

Smart infrastructure for carbon foot print analysis of Electric Vehicles

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Abstract—Electric powered vehicles use energy stored in some form of battery for the vehicle propulsion drive and to power auxiliary instruments such as air conditioning, stereo and in car equipments. Many research initiatives are currently underway to evaluate the potential and performance of electric cars and to identify any barriers to their uptake (being, technical, economic or social) as a greener alternative to the internal combustion engine traditionally powered by the fossil fuels. This study provides an early insight into research being undertaken by Newcastle University to investigate the performance of electric vehicles through on-road testing, user led trials and the analysis of the data collected from the vehicle.

Newcastle University is currently involved in creating a smart ITS infrastructure to analyse the electric vehicle performance by monitoring the vehicles in terms of the power consumed, distance traveled, trip profile, auxiliary loads and driving styles to determine how the battery discharges and recharges under different conditions. By measuring the energy usage on any particular journey the equivalent carbon footprint for the journey can be estimated from the prevailing CO₂ emissions per KWh of the mean electricity generation profile in the UK. This paper will discuss the results from electric vehicle monitoring infrastructure by analysing the energy regeneration and energy usage, thereby calculating the impact to the environment.

I. INTRODUCTION

Around 22% of United Kingdoms carbon emissions come from transport, with 13% of these from private cars. Based on studies published by Department for Transport (DfT), electric vehicles are capable of ranges of between 50km and 200km (with an average range of current products of around 80km. The emissions from an electric vehicle are, on average around the equivalent of 100g/km, whilst in the UK petrol/diesel fleet the average is around 173g/km. The UK is committed to a target on reducing average emissions for a car to 130g/km by 2020. Migrating to cleaner forms of transport cannot be achieved by single technology and although in Europe the use of electric vehicles are at the top of both the political and automotive agendas at the moment, other solutions, such as hybrid, hydrogen fuel cells, plug in hybrid and bio-fuels are all also being actively researched and will have a role to play in the future [1].

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Fig. 1. Electric Smart Cars on Trial

There is a vital need to address the lack of knowledge surrounding the practicalities of introducing electric vehicles as a viable mass market technology for both businesses and the general driving public. To urgently address this, the SWITCH-EV (also known as the EVADINE project), a national demonstration project backed by government agency called Technology Strategy Board (TSB) is being rolled out to monitor a range of electric vehicles which will be evaluated from the technical, economic and social aspects of living with an all-electric vehicle [2]. In addition to the testing of vehicles the North East has won a large Plugged in Places project from government to install a widespread EV charging infrastructure to support the growth in electric vehicles in the region [3].

In advance of the EVADINE trial vehicles being delivered to the North East in September 2010, Newcastle university have extensively tested their data logging and analysis system on a fleet of electric vehicles provided to test and evaluation in the region by CENEX (the UKs Centre of Excellence for Low Carbon and Fuel Cell Technologies). These vehicles have been sued to prototype the data logging equipment and analysis techniques and were on trial with various local authorities in the North East Region (Gateshead, Newcastle, Sunderland, Stockton-on-Tees and Durham County Councils) from October 2009 to March 2010 [4]. The vehicles provided by CENEX were Mercedes SmartCars (figure 1) with a Sodium nickel chloride Battery with 15KW storage capacity, a 20KW drive motor, a top speed of 60mph and a maximum range of approximately 80miles.

The Electric Vehicle Monitoring Infrastructure:

The main objective of the electric vehicle monitoring infrastructure is to develop new techniques to monitor and assess the performance of electric vehicles in real world driving conditions to help the industry understand in issues associated with electric vehicles. The key objectives for the trial are: Monitor use and performance of vehicles

- Charging performance and battery life
- Charging occurrences (where, how often, what charge etc.)

- Driver influences
- External influences
- Impact on traffic
- Impact on the environment

To meet these objectives the following data was collected:

- Journey details(time, distance, route, location)
- Driving Style (acceleration, braking)
- Battery performance in terms of depth of discharge
- Road topology
- Congestion state in the road network

Of the data to be collected on the vehicle, the state of charge in the battery of a vehicle is by far the most vital information to be monitored and updated consistently to the vehicle user. The battery depth of discharge is dependent on the various factors such as auxiliary and hotel-loads, topography of the drive (inclines and declines), weather, driving style, level of congestion on the road, traffic management schemes (stops and starts, and smoothing of traffic) and the usage of heating or additional electric equipments in the car.

The performance analysis of the vehicle require that the vehicle management units (which are used for the collection of the on-board vehicle data). The units need to be tailored to individual vehicle manufacturers need to provide data from their CAN bus and from other sources. This paper will start with an overview of vehicle management units and the mechanism of data extraction from the battery systems and OBD in section two. Section three illustrates the general system architecture for the data acquisition system to capture the vehicle information. Section five provides the system evaluation in terms of carbon foot print with speed and distance. Section six will describe the carbon foot print analysis by integrating with the geographic information systems. Finally we conclude with the cost analysis alongside the carbon foot print of the electric vehicle drive experiment

II. VEHICLE MANAGEMENT UNITS (VMU):

With the advent of emerging sensing technologies, the simultaneous acquisition of data from heterogeneous systems such as Geographic Positioning Systems, in-vehicle network and analog signals from sensing devices are technically feasible to integrate with minimal set up and time. Vehicle system network irrespective of automotive or heavy duty can be connected for performance evaluation due to the advances in the Controlled Area Network (CAN) [5] and OBD (on-board diagnostics). Most vehicle data acquisition systems are limited to acquire ninety six OBD-II emission related parameters. This limitation is compensated by simultaneous data acquisition from multiple controllers including diagnostic, trouble and pending codes thereby expected to reveal patterns in the vehicle performance useful for research.

CAN message format as shown in figure 2 (Erturk,2002; Navet, 1998; Lawrenz,1997) contains 0-8 bytes of variable data and 47 bits of protocol control information.

A sensing device monitoring the vehicle control area network (CAN bus) observes the changes in acceleration, brake position and throttle position. The logging device



Fig. 2. CAN Message format

uses a vehicle communication interface which concurrently communicates with three CAN channels such as dual CAN physical interface, fault tolerant CAN physical interface and ISO9141 serial interface. The device has a fully populated J1962 interface in which a number of pins are multiplexed to allow for software configuration of these pins to work in network isolation. The on-board serial flash memory allows buffering of data locally on the device. A battery backed runtime clock is incorporated in the device to timestamp the data alongside triggering alarm events.

The power consumption of the unit is designed to be triggered - based on the arrival of new events. On idle conditions the consumption is dropped to 4mA. The GPRS connection, CAN network activity or timed event through a digital interface will change the state of the device from idle to monitor mode. The quad band GPRS [6] modem transmits the data through cellular network to the data centre in the university.

Features of the data acquisition system are summarized below:

- Three channels are measured namely battery current, battery voltage and depth of discharge.
- The distance, velocity and altitude are calculated based on the GPS monitoring systems.
- The auxiliary power unit (APU) on/off activity
- Braking activity
- Signals from windows, internal heating and lights are recorded.
- 16 MB of on-board memory
- Sampling frequency once every second during the drive and every minute is recorded off drive.

III. SYSTEM ARCHITECTURE:

The data from the vehicle sensing system will be gathered by an event monitoring middleware at a sampling rate of 1Hz.

The primary data acquisition system currently functions as a data logger where the data transfer to the central server occurs at the end of each journey when the ignition is switched off. The event monitoring infrastructure acts as a gateway to receive heterogeneous event from the vehicle sensors and positioning systems. The event monitoring infrastructure is built to scale for events from more than thousand vehicles every second.

The interface engine will be provided with the vehicle and battery monitoring rule base to assess the vehicle performance. The interface engine identifies the patterns in real time to monitor the vehicle and also collates the historic knowledge from the previous experiments.

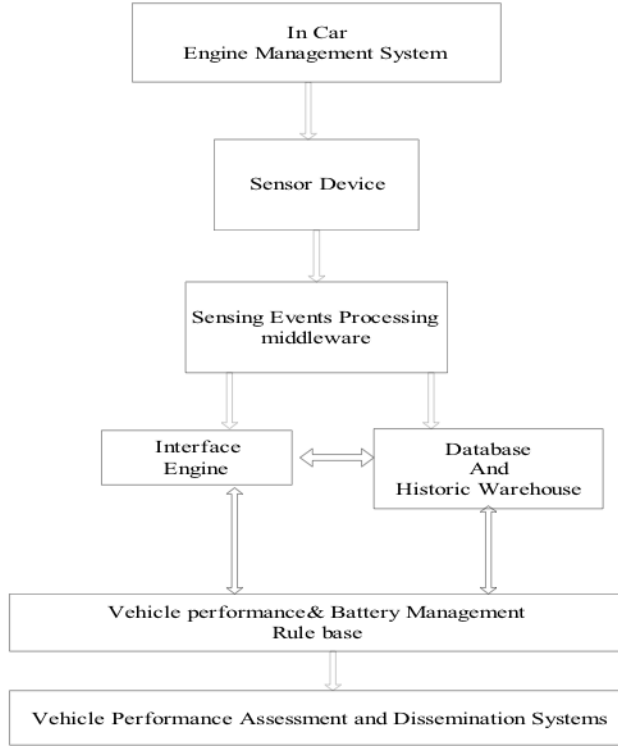


Fig. 3. System Architecture

The information about every individual journey performed by the vehicle will be summarized on the basis of the data analysis, which will be further disseminated using various dissemination platforms such as web site, mobile phone and email alerts.

The system architecture for the performance evaluation of the electric vehicles is shown figure 3).

The processing engine is ambitiously being developed to detect maximum possible occurrences of the mal functioning based on a 3month trials by installing the logging system on the vehicle. There are possibilities for the random errors which are not addressed in this paper.

A. DEDUPLICATION:

Removal of duplicate events in a vehicle tracking system is a key issue to address. This is explained using a scenario where the vehicle is waiting in a traffic signal. The system has two main functions namely disseminate the latest information about the vehicle location in a map and assess the carbon foot print. The dissemination system needs only one occurrence of the event to be shown as the output. The latter need to aggregate all the waiting events to calculate the carbon foot print resulting by the energy consumption due to idling of the vehicle. The following rule illustrates the scenario. The individual event e from vehicle sensors S_x , location information L_t , battery depth of discharge D_t measured in regular sampling interval T is represented in

the rule below.

OBSERVATION (S_x, e, T, L_x, D_x),
 OBSERVATION (S_y, e, T, L_y, D_y), $L_x == L_y$ within (S_x, S_y, T)
 \Rightarrow DROP: OBSERVATION(S_y, e, L_y, D_t)
 \Rightarrow Aggregate(D_x, D_y)

B. ANOMALY DETECTION:

The in-vehicle systems are highly prone to the spurious data. These spurious signals might result in various levels such as voltage, current, depth of discharge or random signals injection in the main stream observations. The individual event e from vehicle sensors S_x observing current and voltage are represented as I and V respectively in regular sampling interval T .

OBSERVATION (S_x, e, T, I_x, V_x, D_x),
 OBSERVATION (S_x, e, T, I_x, V_x, D_x),
 within (S_x, S_y, T)

Three use cases for the anomaly detection is described below as implemented in the process engine:

1) Spurious Current Detection:
 \Rightarrow DROP: OBSERVATION(S_x, e, T, I_x, V_x, D_x) $I_x > 125$

2) Spurious Voltage Detection:
 \Rightarrow DROP: OBSERVATION(S_x, e, T, I_x, V_x, D_x) $V_x < 150$

3) Spurious Depth of Discharge:
 \Rightarrow AGGREGARE: OBSERVATION(S_x, e, T, I_x, V_x, D_x) AVG(D_x) within (T_i and T_i-30)
 \Rightarrow DROP: OBSERVATION(S_x, e, T, I_x, V_x, D_x) $D_x \neq$ within 30% drift from AVG(D_x)

C. TEMPORAL SYNCHRONISATION:

The timestamp is obtained from the vehicle management unit is set as a system configuration parameter. The time synchronisation between the events from heterogeneous event is done based on the relative measurements to the system time.

D. TEMPORAL ANOMOLY:

A major hindrance in the tracking system is the satellite fix that is obtained from the geographic positioning systems (GPS). The positioning system, vehicle diagnostics systems and the CAN are synchronised with relative time stamps. In instances where the time stamp from the GPS are used as a reference, there were many instances where irrelevant year and time period can be logged.

OBSERVATION (S_x, T, e)
 \Rightarrow DROP: OBSERVATION(S_x, T, e) $T \neq$ within 5% drift from Previous (T) within 10 minutes interval.

E. LOCATION TRANSFORMATION:

The logging systems are designed to register observations in a high frequency of one second or lesser than a second to record the braking and acceleration changes. The location information from the GPS tends to drift from the real positions in the road leading to the map-matching scenarios [8].

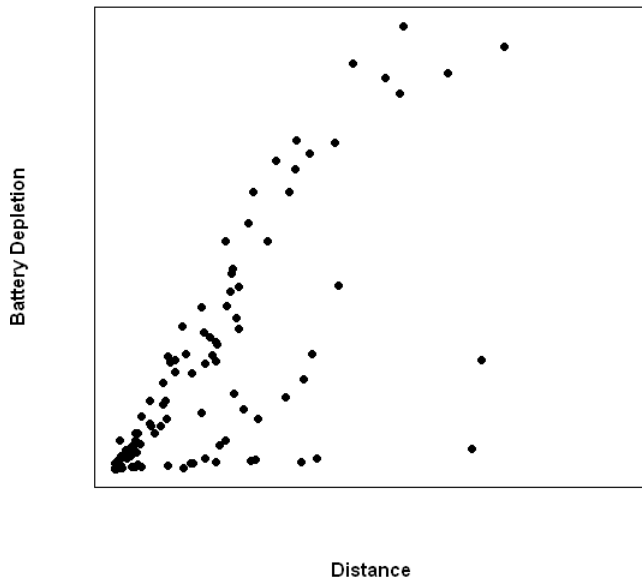


Fig. 4. Graph showing variation of current use against the journey distance.

The location transformation is being designed to use road network data from EDINA [9] to compare the vehicle location with respect to the last updated vehicle position.

When the sensing event sits on a same physical location for an extended period of time, each of this location information generates very little new information. As much as possible the entire series of the reading are compressed within the time range indicated by start time and the end time. The practical challenge presented in this compression method is to set reasonable timeout duration to check for the movement change. If set to at a very low threshold, then many fast movements will be judged in a short duration leading to wrong decision making. In high timeout threshold, it is likely to respond late.

IV. EVALUATION OF BATTERY PERFORMANCE:

The data collected from the Cenex Smart-Move [1] trial is segregated in to multiple individual journeys. The initial brief study is undertaken to examine the effects of each individual journey and derive statistics for each journey.

The figure 4), illustrates the behavior of the battery depletion with respect to the distance travelled. The interesting observation in this graph is the flattening of the battery towards the longer range journeys. It is likely this is due to the greater efficiency of longer journeys compared to the stop/start nature of small journeys likely to be occurring in the city centre.

Although numerous journeys in the datasets examined so far (138) the associated conditions affecting the battery depletion is large. To derive meaningful statistics, it is necessary to aggregate the data sets in to 30 second duration. The figure 5 shows the same behavior as in figure 5). As the distance travelled increases, the level of battery depletion over the time also increases. The flattening off at long distances travelled does not seem as apparent here. However

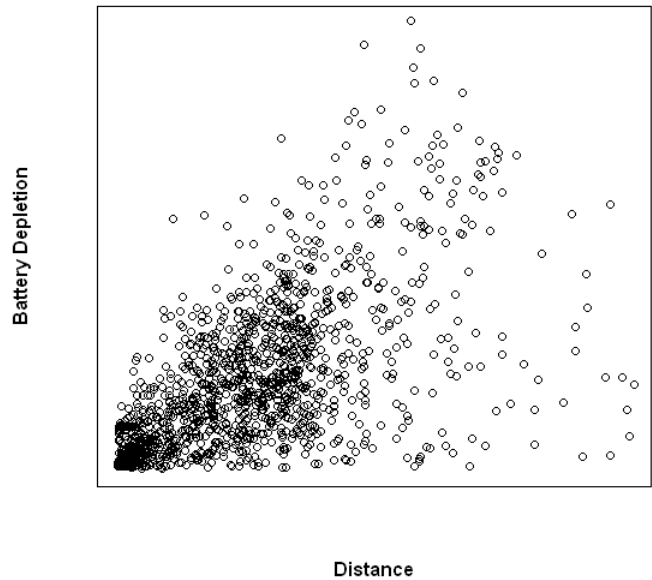


Fig. 5. Graph showing variation of current use against journey distance at the 30 second epoch

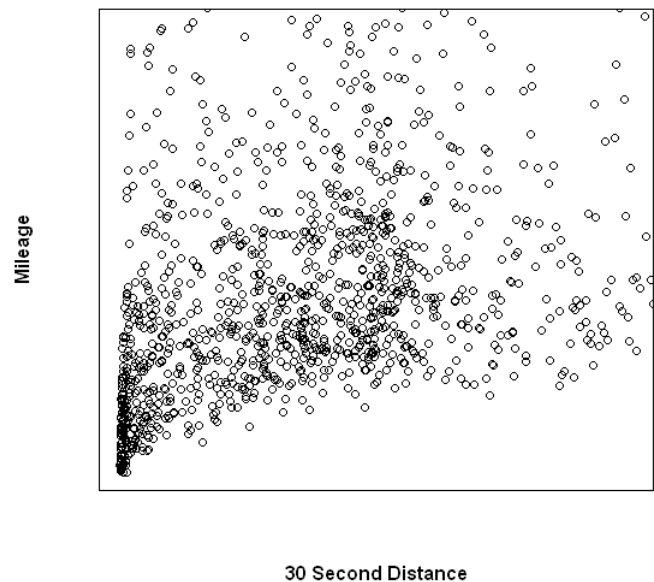


Fig. 6. Mileage against journey distance

there are numerous points where the distance travelled is long and battery depletion is short. This is possible due to battery regeneration on downhill segments of the journey.

A more direct comparison of the journey efficiency can be observed in figure 6). As distance travelled in 30 seconds increases along with the Mileage. However there is a point in which there is no further gain in mileage. This is a point we identify as the ideal speed to drive the car. Its possible this type of analysis could be broken down further to create mileage/distance graphs for different environment, such as urban, rural or motorway.

The figure 7) shows the change in efficiency with a change in braking habit. There is a strong correlation between

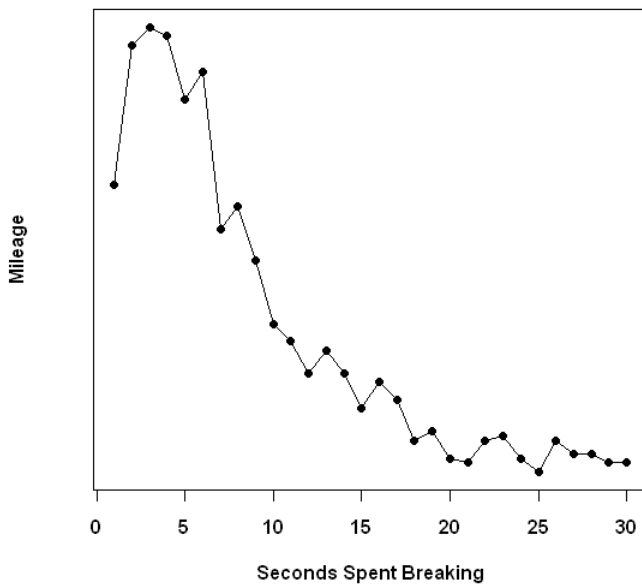


Fig. 7. Comparison of Mileage against seconds spent breaking in a 30 second period.

mileage and the time spent on breaking. This could either indicate a lot of unnecessary breaking, leading to increased inefficiency, or perhaps heavy traffic loads which necessitate breaking. The conclusion seems fairly unavoidable that braking is one of the main factors in the depletion of the battery.

V. CARBON FOOT PRINT ANALYSIS:

The tail pipe emissions and noise is completely eliminated by the electric cars. The electricity generation moves the emissions further upstream to the utility companies.

A car comparison website lists the CO2 emissions for all the UKs major new cars. The average CO2 emissions rating is 173 g/km (grams of carbon dioxide driven), the lowest being 89g/km and the highest 500g/km [10] [11].

The data analysis for the electric vehicles uses approximately 100 trial journeys taken place during January and February 2010. In the smart move trial, CO2 emissions were calculated based on the DEFRA 2009 emission factors [12] namely 544.2 g CO2/kWh. The energy usage is calculated for each journey based on the battery depth of discharge.

From the experiments, the average range achievable from the electric vehicles was calculated to be 72.4 km emitting 81.4g CO2/km when recharged with UK average grid mix electricity. The figure 8), shows the graph between carbon emissions, speed and average speed of the vehicles. The average speed is calculated by further processing the data using location compression techniques mentioned in section 3.5. The data with no movements are identified and speed is estimated for the journey.

The table I shows a sample of data that is used in the graph as in figure 8). The CO2 emissions are higher in few journeys of low speed. This is assumed to be due to the congestion or due to the driving behaviour. The regenerative

TABLE I
CARBON EMISSIONS CALCULATED BASED ON THE DISTANCE

DISTANCE in Km	SPEED Km/hr	ROLLING AVGSPEED Km/hr	CO2 Emissions g/KWh
10.49377	25.79	27.86	74.6
14.65394	33.77	35.17	66.14
7.45799	45.28	47.19	82.96
10.73382	42.46	46.06	71.89

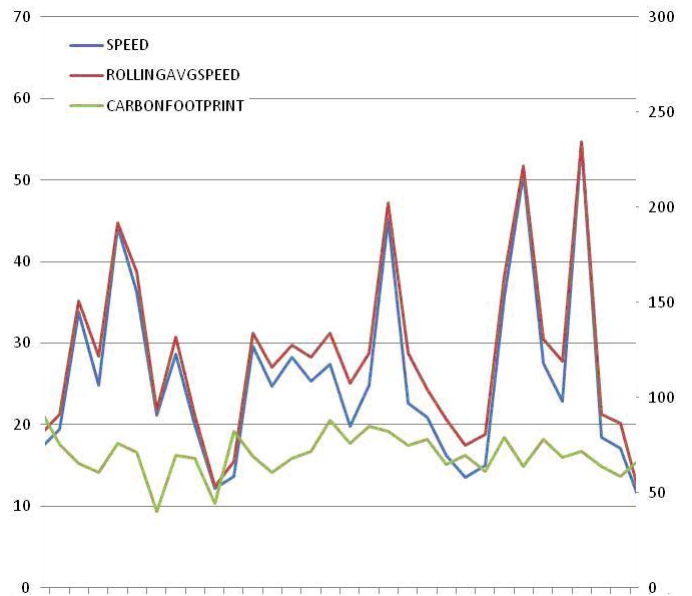


Fig. 8. Carbon foot print vs rolling average speed vs Speed

energy is dependent on the eco friendly driving. This could add to the emissions generated during the trip. The CO2 emissions of the vehicles significantly varied depending on the operating conditions of the vehicle such as weather, driving environments such as urban, rural or city environments. Another factor influencing the CO2 emissions were the hotel loads such as heating, lights and electronic systems in the car.

A. CARBON EMISSIONS IN REFERENCE TO TOPOGRAPHY:

The visualization of the data from the electric vehicle drives with reference to the geographic locations overlaid on a map. The map based overlay give more precise information on the topography of the road network. The altitude measurements are obtained from the geographic positioning systems in real time. The altitude is compared with the battery depth of discharge. Each observation from the sensor is colour coded and overlaid on the maps representing the energy regeneration and consumption thereby relating to the carbon emission. Following rules define the colour coding used in figure 9). The individual event e from vehicle sensors S_x , altitude information A_t , battery depth of discharge D_t measured in regular sampling interval T is represented in the rule below.

Power regeneration is shown by marker colors:



Fig. 9. Energy regeneration and consumption with altitude

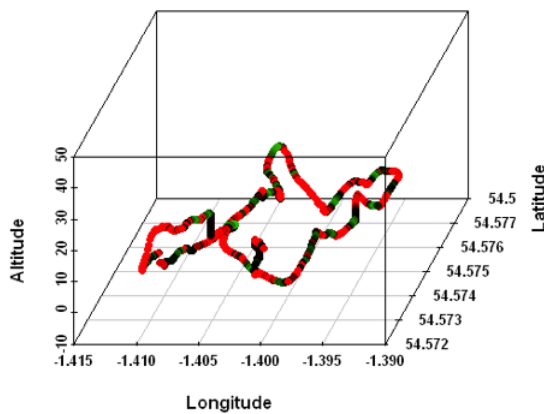


Fig. 10. Energy regeneration and consumption with altitude

- ⇒ Green : OBSERVATION($S_{y,e}, A_x, I_x$) $I_x < 0$.
- ⇒ Green Intensity: $F_n(I_x)$
- ⇒ Bright Green: OBSERVATION($S_{y,e}, A_x, I_x$) $I_x = -35$
- Power consumption shown in marker colours:
- ⇒ Bright Red: OBSERVATION($S_{y,e}, A_x, I_x$) $I_x = 120$
- ⇒ Red Green Intensity: $F_n(I_x)$
- ⇒ Black: OBSERVATION($S_{y,e}, A_x, I_x$) $I_x = 0$

VI. CONCLUSION:

The research described in this paper is intended as an early snapshot of the demonstration and evaluation capabilities being built in the North East of England to test and analyse the performance of electric vehicles and other low carbon vehicles. The data collection and analysis techniques developed by Newcastle University and initially prototyped on a fleet of Mercedes Electric Smart Cars provided by CENEX have enabled the research team to explore the richness of data available from electric vehicles. Of particular importance is the data that can be derived from the battery management system and the power drain of the different components of the vehicle as well as the regeneration of power due to the braking action of the vehicle. This will help automotive companies, traffic managers, and decision makers and ul-

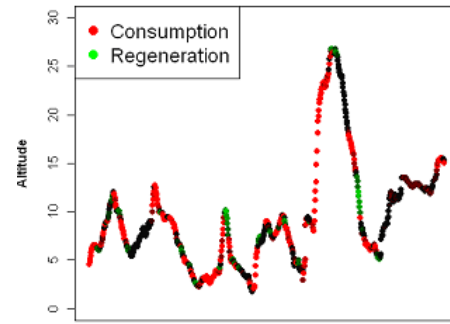


Fig. 11. Energy regeneration and consumption with altitude

timately the general public understands performance issues associated with electric vehicles, more clearly and in depth.

This work is aimed to create an intelligent framework to automatically observe the performance of the electric cars and provide useful information to the vehicle driver to reduce carbon emission and to gain better vehicle performance. The technical infrastructure for data acquisition, processing and dissemination is briefly described. The evaluation of the system is done based on the early results from battery performance using Smart-Move trials in United Kingdom. The battery performance and depth of battery discharge is used to calculate the carbon emissions for the electric vehicle drive. When electric vehicles are charged with low carbon sources of electricity, the vehicles can achieve emissions of 45.0 g/CO₂/Km [4] and 0 g/CO₂/Km from renewable energy. The early results obtained from the Smart Move trials as narrated in this paper based on Newcastle Universitys data logging and technical infrastructure to monitor electric vehicles. The infrastructure has now been proven through the CENEX trials and is intended to be used for more extensive trials such as Switch-EV funded by Transport Strategy board from September 2010, which will provide at least 35 electric vehicles from four different manufacturers (Nissan, Avid, Liberty and Smiths Electric Vehicles).

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