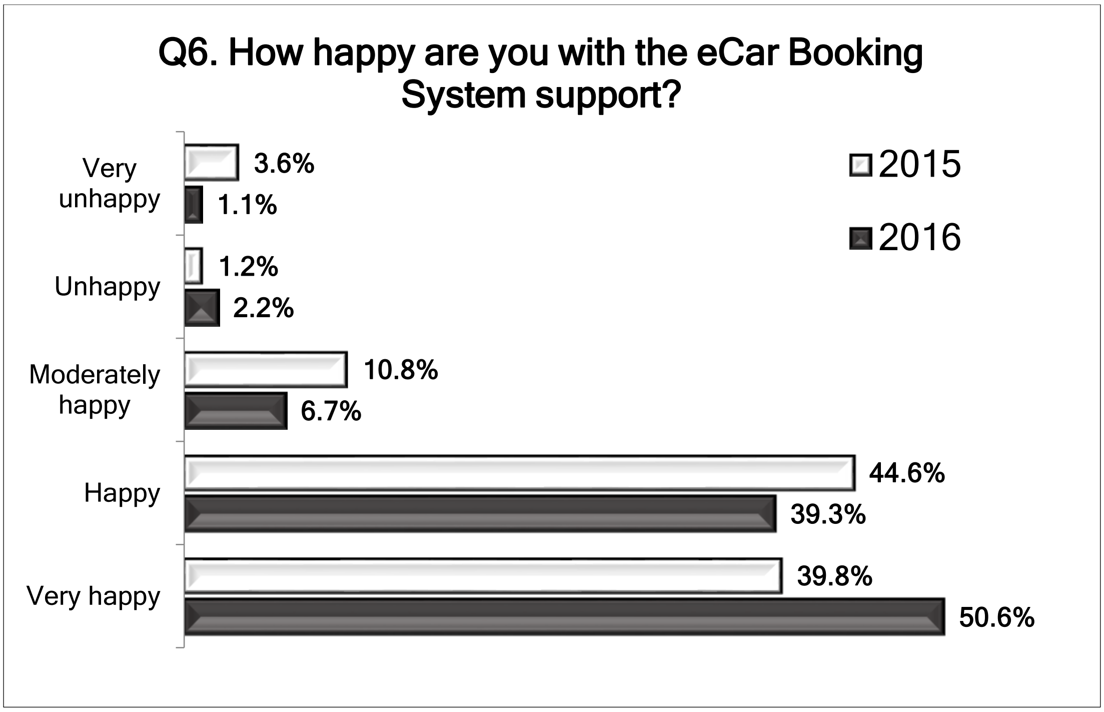


Figure 121 Staff survey and annual comparison – Q6

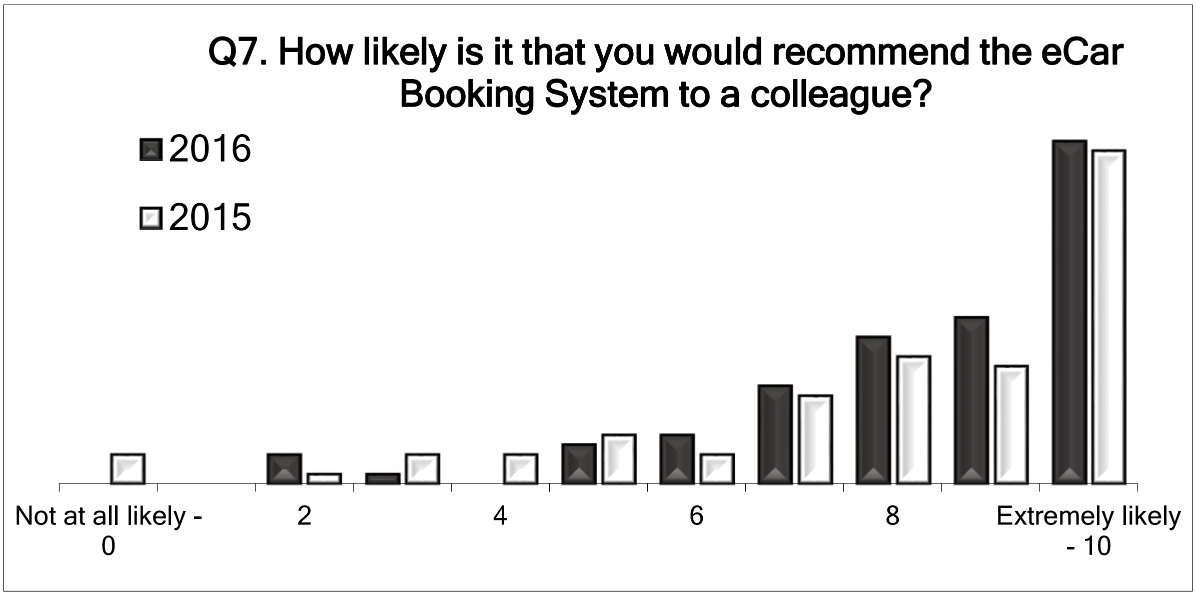


Figure 122 Staff survey and annual comparison – Q7

The response to question 6 has been positive since the mobility exercise began. This indicates that having foundation training, user support and proactive assistance from inception gives the user confidence in the exercise.

7.4.1 Results and findings from staff analysis

Figure 123 and 124 illustrates the findings from this in the form of a ‘word cloud’. It can be seen that in the early questionnaire that the concerns portrayed in the free text were with the lack of vehicles to satisfy the users requirements and in the later study the complaints were with staff block booking and preventing the staff group access.

A study by (Thompson et al. 2011) reviewed a demand responsive transport system (DRTS) and the growing pressure of higher levels of service in transport systems. This present DRTS and the associated financial constraints, increasing the number of vehicles at a reasonable cost was implemented. The current study realised that the demand for flexibility through additional vehicles was being requested by personnel reducing their dependency on the ‘grey fleet’.

Figure 123 April 2015 word cloud

In response to this earlier survey extra vehicles were introduced to the initiative in an attempt to increase availability across all campuses. This proved to be on the whole successful but with the increased number of vehicles introduced, an increased number of users followed which put a greater focus on the charging infrastructure.

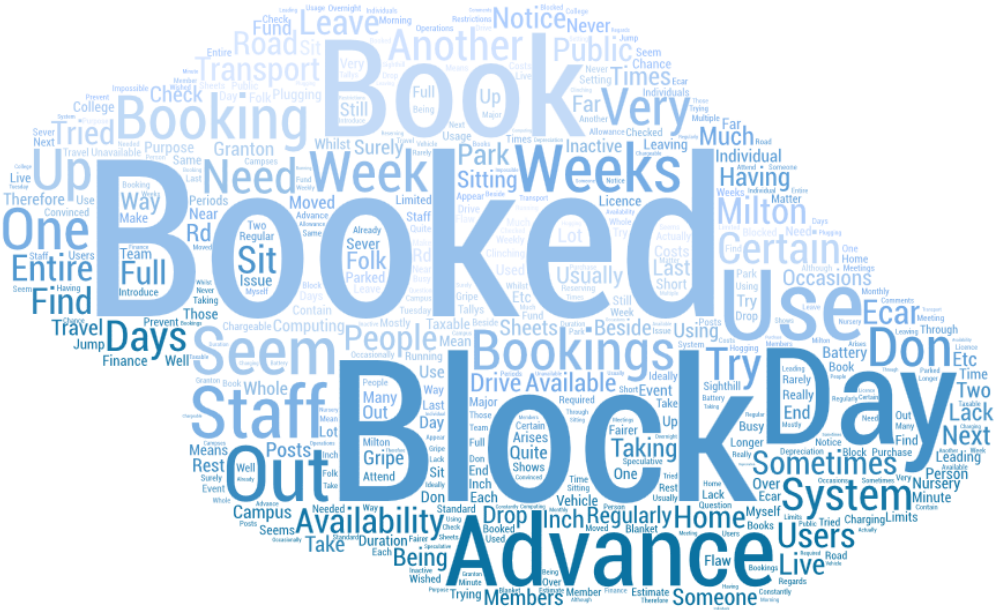


Figure 124 April 2016 word cloud

In an attempt to improve on the activity for all user's additional vehicles have been incorporated at each Campus and the maximum time a vehicle can be booked is now restricted by permissions being set on their user profile.

The majority of staff have only single campus user access and this will be their primary campus. The rationale behind this was remove any confusion and the requirement to identify vehicle registration numbers as it was a concern that cars may not be returned to the 'correct' campus and the possibility of a campus being without its allocation of vehicles.

The volume of vehicles is currently marginal to the user's needs and any downtime such as infrastructure failure or vehicle of road for servicing can cause disappointment.

7.5 Analysis of user groups

The College has a wide range of user groups which can be broadly divided into the following categories:

Academic staff

- Lecturers
- Instructors
- Workplace assessors

Support staff

- Administrative
- Facilities
- Janitorial
- Management

From the present study it was identified that the BEV's suited the needs primarily of Workplace assessors, Facilities and Janitorial staff as being the most frequent users. Table 44 illustrates the breakdown across the staff base where the role of the Lecturer, Instructor and Management staff were recorded as users but to a lesser extent. This is due to the nature of their role; with the Lecturer and Instructor focus being located mainly at one campus for longer periods.

Table 44 Frequent users and designation

1st September 2015 to 31st August 2016

Name	Area	Bookings
College staff No.1	Support (Workplace Assessor)	179
College staff No.2	Support (security)	166
College staff No.3	Support (security)	138
EV Admin	Support	100
College staff No.5	Support (IT)	95
College staff No.6	Support (Janitorial)	94
College staff No.7	Support (Maintenance)	79
College staff No.8	Teaching	78
College staff No.9	Support (Schools Coordinator)	78
College staff No.10	Support (Janitorial)	63
College staff No.11	Support (Maintenance)	55
College staff No.12	Teaching/Support	51
College staff No.13	Support (Business Development)	43
College staff No.14	Support (Curriculum Management)	39
College staff No.15	Support (IT)	37

A greater understanding should be portrayed around why we are using and potentially buying the vehicle in the first place, is it necessary to choose the ICE option and is the BEV option being overlooked or is it the case of the BEV is perceived as not being suitable for the individual’s intentions.

Environmental concerns and as discussed by (Rauh et al. 2015) human behaviour should be taken into account and if correctly considered the BEV could easily become the second car of the individual user that currently has two cars in their household.

This study is supported by the work of (Moons & Pelsmacker 2012) that gives insights into the specific motivators for segments of users that might become the early adopters of the electric car compared to those who would adopt this innovation at a later stage. More specifically, and following suggestions by (Albayrak et al. 2011), the difference in the decision-making process between individuals with high and low environmental concern and behaviour, and individuals that express more willingness to pay higher prices with different personal value orientations has been reported.

From the present study users appraised range as a resource to which they could successfully adapt and that satisfied most of their daily mobility needs and this was evidenced within the user group survey. However, early indicators were found that suggested further vehicles were required at each campus and later suggestions indicated that block bookings were problematic and detrimental to utilisation.

There is a fine balance between the need for further vehicles across campuses and greater control and permissions to allow ‘inter-bookings’ within the main booking to maximize the initiative whilst keeping the cost incurred at a minimum.

Presently, ‘inter-bookings’ are being trialed to gauge effectiveness with respect to recharge and availability.

7.6 Conclusion

The BEVs allocation booking system has been analysed with a view to amend as the demand has indicated. Results of this chapter will be very useful for developing e-vehicle management tool as well as demand responsive transport system in corporate environment for business use.

The early adopters of the electric vehicles within the College were the Workplace assessors and high initial users were also academic staff moving from campus to campus. As the legacy Colleges' merge became consolidated into Edinburgh College there was less academic mobility. With the introduction of the second phase of the 'appraisal management booking system' a greater emphasis was portrayed on the user hence, it may be possible to overcome perceived range barriers with the assistance of psychological interventions such as information, training, and interface design.

Providing drivers with a reliable usable range may be more important than enhancing maximal range in an electric mobility system. Indeed, with the four campus locations being within ten miles from each other user confidence developed and the vehicles capabilities were identified through use and systems support.

The appraisal booking system is an integral component of the overall project from intranet self-service to safe key administration. The system has identified shorter idle times and shorter turnaround times. Individual campus users can accurately self-monitor the systems live data, and with confidence know the vehicle can be booked-used-returned within a time frame and have sufficient charge for the next user.

Chapter 8 Conclusion and Future Work

8.0 Overview

Battery electro-mobility provides a solution that maintains personal freedom and autonomy while addressing the many public (environmental and health) challenges posed by the internal combustion engine. Realising this change however requires new ways of looking at the problem to identify the economic opportunities and, given the challenges of the financial crisis to effectively implement these solutions.

While the final approach must lie with the local communities, cities do have an important role to play. Vehicle manufacturers in general expect people to charge in off-street locations at home. With dedicated off-street parking being severely limited in most urban areas, city authorities must find a way to reconcile the competing needs until such a time as 'electric service stations' are commonplace.

The implementation of an acceptable infrastructure will be wholly dependent on authority and the respective city in mention. The author is of the opinion that this will be adopted in certain cities before others and the nature of their own transportation structure will be an important factor.

While EVs are more expensive than comparable ICE vehicles, their lack of tailpipe emissions provide health and environmental benefits that promise to make a substantial impact on the quality of life in our cities. While we understand the effects of poor air quality, to fully grasp its impact we only need to look at mortality rates both nationally and globally.

8.1 Introduction

This research work is focused on analysis of real operational data from the electric vehicle fleet both in proprietary data logging as well as reading and investigating the data coming from the vehicles own electronic control unit. In this work >50 electric vehicles data have been monitored for a four-year test period. The key characteristics of the electric vehicles operations e.g. journeys, speeds, distances, routes as well as the vehicle energy consumption have been investigated over the evaluation period. It has been noticed that driving cycle patterns have significant impact on vehicle's energy intensity.

Extensive evaluation testing has been reported for different types of batteries for their characteristics. Also, different operational modes e.g. acceleration, deceleration, cruise, ascent, decent have been evaluated and validated using real operational data for determining the regenerative braking efficiency of the electric vehicles fleet.

This research has attempted to estimate vehicular driving patterns in the Edinburgh region and to offer an option of battery electric vehicles for sustainable mobility. The results of this work will be directly useful to the Scottish Government for installing the charging points for the electric vehicles as well as in knowing the power requirements of the charging stations. This work will also inform smart electric vehicle charging management system for reducing the demand on the electrical network.

This thesis had identified a number of possible routes for investigation, but the author had decided to concentrate the focus on the following four points:

- Charging Infrastructure

The charging infrastructure and strategic locations are of great importance when designing any system that is reliant on recharging. It was found that users adopted a pattern that suited their own needs and with driving experience confidence developed, range was extended and this removed the constant requirement to plug the vehicle into a charger at every opportunity.

A battery usage report with different electric tariffs have been presented. Yearly breakdown of travels and energy consumptions among different campuses of the Edinburgh College have been reported and these results can be used for transport planning among corporate users and the demand of electricity due to BEV charging on the network of that areas.

- Monitoring of Energy Use

Accurate monitoring of the costs associated to recharging is essential and this gives the user an understanding of the comparative costs when compared to an internal combustion engine vehicle. In performance evaluation, the traction motor operational control with distance of travelling and driving cycle patterns have been considered. The focus of this study has been to analyse the impact of the market share of BEVs (with different technologies) in terms of energy consumption in the area Edinburgh region. The Vehicle Dynamics and Energy Consumption simulation tool has been used for modelling energy consumption. The discussed sustainable transport planning of the Edinburgh College can provide a very good example for other organisations in developing their own strategies using the real operational results of Edinburgh College study and their analysis of the impact of electric mobility on transport in the corporate environment. The author has also discussed impact of user behavior on finding charging patterns and this analysis can be useful for further studies on finding the impact of charging patterns / charging strategies of BEVs on electrical loading in the distributed network and main grid.

- Driving Cycle

One of the main areas of focus was within the physical driving and the practicality of the battery electric vehicle when used as a commuting vehicle. The drive cycle evaluation gave comparisons when removing ICE vehicles from use and introducing BEV's as the replacement. It has been observed that there is variation in the range based on speed, driving style, terrain of the road, air conditioning and heating requirements of the BEVs. The drive cycle analysis of BEVs has given an indication of the practicality and vehicle range. It has also considered BEVs' operating cost and energy analysis for long range mobility. It has been reported that NEDC tests have been carried out in the laboratory. Also, the drive cycle experimental work has been reported for seasonal drive cycles. The presented results and collected experimental data can be further elaborated in finding the driving cycle patterns based on seasons as well considering real driving conditions. Carbon intensity and energy analysis of urban and long range intercity BEV mobility have been discussed. The real driving operational results of the BEV's performance / evaluation on a particular area will be very useful for conducting further analysis on BEVs' energy consumption. Seasonal comparisons have given good indication for evaluating BEV's specific capabilities. These analyses will be very useful in finding the driving range as well as battery conditions and for finding the appropriate locations for BEVs charging points.

- Management system

Correct systems implementation into an existing business is of paramount importance. To ensure that the vehicles could be correctly accounted for and to make this auditable and user friendly a system was developed for effective booking. As the project moved from the nascent stages adaptations had to be introduced to make this system quick and easy to use.

Training is obligatory to all staff at registration as it is the author's opinion that this will install confidence and a realisation that robust systems support is in place.

The output from this will help in the development of an e-vehicle management tool as well as demand responsive transport systems in corporate environment for business use.

8.2 Summary and deductions

The focus within this study has been to offer a low/zero carbon alternative to College staff transportation. It is understood that outwith College peak demand periods, and BEV's permitting, it could be possible to offer these vehicles to the general public for their own use as a commercial source of income. This would require further study on the feasibility and practicality as the initiative was embedded into the College activity without giving this consideration at inception. This would create challenges around a correct charging strategy and an understanding of 'ownership' and the next user.

The present research has indicated that for a commercial mobility study the BEV has the capabilities to be used for inter campus journeys and staff have developed confidence in the BEV abilities.

It is understood that the range is reduced in colder weather and this is aligned to a reduction of range when used in a laden condition. Correct route planning to maximise the regeneration capabilities and reduction in range when utilised in an inter-city cycle.

To complement this research a revised vehicle booking system would be initiated – this would require further study and a suggested future topic of research.

The charging infrastructure, monitoring of BEVs energy use, driving cycle, vehicle management system has been considered as focus points in concluding the thesis.

The total cost of ownership (TCO) of current BEV are uncompetitive with conventional fossil fuel comparative vehicles and series hybrid PHEV (plug-in hybrid electric vehicles) by more than £600 per year. TCO of future PHEV's may become competitive when batteries cost less than £250 per kWh. This comparison must be calculated without tax incentives and one battery pack must last for the lifespan of the vehicle as this is an expectation of the conventional fuel vehicle. However, TCO of future battery powered cars is at least 25% higher than of PHEV or conventional vehicles. This cost gap will remain unless cost of batteries drops to under £120 per kWh in the future. Variations in driving cost from charging patterns have negligible influence on TCO.

Electric motors and batteries have improved substantially over the past one hundred years, but today's much hyped electric cars have a range that is - at best - comparable to that of their predecessors at the beginning of the 20th century. Weight, comfort, speed and performance have consumed any real range progress.

An improvement in the BEV as a vehicle should take precedence over the improvement in battery developments.

If today's supporters of BEV's would refer to the specifications and the sales brochures of early 20th century electric "horseless carriages", their enthusiasm would quickly disappear. Fast-charged batteries (to 80% capacity in 10 minutes), automated battery swapping stations, public charging poles, load balancing, the entire business plan of Better Place, in-wheel motors, regenerative braking: it was all there in the late 1800s or the early 1900s. It did not help. Most surprisingly, however, is the seemingly non-existent progress of battery technology. (Kris De Decker 2010b)

The Mitsubishi i-MiEV and the Nissan Leaf, were two BEV's that were introduced on the market in 2010 and 2011 respectively have a similar range to the 1908 Fritchle Model A Victoria - 100 miles (160 kilometers) on a single charge. The "100-mile Fritchle" was an impressive engineering feat for its time.

Electric vehicles consume less primary energy and substantially less final energy than fossil fuel vehicles of same weight and performance (excluding driving range).

Taking account of the emissions generated by the production of electricity, the refining of oil and the distribution of energy, electric vehicles generate, with the EU electricity mix, less than half the CO_2 of fossil fuel vehicles of same weight and performances (excluding driving range).

In addition, because of their limited range, electric vehicles will mainly be used for daily commuting and urban traffic. They will therefore generally be smaller and lighter than fossil fuel vehicles and consequently even cleaner and more fuel-efficient. They will also contribute to a reduction in traffic and car park congestion.

Taking account of the production of electricity and the production and refining of oil, as well as of their distribution, it appears that the four electric vehicles analysed in this study consume around 1.7 times less primary energy and generate on average, with the EU electricity mix, less than half the CO_2 of a Toyota Prius.

Electric vehicles will not require significant increases in electrical infrastructure until their number reaches 20-25%. However, they will provide electricity producers with financial incentives towards improving the energy efficiency and CO_2 emissions of electricity production.

If the use of electric vehicles became commonplace for city driving, the results worldwide would be:

- To save around 20% of oil production.
- To significantly reduce urban pollution.
- To eliminate almost all traffic noise.
- To reduce traffic and parking congestion.
- To be a sector leading solution to urban mobility.
- To be instrumental in stable grid balancing.

Significant understanding and additional knowledge came from this research around the practicality of introducing and managing a new all-electric fleet of vehicles and the user's capabilities that developed and how this adapted with time. The vehicles restrictions too were understood with regard to charging strategies and temperature variance, these were considered and aligned to the business needs to support the implementation.

The author's research has shown that battery electric vehicles (BEVs) satisfy the range needs of a significant share of the driving population however, BEV buyers seem to prefer vehicles with high available range and as discussed this is irrespective of whether this is required or not.

In the experimental route tests the BEV could for the purpose demanded on it by the College offer an alternative to the ICE vehicle. The BEV under test was capable under all conditions to successfully complete the four Campus commute irrespective of the number of passengers and the weather conditions.

One of the objectives of the present research was to advance understanding of the factors that influence the range preferences of potential BEV customers who had the opportunity to test a BEV and accept or adapt their own vehicle use to its limitations.

Limitations were understood within the drive cycle as route planning for staff can be constantly changing and that external factors such as traffic congestion, roadworks and detours all have to be considered in their own individual merits. Another external limitation can be depicted by a road speed change where the acceleration and deceleration phase will be altered thus giving a different data set for that route. All vehicle testing was conducted with a fully charged HV battery at the start of the experimental work, and it is realised that this may not always be the case when used by the full staff potential. Throughout, the overall accuracy and tolerance of the obtained data was dependant on other sources and the data transmission frequency and reliability was also controlled and limited by the hardware and software providers.

Infrastructure funding was another limitation as this may not be directly linked to the actual vehicle under test conditions. Furthermore the test vehicles were reliant on the charging network and that this is fully functional. Within this four year work, a number of the tests conducted had to be repeated due to faulty charge points of 'back office' data capture software faults.

8.3 Future work on support infrastructure

The uptake of electric mobility will ultimately necessitate improved control over ‘dumb charging’ that is to control when the electricity is supplied to the vehicle. This ‘smart charging’ as discussed by (Lopes et al. 2010) is expected to establish a positive loop with renewables integration, given that electric vehicles is a moveable, mobile and controllable load which could allow energy flow back into the grid as well as taking power from it. This vehicle to grid concept will require a bi-directional communicational link between the car and the grid.

Smart charging could lead to further decarbonisation of electric transport as lower emission power plants outside peak hours are used and more renewable capacity is utilised - achieving in addition annual savings of 1,863 million EUR as a result of avoided costs on CO_2 emissions in 2050 (McGrath Senan 2015).

In addition, the BEV potential in terms of reducing energy consumption is also significant. Electric vehicles can be three times more energy efficient than conventional cars, with a potential to achieve a net reduction of 137 Mtoe (million tons of oil equivalent) per year (McGrath Senan 2015).

Smart charging will help boost these values, as it reduces societal costs and benefits the environment, while increasing power system efficiency.

8.3.1 Battery energy supply and demand

A larger battery pack enables the vehicle to travel longer distance on electricity alone (the all-electric range, or AER) without the use of gasoline, which reduces use phase GHG emissions (also called operating emissions) over the vehicle life under today’s average grid mix. However, a larger battery pack costs more initially, has production implications including additional GHG emissions, and may reduce vehicle efficiency due to its weight (Delucchi & Wang 2006).

Availability of charging infrastructure at the workplace and/or in public locations can enable a longer effective AER with a smaller battery pack. Availability of such infrastructure also affects charge timing, which has implications for marginal electricity generation and resulting emissions (Sioshani, R., Fagiani, R., Marano 2010).

If sustainable energy sources are considered overall societal improvements can be made relative to ICE vehicles. However the author agrees with (Hawkins et al. 2013) that it is counterproductive to promote the electric vehicle in regions where the electricity is generated by coal, oil and gas. This will require a government policy shift to accommodate electrification that supports mobility.

8.4 Future work on vehicle recharging

The future technology and chemistry of BEV batteries is uncertain but to sufficiently fulfil their role they will have to be designed to have a life expectancy of over 150,000 miles and 15 years. Battery ‘end of life’ is considered when they cannot hold more than 80% performance and manufacturers rated capacity.

The author would give consideration to future study on this topic as battery packs at 80% capacity and deemed to be replaced/recycled may be a low cost alternative to an electric vehicle owner. If charging or smart charging occurs at home or the user has access to a charging strategy, coupled to their travel requirements, the BEV industry could offer a solution to offset the high upfront battery cost. This ‘second life’ battery pack could be a solution to new low cost BEV emerging markets where the high battery cost is limiting the potential of all applications.

There are opportunities to further explore through studies into maximising the available regeneration, what this is, and how it can work with current battery management system technology or in conjunction with the use of ultra-capacitors giving an additional areas for future studies.

8.5 Future work on battery technology

Past and present battery technology has focussed on NiMH and Li-ion. NiMH technology did feature in a wide range of vehicles due to its mature technology but now has been superseded by Li-ion due to its higher energy density (see appendix 10). Further to the work undertaken by the Variable Load Discharge Tester, limitations were realised with regard to the timer and its cycles being dependant on the controllers' capabilities. This will be an area for further study as the charge/discharge frequency could be aligned to the actual user drive cycle so that the charge/discharge periods and the time frames are aligned to the real world drive cycle.

Key parameters of BEV battery technology are:

- Safety
- Energy
- Life

Battery manufacturers are constantly developing new alternatives to lithium-ion. Lithium-sulphur chemistry is under development and manufacturers indicate greater energy density from this however the production of this chemistry is unlikely to be commercially viable till 2020.

Sodium-ion chemistry is also under development, this low cost alternative is safer to transport in the discharged state and unlike lithium where there are no domestic reserves, this salt could be sourced and cells manufactured within the UK.

Research and development across many differing chemistries is being conducted to improve on performance but also to ensure that they are lightweight, affordable and compact. Additional features of the new battery materials are that they must be matched to the lifetime of the vehicle, can be cycled repeatedly and recycled and safely disposed of at the end of life which should be further explored.

The HV battery 'end of life' has a significant impact into the 'vehicle end of life' and this will introduce trends with the 'vehicle residual value' all which are areas requiring further study as it is this residual value that is one the main important factors to influence BEV buyer.

8.6 Recommendations for Edinburgh College future work

Future studies will be necessary on the viability of the BEV over the conventional powered vehicle and their level of penetration into the market place. The likelihood of the penetration reaching 25% of the total vehicle sales, as the current figures indicated this may not be achievable within the near future. The increase in BEV sales and use will have a greater polluting effect from the increased generation required by the conventional fossil fuelled power stations.

The system has been developed from the phase one BEV booking system that accommodated the launch of the fleet with four cars controlled within the one campus. The phase two booking system incorporated multiple Campus activity with a potential 1500 users. The actual users of the BEV's are currently is approximately 550 across all sites and further work can be proposed here to incorporate all Edinburgh College travellers regardless of where the end destination is and the mobility activity mode.

Initial studies are underway to investigate user trends and the author is leading the project team to analyse users' 'clicks' for the monitoring system to determine activity that cannot be delivered due to BEV's being unavailable at the required time, data collection in this area will allow the College to improve on the service.

Figure 125 illustrates phase three of the administration system will utilise a self-service desk as an Integrated Travel Portal which will offer staff multiple travel options, aligned with both the Green Travel Plan and the Carbon Management Plan.

Figure 125 Integrated travel portal

This integrated travel portal as shown in figure 125 will be the initial screen and each of the six ‘buttons’ will direct you to the required selection. Accessible from the staff users’ desktop and will become a transportation hub with links to the external operators for services such as flights, buses and trains. This will consolidate all travel options and after a travel option and cost has been selected the request will require authorisation from the appropriate cost centre and line manager.

It is anticipated that the ‘grey fleet’ option may still be required as an alternative, but will be monitored for trends, usage and fuel expense claims.

Further development on the analytics to allow tracking of ‘clicks’ for each option to improve on the service and creating greater focus on business travel and cost centre financial accountability.

The ultimate function of this transportation hub will be to give maximum travel flexibility for minimum cost to the College. It will also focus the user and will encourage accountability for the most sustainable and controlled travel method whilst giving transparency with regard to the expense.

In addition to the travel hub, future studies could include off-grid BEV charging as a project that will complement the current charging facility that exists on all campus sites. This is of interest as it will bring other focus areas of the College together (design, project consideration, construction and emerging technologies) as well as being an area of potential interest to third parties and to businesses that may not have a permanent or reliable grid connection.

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Appendix 1 Department of Transport VEH0131

Department for Transport statistics

Vehicle Licensing Statistics (UK Government 2016c)

Table 45 Licensed cars and vans VEH0131

Plug-in cars and vans licensed at the end of quarter, UK, by location of registered keeper

Quarter (stock as at end of quarter)		2011 q4	2012 q1	2012 q2	2012 q3	2012 q4	2013 q1	2013 q2	2013 q3	2013 q4	2014 q1	2014 q2	2014 q3	2014 q4	2015 q1	2015 q2	2015 q3
England	TOTAL	1,093	1,426	1,910	2,536	3,069	3,724	4,521	5,391	6,244	7,793	9,891	14,217	19,196	26,391	31,287	36,415
Wales	TOTAL	15	27	34	46	53	66	85	107	131	169	245	379	517	701	852	994
Scotland	TOTAL	71	98	137	198	249	290	362	422	476	613	792	1,074	1,344	1,718	2,053	2,363
Great Britain [4]	TOTAL	1,199	1,587	2,116	2,828	3,562	4,183	5,114	6,103	7,066	8,796	11,200	15,976	21,286	29,233	34,669	40,607
Northern Ireland [4]	TOTAL	6	11	24	44	54	72	103	123	137	164	204	275	363	484	606	701
Vehicle under disposal [3]		20	36	35	48	191	103	146	183	215	221	276	311	234	429	481	837
United Kingdom	TOTAL	1,205	1,598	2,140	2,872	3,616	4,255	5,217	6,226	7,203	8,960	11,408	16,256	21,654	29,723	35,279	41,311

Notes:
1. Refers to electric or hybrid electric vehicles eligible for Department for Transport Plug-in Car or Vans grants.
For more details, see: (UK Government 2016a)

2. The location of the registered keeper is based on the contact address held by DVLA, and does not necessarily reflect where the vehicle is kept.

3. Vehicles between keepers.

4. Northern Ireland and Great Britain figures are provisional and may be revised for greater consistency with table veh0104.

5. Regional totals may exceed the total of the local authorities within the region. This occurs when we have vehicles with incomplete postcodes that allow allocation to a region but not precisely enough to allocate to a local authority.

Notes & definitions see: (UK Government 2016c)

Appendix 2 Abbreviations and Glossary

Abbreviations

AC:	Alternating Current
ABS:	Advanced battery systems: A new generation of batteries characterised by improved efficiency and power, as well as fast charging.
AER:	All electric range
AFV:	Alternate fuel vehicle.
AGM:	Absorbed Glass Mat (battery)
Ah:	Amp hour, a unit of electrical energy.
BCM:	Battery Capacity Meter
BCM:	Body Control Module
BEV:	Battery electric vehicle.
BMS:	Battery Management System
CAN:	Controller Area Network
CC:	Climate Control
CCC:	A ‘charge coupler connector’ and vehicle receptacle for hybrid and electric vehicle charging.
CHADeMO:	is an abbreviation of "CHArge de MOve", equivalent to "move using charge" or "move by charge".
DC:	Direct Current
DCQC:	Direct Current Quick Charge. This is a charger (not an EVSE) that provides electricity directly to the EV battery at a rate of up to up to 50kW under control of a computer in the post. It uses a special connector to the car.
DOD:	Depth of Discharge
DPF:	Diesel Particulate Filter
DRTS:	Demand responsive transport system
DTE:	Distance to Empty
Ebike:	Electric bicycle.
ECU:	Electronic Control Unit
ED:	Energy density: The amount of energy in a fuel source, such as lead acid and lithium-ion batteries.
EPA:	Environmental Protection Agency
EPS:	Electric Power Steering
EV:	Electric vehicle operating exclusively on electric power. BEV.
EVSE:	Electric Vehicle Supply Equipment -- a system and cable to connect your household circuit (120V or 240V) to your car's charger.
EVCS:	Electric vehicle charging station: The facility that provides battery charging for EVs. Many new installations provide electricity from wind and solar sources.
FH:	Full hybrid: A hybrid electric vehicle capable of running on battery power only.

FFE: Ford Focus Electric

GDP: Gross Domestic Product

GHG: Greenhouse Gas

GID: Unit of Charge reported by Gary Giddings' SOC meter. 1 Gid = 80Wh nominally, 100% Charge (Nissan LEAF) = 281+ Gids on a new battery in a cold climate.

GOM: Guess-O-Meter -- the standard mileage range meter displayed on the Leaf's dashboard.

GWP: Global Warming Potential

HEV: Hybrid electric vehicle with two or more sources of power, with one source electric.

HTP: Human Toxicity Potential

ICCT: International Council on Clean Transportation

ICE: In Car Entertainment

ICE: Internal Combustion Engine

kg: kilogram

kWh: kilowatt-hour

L1: Level 1 charging, from ordinary 240 volt household electricity. Normally done using the "trickle charge cable" (which really has a built-in EVSE) supplied with the car. Provides electricity to the battery at a rate of up to about 1.1kW via the J1772 charging port.

L2: Level 2 charging, using 240 volt electricity. This can be by plugging a portable EVSE into a 240v outlet, but more commonly involves a permanently mounted EVSE. Provides electricity to the 2011 and 2012 LEAF battery at a rate of up to about 3.3kW via the J1772 charging port. The 2013 Leaf can have an 6 kW on-board charger (optional on the S trim, standard on the SV and SL trims.) Some other EVs can accept faster rates.

L3: Level 3 charging; usually refers to charging with a high voltage (up to 500V) DC charger.

LBC: Lithium Battery Controller

LBW: Low Battery Warning

LCA: Life Cycle Assessment

LCI: Life Cycle Inventory

LDV: Light Duty Vehicle

LEAF: Leading Environmentally friendly Affordable Family car

LiNCM: Lithium Nickel Cobalt Manganese

MDP: Mineral Depletion Potential

MH: A mild hybrid (HEV) in which the electric motor requires an additional source of power, such as a gasoline engine.

NEV: Neighbourhood EV, for short trips.

NEDC: New European Drive Cycle

NiMH: Nickel Metal Hydride

Pb: Lead acid battery

PHEV: Plug-in hybrid EV

PM: Particulate Matter
RDE: Real Driving Emissions
RDR: Remaining Driving Range
RFID: Radio Frequency Identification
RV: Residual Value
SOC: State of Charge
SOH: State of Health
SOP: Standard Operating Procedures
TETP: Terrestrial Eco-toxicity Potential
TCO: Total Cost of Ownership
TCU: Telematics Communication Unit
TMS: Thermal Management System
V2G: Vehicle to grid; the integration of EVs with the Smart Grid.
VCM: Vehicle Control Module
VDC: Vehicle Dynamic Control
VEOL: Vehicle End of Life
VLBT: Variable Load Battery Tester
VLBW: Very Low Battery Warning
VOC: Volatile Organic Compounds
VRLA: Vent Release Lead Acid (battery)
VSP: Vehicle Sound for Pedestrians
VEDEC: **VE**hicle **D**ynamics and **E**nergy **C**onsumption
ZEV: Zero emissions vehicle.

Glossary of Terms

- **AC:** "Alternating Current" - an electric current that reverses direction at regular intervals. Electric car motors are either AC or DC (see below), with most of the new breed being of AC type.

- **Amp:** A unit of electric current.

- **Anthropogenic:** produced directly by human activities

- **Battery:** An electricity storage medium that feeds electric current to the motor. Older EVs used lead acid or NiMH batteries, but modern electric car batteries are of lithium ion construction (see below).

- **Battery electric vehicle:** Also called a BEV. This is a vehicle powered solely or primarily by a battery or battery pack. You charge the battery and run the car. There's no petrol engine or hydrogen fuel cell to function and provide more power when the battery is out of energy. And there is no tailpipe or emissions.

- **BHP:** "Brake Horsepower" – the actual power output of an engine or motor before any natural losses in power through components such as a gearbox and other ancillaries.

- **Capacity**: The measurement of an amount of energy a battery can provide in one discharge.

- **Charging:** 'Refilling' an electric car's battery with electricity. The time a battery takes to charge depends on the size of the battery in kWh and the amount of electric current being supplied. Electric cars can take different levels of charge, meaning they can be fast or rapid charged.
- **Charging Point:** A location where electric vehicles can plugged in and charged. These can be at home, at work or in publicly accessible locations.
- **Cycle life**: The useful lifespan of a rechargeable battery before it begins to lose its ability to hold a charge.
- **DC:** "Direct Current" - an electric current of constant direction. Electric car motors are either DC or AC, with DC motors generally being less expensive to buy and simpler to use on an electric car.

- **EREV:** Some automakers call vehicles that run on electric motors and battery power for some distance before a combustion engine starts generating electricity an "extended range electric vehicle." General Motors uses this term to describe its Volt, but others in the industry refer to such a vehicle as a type of hybrid battery – as long as petrol in the tank is topped up, an E-REV has unlimited range. E-REVs can be plugged in and charged up, allowing an electric range of around 40 miles before the ICE starts up. Unlike a PHEV, E-REVs don't use the petrol/diesel engine to directly power the wheels.

- **EV**: "Electric Vehicle" - any vehicle that uses electric motors, either in full or in part, as propulsion. This includes pure electrics, hybrids, plug-in hybrids, extended range electric vehicles and hydrogen fuel cell vehicles.

- **Fast Charge**: Charging at a higher current than a domestic supply (about 7kW as opposed to 3kW). This will fully charge an average electric car in three to four hours. Rapid charging is quicker still.
-

- **HCU:** "Home Charging Unit" - a dedicated charging point for use at home. These incorporate a number of safety features to prevent fires or short circuits and often employ intelligent features such as timers and fast charging. HCU's aren't absolutely necessary but we recommend them for peace of mind.

- **HP:** "Horsepower" - a unit that is used to measure the power of engines and motors. One unit of horsepower is equal to the power needed to lift 550 pounds one foot in one second.

- **Hybrid:** A hybrid electric vehicle, or HEV, is any vehicle that can draw propulsion energy from a combination of the following on-vehicle energy sources: consumable fuel (used in a combustion engine or fuel cell) and an energy storage device such as a battery, capacitor or flywheel.

- **ICE**: "Internal Combustion Engine" - an engine powered through the burning of fossil fuels. The term 'ICE' is often used as shorthand for any vehicle powered by an internal combustion engine, whether petrol or diesel or any other flammable medium.

- **Incentives:** Many governments offer incentives to encourage buyers to choose an electric car. Grants towards the purchase price exist in many countries, for example the UK's Plug-in car grant, which offers 25% off a new electric car's list price up to £5,000. Other incentives for EVs can include free parking, zero road tax, low company car tax and exemption from city emissions and congestion charges.

- **kWh:** A kilowatt-hour is a measure of electrical energy. Batteries (and battery packs) used by electric vehicles and hybrids are rated by the kWh capacity of their battery pack because it represents how far the auto might travel solely on electric power. One kWh generally has enough energy to propel a car four to five miles.

- **Lead Acid Battery:** A type of battery used in less modern electric cars. The energy density is much lower than that of lithium Ion batteries, which is the current standard. That means less power output and the need for more frequent charging. Lead acid batteries also have a shorter service life. They are, however, a lot cheaper than lithium ion batteries.

-

- **Level 1 charging:** Charging from a typical wall socket, typically a 110- or 120-volt outlet. Electric vehicles gain five to six miles for every hour they charge on Level 1.

- **Level 2 charging:** Charging from a 220- or 240-volt outlet. This goes much faster than a regular wall outlet because it pulls more current at a higher voltage. Most electric vehicle owners install Level 2 charging systems in their homes. An EV can get 10 to 60 miles of range per hour of charging depending on the amperage of the circuit.

- **Level 3 charging:** Also known as DC fast charging, this is a specialized high-voltage system that can charge a battery pack in about 30 minutes. It requires a special port on the electric vehicle and a special charging station that, as of now, is not widely available.

- **Lithium-ion battery**: A popular lightweight, high capacity battery. Different versions have differing chemistries, but they're found in everything from EVs to cell phones. These are the current standard in electric vehicle batteries, offering good energy density, power and fast charging ability. The life of a lithium Ion battery is estimated to be the same as the life of the car (eight to ten years). Of course 'end of life' here does not mean the cars or batteries won't work - after 10 years a lithium ion battery is expected to be at 80% efficiency, so they will still be usable - replacement will be a choice, not a requirement. Should you wish to replace your car's battery, it's possible they will still be in demand as storage devices for renewable energy in industry. They are expensive at the moment, but prices will reduce over time as more EVs emerge onto the road.

- **NiMH Battery:** "Nickel-Metal Hydride" - a type of battery used in some older electric vehicles, offering better energy density than lead acid but less than lithium ion.

- **Off-peak charging:** Charging the battery pack during periods of low demand for electricity, usually at night. This can reduce the cost of charging.

- **Paleo-climate:** Climate based on the Earth’s past climates (can go back 800,000 years)

- **Parallel hybrid:** A vehicle in which drive power is supplied by both an electric motor and a combustion engine working together.

- **Plug-in hybrid vehicle:** The vehicle has a battery pack that powers a motor and can be charged through an electrical outlet. Such a car will also have a combustion engine that extends the range of the vehicle once the battery is drained. The extended range can come through the combustion engine powering the wheels or through the engine generating electricity to run the electric motor in the car.

- **Plugged-in Places:** A UK government scheme that provides funding for specific regions to kick-start the use of electric vehicles locally and test charging infrastructure. Different 'PIP's are trialling different technology, with the results helping to inform national EV infrastructure decision-making.

- **Partial zero emissions vehicle:** Also known as a PZEV, the vehicle has some sort of technology, such as an electric motor, that allows the car to travel at least some of the time without spewing emissions. They meet certain California Air Resources Board emission limitations and are covered by a 15-year, 150,000-mile warranty on the emissions system.

- **PHEV:** "Plug-in Hybrid Electric Vehicle" - a type of car that is configured like a regular hybrid, but with a bigger lithium ion battery pack that can be charged up by plugging in to a regular electricity supply. Pure electric driving is increased over a standard hybrid (12.5 miles on the first example to market, the Toyota Prius Plug-in) before the ICE fires up to help power the wheels. PHEVs, as they are known, offer the chance to make short journeys on cheap, zero tailpipe emission electricity but also enable long journeys.

- **Photovoltaic Cells (PV)**: Used on solar panels to convert radiation from the sun into electricity. Solar panels are becoming much more commonplace and can be installed at home to help charge electric cars, allowing true zero-emission motoring and a large cost saving over time. Even in the UK, users report it is possible to completely charge electric cars using solar power only. Feed-in Tariffs may also allow unused electricity to be supplied to the national grid, meaning you could earn money from installing a solar panel.

- **Pure Electric:** A vehicle powered solely by electric motors using power provided by on-board batteries. The batteries are charged using electricity from the national grid.

- **Quadricycle**: A four-wheeled vehicle with low power and of the same class as a moped or scooter. Electric quadricycles do not have the performance of the latest breed of electric cars and as they are not subject to the same stringent crash testing, safety is a concern. The Reva G-Wiz is an example of an electric quadricycle.

- **Range**: The distance you can travel on pure electric power before the battery requires a recharge.

- **Range Anxiety**: A term used to describe the fear of running out of battery while driving a pure electric car. Real-world accounts suggest range anxiety isn’t as common as thought, and trials show that anxiety recedes over time as drivers become more comfortable with their cars’ actual range capability.

- **Rapid Charge**: Rapid charging occurs only at dedicated locations and employs a 20-50kW current, allowing an 80% charge of a typical electric car in around 20-30 minutes. Some rapid chargers can top up the remaining 20% at a reduced rate in order to preserve the life of the battery. Regular rapid charging is not good for the long-term life of the battery, but does offer the chance to top up on the occasional longer journey.

- **Regenerative braking**: Electricity can be generated by most electric motors. In this instance, it is energy captured and stored as drivers use their EV's brakes.
  An energy recovery system used in most electric vehicles that can help charge the battery while the car is slowing down. Typically the electric motor acts as the generator, so power can flow both ways between it and the battery. 'Regen' helps extend the range, while the process also help slow the vehicle in a similar way to engine braking in an ICE powered car.

- **RPM**: "Revolutions Per Minute" - the number of times the shaft of an electric motor turns through 360 degrees in one minute.

- **Secondary use**: The use of PHEV and EV batteries for stationary electric grid storage after they can no longer meet the demands of charging vehicles.

- **Series hybrid vehicle:** A vehicle in which power is delivered to the drive wheels solely by an electric motor but which uses a combustion engine to provide electric energy to the battery or the electric motor.

- **Three-phase electric power**: In an AC motor in an electric vehicle, three-phase current is used instead of single phase, as it generates a rotating magnetic field from zero RPM and is typically 150% more efficient in the same power range. In other words, high torque at zero revs is made possible by a three-phase system on an AC motor.

- **Torque**: The twisting force that causes rotation. In the case of cars, torque rules and is the major factor in a car’s accelerative ability – with generous torque, the car’s throttle response is much sharper. Petrol and diesel engines deliver torque over a curve as RPM increases, meaning they have peak power at a given RPM. Electric motors, on the other hand, deliver maximum torque from zero revs, meaning acceleration from standstill can be phenomenal.

- **V2G**: "Vehicle-to-Grid" - transferring electrical current from the battery of an electric car back into the National Grid while plugged in to the mains. V2G could help balance the grid in periods of high demand, alleviating the risk of power cuts.

- **W2W:** "Well-to-Wheel" - measuring the CO_2 emissions of a car, taking into account the production of the fuel or electricity. This is a fair analysis of the impact on the environment of electric vehicles, as they have zero emissions at point of use but clearly have an environmental impact earlier in the chain. However, for a fair comparison with an ICE vehicle, W2W must also be calculated in the drilling of the oil, refining and transportation, not just the tailpipe emissions. Taking this into account, an average electric vehicle will produce 80g/km of CO_2 compared with 147-161g/km for an ICE (SMMT 2016).

- **ZEV:** A zero-emission vehicle. That means no pollutants come out of its tailpipe. Such vehicles include electric cars and fuel-cell vehicles and often qualify for government sales incentives and other perks such as carpool lane permits.

Appendix 3 Seminar and Conference presentations

Public Speaking Engagements

2012: The EVent: powering Scotland through electric vehicle technology, The Scotsman Head Office, Edinburgh

2012: CICSTART Online: Micro-renewables for Building and Transport- Deliverables and Barriers, Edinburgh Napier University

2012: E-COSSE Stakeholder Meeting, Roxburghe Hotel, Edinburgh

2012: Regional Electric Vehicle Project Business Breakfast, Jewel and Esk College, Edinburgh

2012: CICSTART Online: Integration of Sustainable Infrastructure into the Existing Built Environment, Glasgow Caledonian University

2012: Energy Saving Trust Electric Vehicle Event, Edinburgh

2012: Green Gown Awards – Finalists

2012: Integration of EV technology into sustainable buildings

2013: CICSTART Online: Electric Vehicles and the Environment, Glasgow Caledonian University

2013: Batteries, Fuel Cells & EV Seminar, Munich, Germany

2013: Green Transport Prize, Princes Street, Edinburgh

2013: Electric Vehicle Technologies in a modern curriculum, Glasgow Caledonian University

2013: Introducing EV's based on financial Savings, GreenFleet, Edinburgh

2013: An Electric Vehicle in your business, All Energy, Aberdeen

2013: Plug into the Benefits of Electric Vehicles, Energy Savings Trust, Glasgow

2014: Electric Vehicle all-staff conference, Edinburgh College, Edinburgh

2014: Experimental and modelled used of Battery Electric Vehicles, Transport Research Institute, Glasgow

2015: Electrified fleet in your business, Dundee University, Dundee

2015: CeeD Technology Presentation, Edinburgh College, Edinburgh

2015: How sustainable is the Battery Electric Vehicle, Transport Scotland, Edinburgh

2015: Real world Drive Cycles and the Battery Electric Vehicle, Chennai, India

2015: GreenFleet Awards – Finalists, Birmingham, UK

2015: Management of an eCar Fleet, Napier University, Edinburgh

2016: Electric Vehicle all-staff conference, Edinburgh College, Edinburgh

Appendix 4 Standard Operating Procedure – Charging post

CHARGING POST PRODUCTION SOP

Electric vehicle recharge point fabrication procedure and materials list.

The following gives details of the materials required and the process to be followed to produce a recharge point for a battery electric vehicle. The electronic monitoring and control circuit details can be found in the relevant section of the project folder which contains the circuit diagrams and a graphical representation of the finished circuit board. The detailed drawings can also be found in their section of the project folder and contain all the relevant measurements for the individual components to be fabricated.

Materials required:

1. Stainless steel box section grade 304, 1200x300mm
2. Stainless steel sheet grade 316, 558x136mm
3. Stainless steel base plate grade 304, 300x300mm
4. Electronics box (control unit).
5. Stainless steel hinges grade 316.
6. Outdoor plug socket, IP66 rated.
7. Stainless steel screws, bolts, washers and nuts.

Procedure:

Chassis Production and Preparation:

1. Measure box section to length and cut.
2. Measure and mark where, and the angle (45º), at which the box section is to be cut at the top (*see fig. 126*).
3. Measure and mark out the door section to be milled, 620x125mm.
4. Mill out the door section (*see fig. 127*).
5. Mark the positions of the holes for the LEDs and drill them out using a 13mm drill bit.
6. Mark out and cut the door section from the sheet stainless steel, 650x135mm.
7. Mark out and cut the hole to suit the lock, position may vary depending on the lock.
8. Mark out and cut hinge to the correct length.
9. Press the door and post with the appropriate tool for making the cable clearance feature (*see fig. 128*).
10. Measure and mark out base section for milling, 146.4x76.8mm.
11. Mill out base section (*see fig. 129*).
12. Measure and mark out the mounting feature for the pulse width modulator from the sheet stainless steel, 120x60mm.
13. Cut out the mounting feature for the pulse width modulator.
14. Measure and mark out the mounting bracket for the socket, 142x130mm.
15. Cut the mounting bracket to size.

16. Measure and mark out the locations for the mounting holes (to suit the door aperture), these should then be drilled and tapped for M4 screws.
17. Measure and mark out the lid section from the sheet stainless steel, 150x212.1mm.
18. Cut the lid section to size and file corners to the correct radius, matching the radius of the post as best to suit the finish.
19. Measure and mark out the rain shield from sheet stainless steel, 132x25mm.
20. Cut the rain shield.
21. Mark out the radius on the rain shield and file to the correct radius, r10.
22. File the chamfered edge on the rain shield, which assists in the mounting process, to 25º.
23. Before moving to the next section, ensure that all previously cut material has been filed to remove any burring caused by the previous processes. The edges of the door etc. should have a smooth rounded edge so as to prevent any injury to the end users.

Electronics enclosure Production:

1. Refer to the attached materials list for a detailed list of required components. Also refer to the attached circuit diagram, and graphical representation of the circuit board, for details of circuit construction.
2. Assemble the finished circuit board into the electronic control box, routing all wiring as necessary.

Assembly:

1. Weld the base section to the post.
2. Position the mounting bracket for the socket in the appropriate location and weld to the post.
3. Weld the lid section to the post.
4. Weld the mounting feature for the pulse width modulator to the post (*see fig. 130*).
5. Locate and weld in the earth point bolt (M8 earth stud).
6. Prepare the hinge for mounting by drilling holes in preparation for plug welding.
7. Weld the hinge to the post and to the door (*see fig. 131*).
8. Weld the rain shield to the post.
9. The post should now be cleaned and buffed so as to remove any marks left by the assembly process. Further to this all the visible welds should be ground to an aesthetically pleasing finish.
10. Install the lock into the drilled and finished mounting point.
11. The electronic control unit should now be fitted to the mounting bracket within the post as well as fitting the LEDs into their respective mounting points.
12. With the electronic control unit in place, install the plug socket onto its mounting bracket.

Installation:

The installation of the post is not the responsibility of JEC and as such should be carried out by a suitably qualified person.

Figure 126 Charge post box section

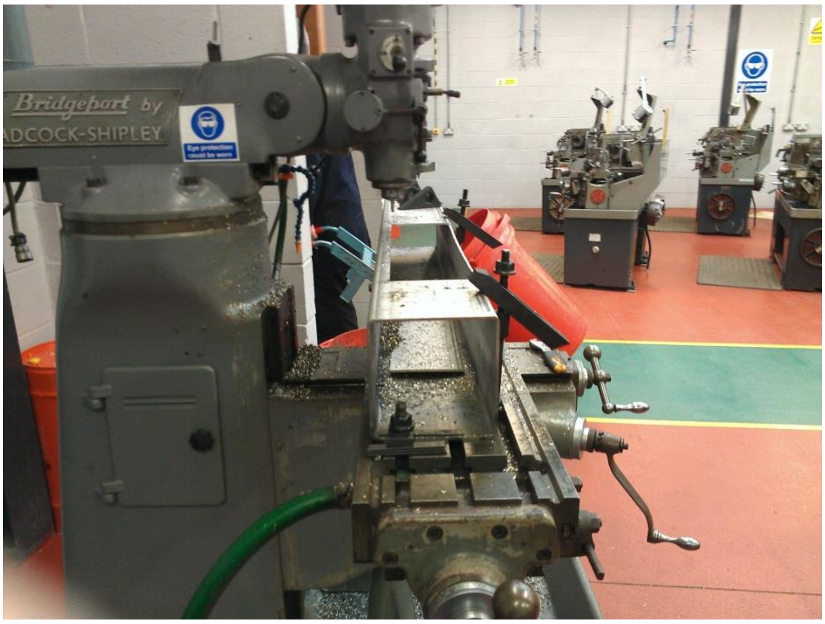

Figure 127 Machining main section

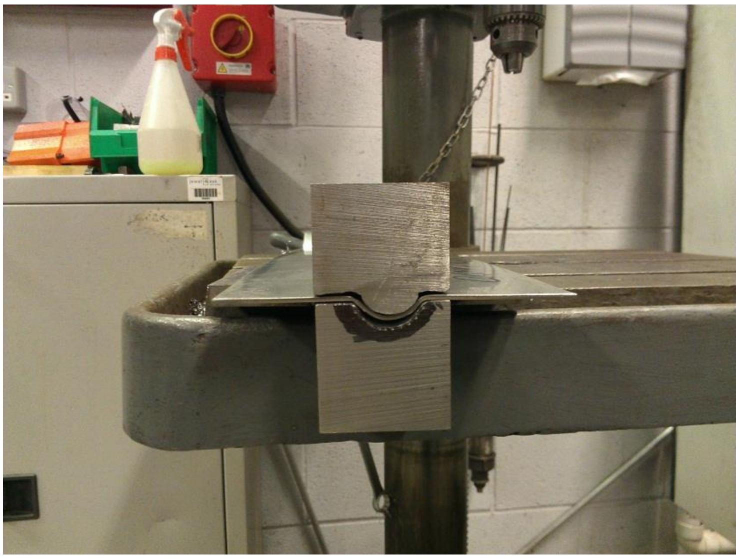

Figure 128 Forming door for cable exit

Figure 129 Milling base plate

Figure 130 Partially completed section

Figure 131 Completed post prior to installation

Table 46 Components (and cost) required for the electronic control unit:

Component	Size	QTY	Unit cost	Comment
ABS Box IP54	120x120x55mm	1	£4.17	
Outdoor socket	13A / 1 gang	1	£35.00	IP 56 (minimum)
Vero-board	95x110mm	1	approx £1.65	Supplied size 119x455mm
PCB mount transformer	16VA (1x24V)	1	£5.47	
LM317T regulator	1.5A	1	£0.12	Pack of 10
LM358N Op-amp	DIP 8	1	£0.12	Pack of 20
Fuse holder	Bayonet cap	1	£1.72	Pack of 5
Fuse	63mA 5x20mm	1	£0.37	Pack of 10
LED (red)	13mm/12Vdc	1	£14.56	Sunlight visible
LED (Green)	13mm/12Vdc	1	£15.98	Sunlight visible
Bridge rectifier (W02)	1.5A	1	£0.13	Pack of 20
Capacitor (electrolytic)	1000µf / 63V	1	£1.00	Pack of 5
Capacitor (electrolytic)	100µf / 25V	1	£0.04	Pack of 100
Capacitor (electrolytic)	1µf / 63V	1	£0.02	Pack of 100
Inductor	10000µH / 0.06A	1	£0.33	Pack of 5
Trimmer	5k / top adjust	1	£0.52	
Trimmer	1M / top adjust	1	£0.57	
Diode 1N4001	1A	1	£0.03	Pack of 10
Transistor C547B (BC547)		2	£0.07	
Transistor C557 (BC557)		1	£0.14	Pack of 5
Resistor (carbon film)	100R / 0.33W	1	£0.02	Pack of 10
Resistor (carbon film)	150R / 0.33W	2	£0.02	Pack of 10
Resistor (carbon film)	220R / 0.33W	1	£0.02	Pack of 10
Resistor (carbon film)	390R / 0.33W	2	£0.02	Pack of 10
Resistor (carbon film)	1k / 0.33W	4	£0.02	Pack of 10
Resistor (carbon film)	56k / 0.33W	1	£0.02	Pack of 10
Resistor (carbon film)	220k / 0.33W	1	£0.02	Pack of 10
Resistor (carbon film)	330k / 0.33W	1	£0.02	Pack of 10
Resistor (carbon film)	1M / 0.33W	1	£0.02	Pack of 10
Cable (brown)	1kV / 0.1mm^2	1m	£0.04	Reel of 100m
Cable (blue)	1kV / 0.1mm^2	1m	£0.04	Reel of 100m

Prices as at 2012

Appendix 5 Electric vehicles nomenclature

Table 47 Data of the most represented electric vehicles models on the market

Model	Battery Type	Energy Storage (kWh)	Nominal Range (km)	Market Release	Power (kW)	Motor Type
BMW i3	Li	22	150	2013	130	-
Tesla Model S	Li	42	258	2012	215	IM
Tesla Model S	Li	65	370	2012	215	IM
Tesla Model S	Li	85	483	2012	215	IM
Lightning GT	Li	40	240	2012	150	PM
Hyundai BlueOn	Li	16.4	140	2012	61	PM
Honda Fit EV	Li	-	113	2012	-	IM
Toyota RAV 4 EV	LI	30	160	2012	-	IM
Saab 9-3 ePower	Li	35.5	200	2011	135	-
CODA Sedan	Li	34	193	2011	100	-
Ford Focus Electric	Li	23	160	2011	100	IM
Skoda Octavia Green E line	Li	26.5	140	2011	85	-
Volvo C30 DRIVe Electric	Li	24	150	2011	82	-
Renault Fluence Z.E	Li	22	161	2011	70	SB
Renault ZOE	Li	22	160	2011	60	SB
Tata Indica Vista EV	Li	26.5	241	2011	55	PM
Ford Tourneo Connect EV	Li	21	160	2011	50	IM
Kangoo Express Z.E	Li	22	170	2011	44	SB
Fiat Doblo	Li	18	140	2011	43	IM
Peugeot iOn	Li	16	130	2011	35	PM

Renault Twizy	Li	7	100	2011	15	-
REVA NXR	Pb	9.6	160	2011	13	IM
BYD F3M	Li	15	100	2010	125	PM
Nissan Leaf	Li	24	175	2010	80	PM
Ford Transit Connect EV	Li	28	129	2010	50	IM
Citroen C-Zero	Li	16	130	2010	49	PM
Gordon Murray T-27	Li	12	130	2010	25	-
Wheego Whip LiFe	Li	30	161	2010	15	IM
Venturi Fetish	Li	54	340	2009	220	-
Mini E	Li	35	195	2009	150	IM
BYD e6	Li	60	330	2009	115	PM
Mitsubishi i-MiEV	Li	16	160	2009	47	PM
Subaru Stella EV	Li	9.2	80	2009	40	-
Smart ED	Li	16.5	135	2009	30	PM
Citroen C1 ev'ie	Li	30	110	2009	30	IM
Zytel Gorila Electric	Pb	10.8	80	2009	17	-
Micro-vett Fiat Panda	Li	22	120	2009	15	IM
Micro-vett Fiat 500	Li	22	130	2009	15	IM
Tazzari Zero	Li	19	140	2009	15	IM
Chana Benni	Pb	9	120	2009	10	-
Tesla Roadster	Li	53	395	2008	215	IM
Th!nk City	Na	24	160	2008	34	IM
Th!nk City	Li	23	160	2008	34	IM
Lumeneo SMERA	Li	10	100	2008	30	PM
Stevens Zecar	Pb	-	80	2008	27	IM
REVAi	Pb	9.3	80	2008	13	IM
REVAi	Li	9.3	80	2008	13	IM
ZENN	Pb	-	64	2008	-	IM
AC Propulsion eBox	Li	35	250	2007	150	IM
ZAP! OBVIO! 828E	Li	39	386	2007	120	IM
Phoenix sut	Li	35	209	2007	100	-

Phoenix sut	Li	70	403	2007	100	-
Smart ED	Na	13.2	110	2007	30	PM
Kewet Buddy	Pb	8.4	40	2007	13	DC
The Kurrent	Pb	-	60	2007	4.1	-
CityCar	Li	7	120	2007	-	-
ZAP Xebra	Pb	7.2	40	2006	5	DC
NICE Mega City	Pb	6.5	81	2006	4	DC
Commuter Cars Tango	Pb	16	100	2005	43	DC
Cree SAM	Li	7	100	2001	11.6	PM
G-Wiz	Pb	9.3	77	2001	4.8	DC
Dynasty IT	Pb	5	48	2001	-	-
General Motors EV1	NiMh	26.4	225	1999	102	IM
Ford Ranger EV	NiMh	26	132	1999	67	IM
Peugeot Partner	NiCd	16.2	96	1999	28	DC
Hypermini	Li	15	115	1999	24	PM
Myers Motors NmG	Pb	8.6	64	1999	20	DC
Peugeot 106	NiCd	12	150	1999	20	DC
GM s-10	NiMh	29	113	1998	85	IM
Ford Ranger EV	Pb	20.6	100	1998	67	IM
Toyota RAV4 EV	NiMh	26	165	1998	50	PM
Renault Express Electr	Pb	22	100	1998	19	-
GEM Car	Pb	-	48	1998	9	DC
CityCom Mini-El	Pb	3.6	96	1998	9	PM
GM s-10	Pb	16.2	76	1997	85	IM
Nissan Altra	Li	32	190	1997	62	PM
Honda EV Plus	NiMh	26.2	240	1997	49	DC
General Motors EV1	Pb	18.7	160	1996	102	IM
Citroen Berlingo	NiCd	16	100	1995	28	DC
Citroen Saxo	NiMh	17	100	1995	20	DC
Subaru Minivan 200	Pb	15.6	70	1995	14	DC
Solectria Sunrise	NiMh	26	321	1994	50	IM
Chrysler TEVan	NiMh	32.4	80	1993	27	DC

Chrysler TEVan	NiMh	36	97	1993	27	DC
Citroen AX	NiCd	12	100	1993	20	DC
VW Golf CityStromer	Pb	17.2	90	1993	17.5	PM
Ford Ecostar	Na	37	151	1992	56	IM
Bertone Blitz	Pb	-	130	1992	52	DC
VW Golf CityStromer	Pb	11.5	50	1989	18.5	PM
City El	Pb	11.5	90	1987	4	DC
City El	Pb	8.6	80	1987	2.5	DC
Oka NEV ZEV	Pb	-	-	1987	-	-
Lucas Chloride	Pb	40	70	1977	40	DC
Citicar	Pb	-	-	1974	2.5	DC
Enfield 8000	Pb	8	145	1969	10	DC

Appendix 6 Transport Scotland – case study

Article Published by Transport Scotland 2013
Switched on Scotland: A roadmap to widespread adoption of plug-in vehicles

ISBN: 978-1-909948-01-3

Case Study: Edinburgh College eCar Project

In 2011, Jewel & Esk College and Stevenson College embarked on a project with the support of SEStran and other partners to acquire and operate a small fleet of plug-in vehicles with the aim of evaluating them from a real-life user's perspective, and integrating their technology with the curriculum for the benefit of students.

Starting with four cars, the vehicles were used for intra-campus transport and other journeys that would have normally been carried out in staff members' own cars – the so called 'grey fleet'. To provide necessary infrastructure to support the operation of the plug-in vehicles, college students planned, designed and manufactured 3kW, single-phase charging posts which were then installed at each campus.

College staff also designed and developed a system to manage eCar bookings and administer the vehicle activity. It is now a college-wide database with well over 300 registered staff users. The vehicles have proved popular with the staff, in many cases positively changing people's opinion of plug-in vehicles.

The use of the vehicles is monitored through the booking system plus GPS tracking units that each car is fitted with. These come courtesy of 'www.TrackYou.co.uk' and allow vehicles to be tracked in real-time, create monthly reports on the mileage travelled, the number of trips, and longest trip each month.

The eCar Project was a success from the outset and expanded in 2012, as the separate colleges merged to become Edinburgh College. More vehicles were added and now the college operates a fleet of six plug-in vehicles plus monitor the data for another four operated by East Lothian Council.

Appendix 7 Rapid charger comparative overview

Table 48 Rapid charger comparison

		Edinburgh East, Milton Road	**Aberdeen South, Garthdee**	**Edinburgh Central, Russell Road**
		Siemens QC 45	Siemens QC 45	DBT Tri-Unit
		Mar – Aug 2015	Mar – Aug 2015	Feb – Jul 2015
Total Sessions		**303**	**860**	**212**
Total Energy Supplied		**2371.647 kWh**	**6427.664 kWh**	**1131.4 kWh**
Number of Unique Users		47	104	41
Connector Used	CHAdeMO	279	612	172
	DC CCS	5	40	17
	AC	19	208	23
Vehicle Types Charged	Aixam Mega City Electric	1	15	0
	Audi e-Tron	0	8	0
	BMW i3	2	39	0
	BMW i3 REX	0	19	0
	Mitsubishi i-MiEV	9	0	1
	Mitsubishi Outlander	35	173	37
	Nissan E-NV200	28	28	7
	Nissan LEAF	163	338	54
	Renault ZOE	11	110	5
	Tesla Model S	4	8	5
	Volkswagen e-Golf	1	0	0
	Unspecified	49	122	103
Night Rate *(00:00 to 07:00 at £0.063585 per kWh)*	Sessions	4	19	1
	Energy Supplied	21.36 kWh	171.13 kWh	13.7 kWh
	Cost	£1.36	£tbc	£tbc
Day Rate *(07:00 to 00:00 at £0.078462 per kWh)*	Sessions	299	841	211
	Energy Supplied	2350.287 kWh	6253.534 kWh	1117.1 kWh
	Cost	£184.41	£tbc	£tbc
Total Cost (estimates)	**Day + Night**	**£185.77**	**n/a**	**n/a**
	Domestic (£0.14 per kWh)	**n/a**	**£899.87**	**£158.44**
	Business £0.078 per kWh)	**n/a**	**£501.36**	**£88.25**
Average Charge Session Duration		32 min 50 seconds	30 mins 22 seconds	17 mins 40 seconds

Appendix 8 Author related articles

Related articles:

1. **The potential use of electric vehicles for provision of a sustainable corporate transport solution**

R Milligan[1], M Pozuelo-Monfort[2], I Smith[2] and T Muneer[2]
[1] Edinburgh College, 46 Dalhousie Road, Midlothian, UK
[2] Edinburgh Napier University, 10 Colinton Road, Edinburgh, UK

Published:
Transport Research Part D (13/03/2014)

2. **Energetic, environmental and economic performance of electric vehicles: experimental evaluation**

T Muneer*, R Milligan**, I Smith, A Doyle, M Pozuelo Edinburgh Napier University, Scotland
M Knez, Maribor University, Slovenia
*T Muneer, Edinburgh Napier University, Scotland
** Ross Milligan, Edinburgh College, Scotland

Published:
Transport Research Part D 35 (2015) 40-61

3. **A comparative range approach using the Real World Drive Cycles and the Battery Electric Vehicle**

Ross Milligan*, Tariq Muneer** and Ian Smith**
*Edinburgh College, Scotland
** Edinburgh Napier University, Scotland

Published:
SAE International (2015)

4. **Carbon Intensity and Energy Analysis of Urban and Long Range Intercity BEV Mobility**

R Milligan*, T Muneer**

*Edinburgh College, Scotland
** Edinburgh Napier University, Scotland

Pending submission:
Transport Research Part D (2016)

Appendix 9 $LiFEPO_4$ Technical data

Table 49 Technical Parameters CALB

No	Item		Parameter Specification
1	Nominal Capacity		40Ah@0.3C Discharging
2	Minimum Capacity		40Ah@0.3C Discharging
3	Nominal Voltage		3.2 V
4	Internal Resistance		≤1mΩ
5	Charging(CC-CV)	Maximum Charging Current	1C
		Charging Upper Limit Voltage	3.65V
6	Discharging	Maximum Discharging Current	2C
		Discharging Cut-off Voltage	2.5V
7	Charging Time	Standard Charging	4h
		Quick-acting Charging	1h
8	Recommended SOC Usage Window	SOC： 10%~90%	
9	Operation Thermal Ambient	Charging	0°C ~ 45°C
		Discharging	-20°C ~ 55°C
10	Storage Thermal Ambient	Short-term (within 1 month)	-20°C ~ 45°C
		Long-term (within 1 year)	-20°C ~ 20°C
11	Storage Humidity		＜70％
12	Battery Weight		Around 1.4kg
13	Shell Material		Plastic

Appendix 10 Battery Nomenclature

Table 50 Battery Specific Energy

Year	Battery Type	Application	Specific Energy (per cell)
1997+	Nickel Metal Hydride (NiMh)	Toyota RAV 4 EV Toyota Prius	80 Wh/kg [(1)]
2007+	Lithium Iron Phosphate ($LiFePO_4$ or LFP)	Aptera Typ-1	90-130 Wh/kg [(2)]
2011+	Lithium Titanate ($Li_4Ti_5O_{12}$ or LTO)	Mitsubishi i-MiEV	109 Wh/kg [(3)]
2012+	Lithium Manganese ($LiMn_2O_4$ or LMO)	Nissan LEAF (24kW) BMW i3	100 to 150 Wh/kg [(4)]
2013+	Lithium Nickel Cobalt Aluminum Oxide ($LiNiCoAlO_2$ or NCA)	Tesla Model S	254 Wh/kg [(5)]
2015+	Sodium Ion (Na-ion or SIB)	n/a – prototype stage	90 Wh/kg or 350 Wh/kg *theoretical* [(6)]
2016+	Lithium Nickel Manganese Cobalt Oxide ($LiNiMnCoO_2$ or NMC)	Nissan LEAF (30kW) VW eGolf Renault ZOE	150 to 220 Wh/kg [(7)]
2017+	Lithium Metal (Li-metal)	TBC	~ 300 Wh/kg [(8)]
	Solid State Lithium	TBC	~ 400 Wh/kg [(9)]
	Lithium Sulfphur (Li-S)	TBC	~ 550 Wh/kg [(10)]
	Aluminium-air (Al-air)	TBC	~ 8,100 Wh/kg [(11)]
2025?	Lithium-air (Li-air)	TBC	~ 13,000 Wh/kg [(12)]

(1) - http://batteryuniversity.com/learn/archive/whats_the_best_battery
(2) - http://www.epectec.com/batteries/lithium-battery-technologies.html
(3) - http://batteryuniversity.com/learn/article/electric_vehicle_ev
(4) - http://batteryuniversity.com/learn/article/types_of_lithium_ion
(5) - http://uk.businessinsider.com/how-teslas-batteries-could-go-further-2016-9
(6) - http://spectrum.ieee.org/energywise/energy/renewables/a-first-prototype-of-a-sodiumion-rechargeable-battery and http://www.csm.ornl.gov/BLI8/presentations/CJohnson-Na-ion_Batteries_BLi8.pdf
(7) - http://www.eco-aesc-lb.com/en/product/liion_ev/
(8) - http://batteryuniversity.com/learn/article/experimental_rechargeable_batteries
(9) - http://batteryuniversity.com/learn/article/experimental_rechargeable_batteries
(10) - http://batteryuniversity.com/learn/article/experimental_rechargeable_batteries
(11) - http://www.power-eetimes.com/news/long-life-aluminium-air-battery-resolves-rechargeable-challenges
(12) - http://www.sciencedirect.com/science/article/pii/S1369702113004586