Lifecycle cost and environmental impact analysis of adopting an electric vehicle fleet for WEST Sussex County Council

Michel Leseure

University of Chichester Business School

28/03/2019

# Abstract

This study was commissioned by West Sussex County Council in order to assess the economic and environmental performance of introducing electrical vehicles in its fleet. Electrical vehicles are typically described as environmentally friendly, expensive to buy, but cheap to run. Based on the data collected over a 4-month trial period, the report confirms this statement, although the extent of the cost difference between electrical and conventional vehicles is not as important as often portrayed. Car utilisation is a major variable when computing a lifecycle cost, and this is especially so in the operating lease context used by the Council to source its cars.

The conclusion is that the electrical vehicles (Renault Zoe) introduced in the fleet reduce lifecycle Greenhouse Gas Emissions by half when compared with conventional cars. The total cost of the electrical vehicles is 70% higher than conventional ones but this could be reduced to 38% through increased utilisation. The evaluation framework of Granoskii et al. (2016) is customised to the case of the fleet and used to conclude that overall, electrical vehicles are the best, especially if the UK electricity portfolio continue to increase its renewable energy content.

Issues are raised with the charging regimes of the electrical vehicles though. Charging tends to only happen during peak demand time and the long periods of time during which cars are connected to the charging station could be detrimental to battery life.

Contents

[Abstract 2](#_Toc4707600)

[1. Context of Project 4](#_Toc4707601)

[2. Purpose of Project 4](#_Toc4707602)

[3. Prior Research 5](#_Toc4707603)

[4. Methodology 6](#_Toc4707604)

[4.1. Approach 6](#_Toc4707605)

[4.2. Cost data 7](#_Toc4707606)

[4.3. Environmental Data Performance 8](#_Toc4707607)

[4.4. Framework 11](#_Toc4707608)

[5.results 11](#_Toc4707609)

[5.1. Trips 11](#_Toc4707610)

[5.2. Charging 16](#_Toc4707611)

[5.4. Fuel Cost Analysis 17](#_Toc4707612)

[5.5. Total Cost Analysis 18](#_Toc4707613)

[5.6. Environmental Analysis 18](#_Toc4707614)

[5.6. Framework 19](#_Toc4707615)

[6.Scenario Analysis 20](#_Toc4707616)

[5. Conclusion 21](#_Toc4707617)

[6. References 21](#_Toc4707618)

# Context of Project

Energy efficiency is the key to reducing greenhouse gas emissions; in the UK almost a third of the primary energy is lost during energy conversion and delivery. One significant user of energy is the transportation sector, which in the UK uses more that 30% of the total energy delivered. Therefore, improving efficiency in this sector is imperative for reducing greenhouse gases. One way of improving energy efficiency in transportation is by replacing the internal combustion engine with an electric motor. Generally, Electric Vehicles (EV) have an efficiency in the region of 90% compared to their petrol counterpart of about 40%. However, there are some obstacles to EV, which are mainly the higher initial cost to consumer and the lower range. However, the operating cost of an EV is less than those of a petrol equivalent.

West Sussex County Council (WSCC) is piloting 3 electrical vehicles for its service fleet. These vehicles will replace traditional fuel-powered vehicles. The entire service fleet could be replaced over time. The pilot project will require the installation and operations of charging points. The charging station could be solely for the use of WSCC but it is an aspiration of the pilot that they will also be deployed as a service (either a service to employees or a public service).

# Purpose of Project

The purpose of the project is to develop an evaluation framework to perform a cost/benefit analysis for this transition in economic terms but also in terms of environmental impact. This will involve a rigorous analysis of the costs of the electric vehicles based on a real field test. This evaluation will be performed against a benchmark of an equal number of comparable fuel-powered vehicles. The analysis will be based on real data captured with a data logger system (Traffilog).

In the case of this project, the vehicle types being compared are:

* Kia Rio with a 1.25l petrol engine.
* Hyundai i30 with a 1.6 diesel engine.
* Renault Zoe (EV)
* Toyota Auris with hybrid engines, which were introduced in the data set during the last month (February).

The project was delayed due to the late delivery of the Renault Zoes. Data was collected over 4 months from November 2018 to February 2019. The initial project was supposed to also include Nissan electrical vans, but these were never delivered. The project was designed to analyse a significant amount of ‘live’ data, but only limited data could be collected through the data loggers. It was agreed between the University of Chichester and West Sussex City Council that this report should propose a framework to assess the economic and environmental performance of the different fleet vehicle type based on available data. When data was missing, publicly available estimates were used (see methodology section). It was also agreed that missing data could be collected after the publication of this report to improve the accuracy of the results, as and when agreed between the two parties.

# Prior Research

Comparing the economic and environmental performance of vehicles using different power sources is an active research area. Granovskii et al. (2006) compared conventional, hybrid, electric, and hydrogen fuel cell vehicles. Their research is based on normalised data collected from public sources that covers manufacturing and operation. Their conclusion is that hybrid and electric cars outperform the other types. However, an electric car is only preferable to an hybrid car if the electricity used for charging comes from renewable energy sources. Offer et al. (2010) compare electrical cars, hydrogen fuel cell, and hydrogen fuel cells plug-in hybrids for a 2030 energy scenario. Their conclusion is that by 2030 hydrogen cars could achieve parity with conventional cars, but electrical and hydrogen hybrid plug-ins are the top performers. Driving style determines which one of the two is best.

Bishop et al. (2011) note that a lot of research in this area is based on average manufacturers data and that researchers have to make assumptions about: time of day and day of the week, vehicle trip characteristics, real-world performance, when and for how long electric vehicles are charged, the impacts that electric vehicles may have on the power grid under large-scale deployment, and their overall lifecycle emissions. Their research aims to verify the legitimacy of some of these assumptions for a trial of 11 electric scooters in Oxford equipped with GPS data loggers as well as charging loggers. Their conclusion is that the total operating cost of the electrical scooters is 24% less than a petrol one.

Morrissey et al. (2016) explore Bishop et al. (2011)’s concern with charging assumptions by using data about the whole charging infrastructure of Ireland since its creation. Their analysis shows that charging at home is done in the evening during the period of highest demand. Car park locations are the favourite public charging stations and users prefer to use fast chargers at these.

Prior research therefore confirms that the research undertaken by WSCC is timely as there is a need to verify common assumptions made when assessing the performance of electric vehicles. The Energy Technology Institute is in fact undertaking a similar project which involves researching cost and patterns of use for both consumers and fleet owners (Consumer Vehicles and Energy Integration Project CVEI; [www.cveiproject.trl.co.uk](file:///C:\Users\dcooper\Downloads\www.cveiproject.trl.co.uk)).

The theme of energy integration is important and will be considered throughout this report. The first phase of the CVEI project confirmed that cost of ownership remained the main obstacle to EV ownership, and this especially for fleet owners. This means that reducing carbon emissions is often the main motive for owning EVs, which becomes controversial if the electricity used for charging is generated through fossil fuels. As mentioned above, charging habits are currently sub-optimal. This is confirmed by the first phase of CVEI project for the UK (Erault, 2016) and the research literature is increasingly making recommendations to overcome these issues. For example, Coignard et al. (2018) recommend that EVs in California should be used as a large-scale distributed storage to help the state’s grid to better utilise intermittent renewable energy production.

# 4. Methodology

## 4.1. Approach

The initial specifications of the project were similar to the Oxford-based electrical scooter study by Bishop et al. (2011). However, as explained above, the requisite data for a such a detailed approach was not available. The best framework that could be used given the data available was that of Granovskii et al. (2006).

The framework is based on computing normalised indices for car cost, driving range, fuel cost, Greenhouse Gas Emissions (GHG in kg of CO2 equivalent), and Air Pollution emissions (AP). The main gas considered in GHG emissions are CO2, CH4, N2O, and SF6 because of their impact on climate change. AP emissions are considered because of their impact on human health an include pollutants CO, NOx, SOx, and volatile organic compounds. Granovskii et al. (2016) provide weightings to convert GHG and AP as indices based on CO2 and NOx respectively, and these values were used.

The framework was slightly adjusted as follows to taken into the fact that this study looks at fleet vehicles:

* The dataset revealed that the average distance in a driving session captured by the data logger was 8.6 miles. A typical ‘trip’ will include on outward and inward session, so the average round trip is 17.2 miles. The Renault Zoe are advertised with a range of 228 miles. Their average distance per session is 11 miles, and they were used an average of 9.5 session per day. This means an average total of 103 miles per day. Based on this data, it is reasonable to assume that range is not a major performance consideration and therefore it was removed from the framework.
* The cars are leased under an operating lease arrangement allowing for 15,000 miles per year. Out of the 279 car-month entries in the data set, only 24 cars exceeded the maximum distance driven of 1,250 miles per month[[1]](#footnote-1). The average utilisation of the fleet was 56%. In their framework, Granovskii et al. (2016) considered purchase cost and fuel cost as two separate variables. This assumes that a car with low mileage retains value, but this is not the case with an operating lease, as the cars have no terminal values. For this reason, the framework in this report combines all costs together, that is we combine fuel and lease costs together and uses a £ per mile full lifecycle cost performance measure. To perform well a fleet car should be fully utilised (as it incurs the same lease payment) and should incur a low fuel cost.
* The useful life of a car used by Granovskii et al. (2006) of 241,350km was changed to 100,000 miles to better represent UK car consumption patterns. When lifecycle values are considered, a portion of that lifecycle value is allocated to the fleet based on the lease arrangement. For example, when considering the GHG of manufacturing a Kia Rio, these emissions are allocated over the 45,000/100,000 miles, or 45% of the useful life of that car at WSCC. The ‘responsibility’ for the manufacturing emissions for the remaining 55% of the useful life of the car is allocated to the next owner.

## 4.2. Cost data

Table 1 shows cost and related data for each car type.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Car Type** | **Kia Rio** | **Hyundai i30** | **Renault Zoe** | **Toyota Auris** |
| Operating lease cost (£/year) | 4,325 | 1,329 | 2,205 | *£5,151* |
| Cost of road tax (£/year) | 160 | 20 | 0 | 130 |
| Cost of insurance (£/year) | 434 | 434 | 434 | 434 |
| Maximum miles per year | 15,000 | 15,000 | 15,000 | 15,000 |
| Lease life (years) | 3 | 3 | 4 | *3* |
| Cost of maintenance (£/year) | 533 | 512 | *250* | *500* |
| Useful Life (miles) | 100,000 | 100,000 | 100,000 | 100,000 |

*Table 1. Cost Characteristics per Type of Car*

Numbers shown in italics in table 1 were estimated. The cost of maintenance for the Renault Zoe is not known and was estimated to be £250 per year (£1,000 over the lease-life of the car). This is because there is very little to service in an EV, with the most expensive service item for a Zoe being the change of the 12V battery after 3 years at a cost of £250.

In estimating this cost, the key question to consider was the useful life of the 400V drivetrain battery. Renault provides a 3-year or 100,000 miles warranty. The cars are leased for 4 years with a 15,000 miles per year allowance, so it was assumed that the 400V battery will not need replacing outside of a warranty claim. This is an important assumption as the 400V battery costs about £4,000, and having to change it once would highly increase yearly maintenance costs. Internet forums revealed users with a battery at a 90% state of health after driving the car for 22,000-48,000 miles. This confirms that the battery capacity will decline during the 4-year lease, but it should not reach the stage at which a replacement is needed.

However, there was evidence that the charging regime at WSCC could be detrimental to the batteries. It is not ideal to overcharge the batteries as the resulting overheating reduces the charge-discharge capacity. The charging dataset shows that cars are left charging for long times. A full charge for the Renault Zoe will normally take 7.5 hours, and on average the Zoes were left connected to the chargers for 21 hours, with one car being left connected for 138 hours! It is normally recommended to operate the battery in the 50-80% range of charge capacity to maximise their useful life, which is clearly not happening when cars are left charging for long periods of time. Observing charging patterns and associated costs should therefore become part of the fleet management. The problem should partially disappears as more cars need access the charging points.

Cost of fuel estimates were based on UK averages: £1.14/litre for petrol, £1.16/litre for diesel, and £0.12/kWh for electricity.

Computing operating cost requires fuel consumption data. The data loggers were disappointing in this respect as reliable data was only obtained for the Toyota Auris. Fuel consumption was never provided by the data loggers for the Hyundai i30s. The manufacturer advertises 67 mpg, but an internet forum average of 49 mpg will also be considered. The data logger sometimes provided fuel consumption data for the Kia Rios. The advertised value is 51 mpg, but the data loggers suggest an average of 39 mpg. The data loggers do not provide consumption data for each trip for the Renault Zoes, so an average monthly consumption was computed by matching the data logger with the charging database.

## 4.3. Environmental Data Performance

Table 2 shows the mass and driving emissions of each car type.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | kg | Total life | % | g/km |
| **Type of car** | **Curb Mass** | **Miles** | **WSCC Life** | **Emissions** |
| Rio 1.25 | 1099 | 100,000 | 45% | 114 |
| I30 | 1263 | 100,000 | 45% | 102 |
| Zoe | 1575 | 100,000 | 60% | 0 |
| Auris | 1425 | 100,000 | 45% | 103 |

*Table 2. Curb Mass and Emissions for each type of car*

Table 3 shows Granovskii et al. (2006) environmental impact data per kilogram of curb mass to take into account the extraction of raw materials, manufacturing, and the end of life treatment of the cars.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Environmental Impact Data (Non driving)** | **Curb Mass (kg)** | **GHG (kg)** | **AP (kg)** | **GHC per kg** | **AP per kg** |
| Conventional | 1134 | 3598.8 | 8.74 | 3.173545 | 0.007707 |
| Hybrid | 1311 | 4156.7 | 10.1 | 3.170633 | 0.007704 |
| Electric | 1588 | 4758.3 | 15.09 | 2.996411 | 0.009503 |

*Table 2. Production Stage Environmental Impact Data (adapted from Granovskii et al., 2006).*

These values are applied to compute production emissions and pollution per mile for each type of car, as shown in table 3.

|  |  |  |
| --- | --- | --- |
|  | kg/mile | kg/mile |
| **Emissions per Mile (Production stages)** | **GHG** | **AP** |
| Rio 1.25 | 0.0349 | 8.47025E-05 |
| i30 | 0.0401 | 9.73423E-05 |
| Zoe | 0.0472 | 0.000149665 |
| Auris | 0.0452 | 0.000109783 |

*Table 3. Production Stage Environmental Impact in kg CO2-eq per mile*.

Table 4 shows the lifecycle environmental impact of electrical batteries:

|  |  |  |
| --- | --- | --- |
|  | kg | kg |
| **Environmental Impact of battery** | **Life GHG** | **Life AP** |
| Hybrid car | 89.37 | 0.507 |
| Electric | 1087.6 | 6.167 |

*Table 4. Lifecycle Environmental Impact of Batteries (from Granovskii et al., 2006).*

To assess the environmental impact of EVs, it is necessary to consider the carbon conversion factor of electricity. The scenario-based approach proposed by Granovskii et al. (2006) is used. Three scenarios are considered:

* In scenario 1, electricity is exclusively generated by renewable energy sources and nuclear energy.
* In scenario 2, 50% of the electricity is generated by renewable energy sources and 50% by gas turbines.
* In scenario 3, 100% of the electricity is generated by gas turbines.

Table 5 displays the environmental impact of electricity production for each scenario in grams of CO2-eq per Mega Joules. This is converted in kg of CO2-eq per KWh and then combined with the Renault Zoes KWh/mile consumption to compute an environmental impact in kg of CO2-eq per mile.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | g/MJ | | kg/KWh | | Kg/mile | |
| **Environmental Impact of electricity production** | **GHG** | **AP** | **GHG** | **AP** | **GHG** | **AP** |
| Scenario 1: no fossil fuel | 5.11 | 0.0195 | 0.0184 | 0.0001 | 0.0067 | 0.0000 |
| Scenario 2: 50% renewable | 77.5 | 0.296 | 0.2790 | 0.0011 | 0.1009 | 0.004 |
| Scenario 3: Fossil fuel | 149.9 | 0.573 | 0.5396 | 0.0021 | 0.1951 | 0.0007 |

*Table 5. Environmental Impact of Electricity Production*

It is worth noting that the official UK Government carbon conversion for electricity is 0.28307 kg/kWh, which means that scenario 2 (0.2790 kg/kWh) matches current UK conditions. It makes sense as the current combined share of nuclear, offshore wind, and solar is close to 50%.

Table 5 represents the indirect emissions of EVs as they have no direct emissions. Table 6 shows the indirect emissions associated with liquid fuels, i.e. the lifecycle impacts of extracting, refining, and transporting oil products. The values in kg of CO2-eq per mile were computed based on UK Government values and fuel consumption figures (actual for Toyota Auris, manufacturer’s value for Kia Rio and Hyundai i30, see section 4.2). Air pollution was not estimated.

|  |  |  |
| --- | --- | --- |
|  | kg/m | kg/m |
| **Well to Tank GHG emissions** | **GHG** | **AP** |
| Rio 1.25 | 0.0531 | Not Known |
| i30 | 0.0478 | Not Known |
| Zoe | 0.0000 | Not Known |
| Auris | 0.0625 | Not Known |
| *Petrol* | *0.5959* | *kg/l* |
| *Diesel* | *0.6325* | *kg/l* |

*Table 6. Well to Tank GHG emissions for each type of car.*

## 4.4. Framework

The framework is adapted from the framework proposed by Granoskii et al., (2006). The performance of each car is assessed against the following three dimensions:

* Cost: Average lifecycle cost for each car in £/mile. This includes the fuel/electricity cost of operating the car and ownership costs (lease, insurance, maintenance, road tax). The average total cost is computed by allocating fixed ownership costs to miles driven over a lease period and takes into account the average utilisation of each type of car.
* GHG: The CO2-equivalent greenhouse gas emissions per miles, including all stages of the lifecycles, as described in the previous sections.
* AP: The air pollution, in kg of NOx per mile driven, including all stages of the lifecycles, as described in the previous sections.

The scores for each type of car is normalised by computing the ratio of the inverse value for a car divided by the inverse of the best performing (i.e. lowest) car. This means that the best performing car receives a score of 1 in each measure. All scores are between 0 and 1.

The overall performance of a car is measured by taking the geometric average of all three performance measures. This assumes that the dimensions are equally important.

# 5.results

## 5.1. Trips

Table 7 displays the total miles driven for each car over the 4 months trial period. For each car, the monthly miles should be compared to the notional 1,250 miles allowed by the lease, and the grand total to 5,000 miles.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **January** | **February** | **November** | **December** | **Grand Total** |
| **EV** | **2320.26** | **2139.77** | **2958.01** | **1498.66** | **8916.7** |
| LV18 LYP | 159.52 | 613.22 |  | 424.91 | 1197.65 |
| LV18 VHR | 642.87 | 674.72 | 907.19 | 356.44 | 2581.22 |
| LV18 VJX | 745.67 | 540.68 | 598.7 | 375.29 | 2260.34 |
| LV18LYP |  |  | 946.63 |  | 946.63 |
| LY18 AZZ | 772.2 | 311.15 | 505.49 | 342.02 | 1930.86 |
| **Hybrid** |  | **1423.6** |  |  | **1423.6** |
| HN68 JJF |  | 475.98 |  |  | 475.98 |
| HN68 JJK |  | 495.25 |  |  | 495.25 |
| HN68 JJY |  | 452.37 |  |  | 452.37 |
| **Non-EV** | **53137.02** | **53084.39** | **37886.66** | **42771.21** | **186879.28** |
| EF66 DZW | 484.06 | 558.57 | 427.64 | 402.41 | 1872.68 |
| EF66 EAA |  |  | 929.53 |  | 929.53 |
| EF66 EAC | 1037.97 | 692.54 | 894.36 | 165.1 | 2789.97 |
| EF66 EAJ | 398.19 | 703.35 | 1544.28 | 585.78 | 3231.6 |
| EF66 EAK | 845.59 | 446.9 | 1671.97 | 381.53 | 3345.99 |
| EF66 EAO | 775 | 1478.53 | 2162.93 | 620.08 | 5036.54 |
| EF66 EAW | 837.01 | 680.23 | 574.04 | 269.93 | 2361.21 |
| HK17 VFA | 678.55 | 572.95 | 594.53 | 368.99 | 2215.02 |
| HK17 VFB | 858.89 | 344.59 | 808.46 | 500.89 | 2512.83 |
| HK65 CHJ | 671.35 | 584.17 | 1024.61 | 680.23 | 2960.36 |
| HK65 CJU | 1254.71 | 733.24 | 648.17 | 331.82 | 2967.94 |
| HK65 CJV | 1441.19 | 2277.7 | 716.03 | 507.05 | 4941.97 |
| HK65 CJX | 1270.3 | 992.36 |  | 959.17 | 3221.83 |
| HK65 CJY | 1668.12 | 1508.23 | 898.03 | 1335.24 | 5409.62 |
| HK65 CJZ | 682.84 | 494.25 | 481.2 | 451.87 | 2110.16 |
| HK65 CKV | 403.78 | 190.64 | 1186.04 | 245.14 | 2025.6 |
| HK65 CLF | 662.77 | 323.62 | 620.27 | 236.07 | 1842.73 |
| HK65 CLJ | 577.7 | 1021.31 | 844.72 | 970.17 | 3413.9 |
| HK65 CLO | 1093.64 | 940.91 | 1858.57 | 1643.13 | 5536.25 |
| HK65 CLU | 962.84 | 504.75 | 469.77 | 473.81 | 2411.17 |
| HK65CJX |  |  | 913.19 |  | 913.19 |
| HN68 HKV | 1124.77 | 788.22 | 133.43 | 603.58 | 2650 |
| HN68 HKW | 1038.75 | 794.61 | 25.71 | 1389.64 | 3248.71 |
| HN68 HKX | 617.75 | 793.41 | 0 | 333.15 | 1744.31 |
| HN68 HKY | 744.13 | 570.8 |  | 891.64 | 2206.57 |
| HN68 HKZ | 887.47 | 506.16 |  | 979.98 | 2373.61 |
| HN68 HLP | 341.92 | 214.85 | 24.84 | 877.88 | 1459.49 |
| HN68 HLR | 541.36 | 669.75 |  | 199.7 | 1410.81 |
| HN68 HLU | 934.65 | 858.14 | 26.09 | 1600.23 | 3419.11 |
| HN68 HLV | 998.87 | 1063.04 | 23.94 | 668.41 | 2754.26 |
| HN68 HLW | 944.16 | 691.28 |  | 1604.88 | 3240.32 |

*Table 7. Drive Statistics in miles per month per car (Part 1)*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **January** | **February** | **November** | **December** | **Grand Total** |
| HN68 MYP | 709.76 | 686.32 | 24.82 | 754.59 | 2175.49 |
| HN68 WUY | 924.82 | 823.54 | 22.92 | 287.67 | 2058.95 |
| HN68HLR |  |  | 0.02 |  | 0.02 |
| HN68HLW |  |  | 24.85 |  | 24.85 |
| HT65 JWP | 184.8 | 308.15 | 272.04 | 295.1 | 1060.09 |
| HT65 JWU | 281.36 | 437.58 |  |  | 718.94 |
| HT65 JWV | 430.93 | 509.04 | 967.38 | 626.3 | 2533.65 |
| HT65 JWW | 990 | 714.78 | 449.55 | 505.62 | 2659.95 |
| HT65 JWX | 1055.74 | 1252.47 | 862.42 | 1232.83 | 4403.46 |
| HT65 JWY | 841.17 | 511.28 | 661.34 | 884.55 | 2898.34 |
| HT65 JWZ | 740.94 | 507.05 | 709.44 | 1229.42 | 3186.85 |
| HT68 FBK |  | 668.66 |  |  | 668.66 |
| HT68 FBL |  | 201.42 |  |  | 201.42 |
| HT68 FBN | 757.69 | 616.04 |  |  | 1373.73 |
| HT68 FBO |  | 332.82 |  |  | 332.82 |
| HT68 FBV |  | 316.37 |  |  | 316.37 |
| HT68 FBZ | 1580.38 | 962.08 |  |  | 2542.46 |
| HT68 FCD |  | 569.69 |  |  | 569.69 |
| HT68 FCG |  | 525.15 |  |  | 525.15 |
| HT68 FCM |  | 737.75 |  |  | 737.75 |
| HT68 FCP |  | 404.41 |  |  | 404.41 |
| HT68 FDJ | 726.4 | 1193.64 |  |  | 1920.04 |
| HT68 FDL | 771.39 | 1029.39 |  |  | 1800.78 |
| HT68 FDO |  | 1233.72 |  |  | 1233.72 |
| HT68 FEH | 1226.53 | 1062.21 |  |  | 2288.74 |
| HT68 FEP | 803.52 | 526.63 |  |  | 1330.15 |
| HV68 WUX | 1206.41 | 724.62 |  | 468.87 | 2399.9 |
| HV68 WVA | 983.19 | 555.04 | 0.04 | 614.65 | 2152.92 |
| HV68 WVB | 621.03 | 614.63 | 0.02 | 630.08 | 1865.76 |
| HV68 WVC | 1204.67 | 760.19 | 24.84 | 1411.82 | 3401.52 |
| HV68 WVD | 1123.46 | 613.25 | 14.87 | 983.18 | 2734.76 |
| HV68 WVE | 653.58 | 477.01 |  | 620.75 | 1751.34 |
| HV68 WVF | 574.23 | 818.6 |  | 1481.73 | 2874.56 |
| HV68 WVG | 563.88 | 400.55 | 24.76 | 152.63 | 1141.82 |
| HV68WUX |  |  | 26.54 |  | 26.54 |
| HV68WVF |  |  | 0.08 |  | 0.08 |
| HX12 GCZ |  |  | 1161.25 |  | 1161.25 |
| HX16 GBU | 465.3 | 1973.53 | 1206.49 | 699.93 | 4345.25 |
| HX16 GBV | 425.53 | 303.49 | 578.7 | 353.51 | 1661.23 |
| HX16 GBY | 759.09 | 540.67 | 988.19 | 637.67 | 2925.62 |
| HX16 GBZ | 576.46 | 426.65 | 691.54 | 650.84 | 2345.49 |
| HX16 GCF | 572.98 | 1221.28 | 1108.62 | 442.12 | 3345 |
| HX16 GCK | 509.04 | 276.46 | 759.83 | 346.92 | 1892.25 |
| HX16 GCO | 1001.74 | 701.36 | 1092.03 | 293.23 | 3088.36 |

*Table 7. Drive Statistics in miles per month per car (Part 2)*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **January** | **February** | **November** | **December** | **Grand Total** |
| HX16 GCU | 931.09 | 330.39 | 834.4 | 409.93 | 2505.81 |
| HX16 GCV | 694.4 | 1091.59 | 922.51 | 562.36 | 3270.86 |
| HX16 GCY | 142.17 | 350.96 | 595.17 | 180.39 | 1268.69 |
| HX16 GCZ | 704.53 | 558.38 |  | 553.41 | 1816.32 |
| HX16 GDA | 609.27 | 470.39 | 1084.2 | 382.71 | 2546.57 |
| HX17 UAV | 845.62 | 633.1 | 718.54 | 1556.78 | 3754.04 |
| HX17 UAY | 515.88 | 680.95 | 1215.48 | 2813.5 | 5225.81 |
| HX17 UBF | 649.71 | 432.01 | 1341.43 | 430.62 | 2853.77 |
| **Grand Total** | **55457.28** | **56647.76** | **40844.67** | **44269.87** | **197219.58** |

*Table 7. Drive Statistics in miles per month per car (Part 3)*

The average utilisation for the 4 months is 56%. Computing utilisation is complicated by the fact that cars are frequently switched in and out of the fleet. This can be seen in table 7 when a car is seemingly only used for 1 month and sometimes for very few miles. This means that the real utilisation rate is likely to be higher than 56%. In order to have a better feel for utilisation rates, these were computed per type of car but only for cars used in all 4 months:

* The Hyundai i30s were utilised at 67%.
* The Kia Rios were utilised at 57%.
* The Renault Zoe were utilised at 40%.
* The Toyota Auris were utilised at 38%.

The fact that the Renault Zoe are the least utilised is quite counter-intuitive as they are, by far, the cheapest car to use in terms of incremental costs (see section 5.4). When considering a fleet which is not fully utilised, it is best to first use cars with the lowest operating cost per mile (the ownership costs becomes a sunk cost).

As stated previously, the average distance in a driving session captured by the data logger was 8.6 miles. The ‘typical’ use of a car in a month is: 20 sessions of 8.6 miles for a total of 172 miles. However, a look at table 7 reveals that these numbers are not representative of use as some cars have probably reached the end of their lease during the trial period. Others have been introduced and some cars appear for only 1 month, presumably to replace a fleet car needing maintenance. Table 8 contrasts the driving statistics of (i) the full data set without any data cleaning, (ii) the driving of cars that were used in all 4 months of the trial period, and (iii) the data logger data obtained for a single car (registration EF66 DZW) for December. Table 8 shows that once only cars utilised throughout the trial period are considered, cars are driven on average 41 miles per day. Yet the specific example of EF66 DZW shows an average daily mileage of 18 miles. Figure 1 displays the number of sessions logged in for each day of the month for that car.

|  |  |  |
| --- | --- | --- |
|  | **Average Session Length** | **Miles per day per car** |
| Full data set (96 cars) | 8.6 miles | 23 miles per day |
| Cars used in all 4 months (56 cars) | N/A | 41 miles per day |
| EF66 DZW (December) | 6.49 miles | 18.29 miles per day |

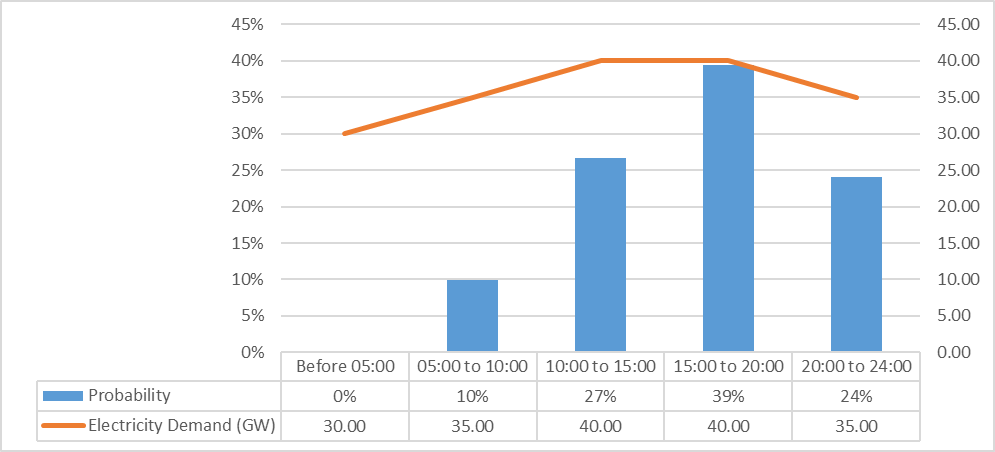
*Table 8. Comparison of Drive Profiles*

*Figure 1. Session per day for a specific car.*

Finally, the dataset reveals that the cars are driven in reasonably fluid traffic conditions as driving time represents 84% of a session time. Engines are therefore running idle for only 16% of the time. An examination of the data set shows that this average value is representative of 95% of all driving sessions as only 5% of the sessions correspond to congested traffic conditions.

## 5.2. Charging

Figure 2 displays the probability that an EV is charging during a time interval and confirms the findings from prior research (Eraut, 2016; Morrisey et al., 2016): user charging behaviour is the least practical from an electricity production perspective, as it increases the variability of electricity demand (power difference between peak and off-peak times).

**

*Figure 2. Probability of a car charging for 5-hours intervals compared to national electricity demand pattern*

Ideally, the charging of EV should take place between midnight and 7 am, the off-peak period. This is because off-peak consumption would extend the base load cycle and make electricity production easier to plan and manage (when it is impossible or expensive to store electricity, it would ideal to produce a constant amount of electricity). It could also allow the utilisation of renewable energy sources that are otherwise curtailed due to lack of demand.

Figure 2 shows that peak demand for charging takes place precisely when electricity demand is at its peak. The average start time for charging a car is 2pm, which means that on normal cycle, charging will be finished at 10pm for a Renault Zoe, still during peak demand.

## 5.3. Fuel Cost Analysis

Table 9 shows the electricity costs of operating the Renault Zoe. The results for LV18 VHR are excluded in the rest of the report, as there were issues with the charging card for this car. This means that the car is likely to have been charged with another ID, and that the operating cost of 2 pences per mile shown in table 9 is not accurate. Renault advertises the car as costing 3 pences per mile, which is confirmed by table 9. LV18 LYP is the Renault Zoe equipped to use the fast charger, and this results in a slightly higher cost, 16% higher than the average of the other two Zoe.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **Cost per mile (£/m)** | | | | |
| **Car** | Jan | Feb | Nov | Dec | **Average** |
| LV18 LYP | 0.033 | 0.044 | 0.030 | 0.042 | **0.037** |
| ~~LV18 VHR~~ | ~~0.015~~ | ~~0.017~~ | ~~0.027~~ | ~~0.021~~ | **~~0.020~~** |
| LV18 VJX | 0.028 | 0.035 | 0.035 | 0.035 | **0.033** |
| LY18 AZZ | 0.037 | 0.028 | 0.025 | 0.035 | **0.031** |

*Table 9. Electricity cost of operating Renault Zoes in £/mile.*

Table 10 compares the energy consumption observed in this study with other studies.

|  |  |
| --- | --- |
|  | kWh/mile |
| Nissan Leaf/Wilson (2013) | 0.34 |
| Zoe (this study) | 0.36 |
| Granovskii et al. (2006) | 0.298 |

*Table 10. Energy Consumption of EV per mile*

The fuel cost of a Renault Zoe is thus much cheaper than the other cars in the fleet, which are:

* Toyota Auris: 0.12 £/mile (based on data logger consumption).
* Kia Rio: 0.10 £/mile (manufacturer); 0.13 £/mile (available data logger data).
* Hyundai i30: 0.08£/mile (manufacturer); 0.11£/mile (internet estimate).

## 5.4. Total Cost Analysis

Table 11 displays the total lifecycle costs of each type of car.

|  |  |  |  |
| --- | --- | --- | --- |
| **Type of car** | **Consumption data** | **Total Cost;**  **in £/mile** | **Cost at 70% utilisation** |
| Kia Rio | Advertised consumption | 0.48 | 0.34 |
|  | Data logger average | 0.51 | 0.37 |
| Hyundai i30 | Advertised consumption | 0.50 | 0.38 |
|  | Internet average | 0.53 | 0.41 |
| Renault Zoe | Data loggers | 0.87 | 0.51 |
| Toyota Auris | Data loggers | 1.21 | 0.71 |

*Table 11. Total cost of each type of car in £/mile (inclusive of lease, insurance, maintenance, utilisation, road tax, and fuel).*

The third column of table 11 shows the average total cost of using a car based on the average utilisation of each type of car. As explained earlier in the report, the fact that cars are switched in and out of the fleet means that utilisation figures are not representative. The real cost of cars to WSCC is thus likely to be less than the figures shown in the third column. To address this issue, the fourth column shows the cost of each type of car after assuming that all cars are utilised at 70%. For comparison, the best utilised car, the Hyundai i30, is utilised at 67% (see page 13). Thus, table 11 also provides an illustration of the sensitivity of lifecycle cost to utilisation when one compares the 4th column (70% utilisation) with the 3rd column (56% utilisation).

## 5.5. Environmental Analysis

Table 12 shows the results of the environmental impact analysis for each type of car and differentiates the driving stage from the total lifecycle environmental impact. It shows that the driving stage represents 96% of total emissions.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Fuel Utilisation Stage** | | **Total** | |
|  | *kg/mile* | | *kg/mile* | |
| **Type of car** | **GHG** | **AP** | **GHG** | **AP** |
| Rio 1.25 | 0.23657 | 0.00067 | 0.2523 | 0.0007 |
| I30 | 0.21199 | 0.00060 | 0.2300 | 0.0006 |
| Zoe1 | 0.00665 | 0.00003 | 0.0415 | 0.0002 |
| Zoe2 | 0.10086 | 0.00039 | 0.1212 | 0.0005 |
| Zoe3 | 0.19508 | 0.00075 | 0.1951 | 0.0009 |
| Auris | 0.22824 | 0.00065 | 0.2490 | 0.0007 |

*Table 12. Environmental Impact Assessment of Each Type of Car, in kg of CO2-equivalent per mile.*

The 3 different Renault Zoe in table 12 are in reference to the three electricity generation scenarios described on page 9. Table 12 reveals that the Renault Zoe has almost no emissions in the scenario where electricity is produced from nuclear and renewable energy sources. Scenario 2 is similar to the current energy mix of the UK and assumes that 50% of the electricity comes from fossil fuels. In this scenario, Greenhouse gas emissions are 0.10 kg of CO2-equivalent per mile. It is very close to the official UK government EV figure of 0.081 kg CO2-equivalent per mile. Table 12 shows that emissions of the Renault Zoe are roughly half of the emissions of the conventional cars used in the fleet.

## 5.6. Framework

Table 13 shows the results of the evaluation framework where a maximum score of 1 indicates the best performing car for a given dimension. It shows that the Kia Rio is the most economical car, closely followed by the Hyundai i30. It is important to note that this cost performance is based on the cost computed for a 70% utilisation rate.

The Renault Zoe is the best car for emissions under all electricity generation scenarios. Assuming equal weights between lifecycle cost, GHG emissions, and air pollution the Renault Zoe is the best car overall, even under the current electricity generation mix in the UK. The Hyundai i30 and Kia Rio come second and third, just ahead of the Renault Zoe in the case of 100% fossil fuel energy mix. Figure 3 depicts the performance of the cars graphically.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Normalised Indicators | | | General Indicator | Overall Indicator |
| Car Type | Cost | GHG | AP |
| Rio 1.25 | 1 | 0.164476 | 0.214819 | 0.32814 | 0.365186 |
| I30 | 0.902439 | 0.180376 | 0.236137 | 0.33748 | 0.375586 |
| Zoe1 | 0.72549 | 1 | 1 | 0.89855 | 1 |
| Zoe2 | 0.72549 | 0.342371 | 0.297215 | 0.41950 | 0.466863 |
| Zoe3 | 0.72549 | 0.212693 | 0.174416 | 0.29968 | 0.333513 |
| Auris | 0.521127 | 0.166648 | 0.217902 | 0.26648 | 0.296568 |

*Table 13. Overall Results*



*Figure 3. Cost vs GHG Performance of each type of car (X= lifecycle cost in £/miles; Y= kg CO2-equivalent per mile).*

# 6.Scenario Analysis

Time did not permit to perform a scenario analysis as initially agreed between the University and WSCC. It was agreed that this would happen after the writing of this report. Key variables to consider are:

* The future of the UK electricity mix;
* Possible strategies to increase utilisation (Figure 3 shows that well-utilised Renault Zoe would compete in terms of cost with the Kia Rio at their current utilisation rate).
* The impact on increasing EVs in the fleet in terms of charging station (whose cost were not considered in this report).
* The emergence of new technologies, such as hydrogen fuel cells and plug in hybrids.

# Conclusion

Despite the high cost of purchase of electrical vehicles, this report shows that the Renault Zoe offers clear environmental benefits. It is currently more expensive in terms of lifecycle costs, although this could be reduced with better utilisation.

Recommendations to WSCC are:

* Adopt a fleet management policy of keeping the Zoes charged between 50 to 80% of their capacity, and find a solution to avoid the cars being left at the charging station for long periods of time.
* If utilisation of the fleet is low, use EVs as a priority to lower variable fleet costs.
* Consider researching the cost/feasibility of updating the charging stations to charge the cars off-peak, including the negotiation of a reduced off-peak rate. Doing so is recognised as an approach to compensate the intermittency issue of renewable energy sources and thus makes the electricity grid cleaner and more cost-efficient (Coignard et al., 2018).
* Collect actual fuel efficiency data for the conventional cars (Rio, i30) in order to clarify the extent of the cost performance difference with EV.
* Collect maintenance cost data for the Renault Zoe.
* Collect more data about the Toyota Auris. Consider fleet management allocations rules that match the % of idle vs. driving time to EVs, hybrid, and conventional cars.
* Perform more data analysis of driving patterns to determine what the maximum possible fleet utilisation is.

# References

Bishop, J.D.K., Doucette, R.T., Robinson, D., Mills, B., and McCulloch, M.D. 2011. “Investigating the technical, economic and environmental performance of electric vehicles in the real world: a case study using electric scooters”, *Journal of Power Sources*, 196: 10094-10104.

Coignard, J., Saxena, S., Greembaltt, J., and Wang, D. 2018. “Clean vehicles as an enabler for a clean electricity grid”, *Environmental Research Letters*, 13: 054031.

Eraut, N. 2016. *Consumers, Vehicles and Energy Integration (CVEI) Project: Achieving the benefits of integrating vehicles into the energy supply system*, presentation made at the Low Carbon Vehicle Partnership Annual Conference, 30/06/2016, available at: <https://www.eti.co.uk/programmes/transport-ldv/consumers-vehicles-and-energy-integration-cvei>

Granovskii, M., Dincer, I. and Rosen, M.A. 2006. “Economic and environmental comparison of conventional, hybrid, electric and hydrogen fuel cell vehicles”, *Journal of Power Sources*, 159: 1186-1193.

Morissey, P., Weldon, P., and O’Mahony, M. 2016. “Future standard and fast charging infrastructure planning: an analysis of electric vehicle charging behaviour”, *Energy Policy*, 89: 257-270.

Offer, G.J., Howey, D., Contestabile, M., Clague, R. Brandon, N.P. 2010. “Comparative analysis of battery electric, hydrogen fuel cell and hybrid vehicles in a future sustainable road transport system”, *Energy Policy*, 38: 24-29.

Wilson, L. 2013. *Shades of Green: Electric Cars’ carbon Emissions Around the Globe*, available at: <http://shrinkthatfootprint.com/wp-content/uploads/2013/02/Shades-of-Green-Full-Report.pdf>

1. Driving a vehicle for more 1,250 miles per month would not incur any additional charges from the leasing company as the car could be driven less in a following month. The notional limit of 1,250 miles per month is used to provide a basis to allocate the fixed cost of leasing to miles driven. [↑](#footnote-ref-1)