DATA COLLECTION AND ANALYSIS IN A PAN-EUROPEAN ELECTRIC VEHICLE FLEET

Paul McDonald*
Department of Civil, Structural and Environmental Engineering
Trinity College Dublin
Dublin 2
Ireland
Tel: +353 1 8962084
Email: pmcdonal@tcd.ie

John Brady
Department of Civil, Structural and Environmental Engineering
Trinity College Dublin
Email: jbrady7@tcd.ie

Margaret O’Mahony
Department of Civil, Structural and Environmental Engineering
Trinity College Dublin
Email: margaret.omahony@tcd.ie

Manel Sanmarti
Institut de Recerca en Energia de Catalunya (IREC)
Jardins de les Dones de Negre 1, 2ª pl.
08930 Sant Adrià de Besòs
Barcelona, (Spain)
Tel: + 34 933 562 615
Email: msanmarti@irec.cat

Mark Daly
ESB eCars
27 Lower Fitzwilliam St,
Dublin 2,
Ireland
Tel: 1890 372 387
Email: mark.daly@esb.ie

Senan McGrath
ESB eCars
Email: senan.mcgrath@esb.ie

Norbert Vierheilig
Siemens AG
Infrastructure & Cities Sector
Mobility and Logistics Division
Communications
Gründlacher Str. 260
90765 Fürth,
Germany
Tel.: +49 911 654-2654
Email: norbert.vierheilig@siemens.com

*Corresponding Author
Submitted: 1st August 2012
Word Count: 4806 + (250 *10) = 7,306
ABSTRACT
Electric vehicles are expected to replace a significant portion of existing light vehicle fleets around the developed world over the coming decades. The technology offers several benefits both on environmental and user levels when compared to traditional combustion engines. As the cost of fossil fuels continue to rise and the price of electromobility drops, this method of transport will become more prevalent. Analysis of early stage electric vehicle usage will allow stakeholders to plan the policy and infrastructure needed to facilitate and manage large scale roll out of the technology. A large collection of electric vehicle fleets and infrastructure networks operating in several European regions are monitored for analysis. The authors present preliminary results showing charging infrastructure utilisation for a range of vehicle and charge point use cases. This initial analysis shows that the usage levels for public infrastructure are low, while home charging is responsible for the highest levels of charge consumption. Business use cases, both for charge points and vehicles are characterised by high levels of peak time activity. Private use vehicles and household charge points show a concentration of energy usage in the latter part of the day, with a considerable peak in the early evening. All use cases display several hours of inactivity during the night time, both for charge events and travel patterns, confirming the potential for managed charging to take advantage of periods of low demand for electric vehicle charging. The data highlights the need for pricing incentives to regulate charging behaviour.

INTRODUCTION
Electric vehicles (EVs) present an opportunity to develop integrated and intelligent transport and energy networks. The employment of smart management technology to plan and control activity in both these sectors could see significant improvements in efficiency and emissions (1). Motivated by a need to reduce carbon emissions and backed by commitments to embrace renewable energy, European authorities are committed to adopting new and efficient forms of transport. The first step in the adoption process is the in depth research of the requirements and potential benefits of new technologies. This includes developing an understanding of the technological needs, such as infrastructure and ICT architecture, combined with knowledge of vehicle performance and the attitudes of consumers to changes in mobility patterns. In addition to the gaining an understanding of the performance of new vehicles and associated support infrastructure, it is also necessary to understand the effect that electric vehicles will have on energy supply and generation systems. Governments and utilities across Europe are introducing renewable energy both as a means of building more sustainable systems and reducing carbon emissions (2). These clean energy sources can bring with them new problems of demand management and predictability. Electromobility holds great potential for increasing efficiency in the energy production and management process through regulation and control of what is traditionally a major energy usage sector (3, 4). The nature of energy delivery and usage in the transport sector is changing and electric vehicle research can play a large part in managing the transition by providing insights into user behaviour and the resulting influences on wider energy systems.

Green eMotion is a large scale project aimed at researching and delivering a scalable framework for the rollout of electric vehicle technology (5). The project has received €24 million in funding from the European Union, with a further €18 million being contributed by industry partners. The goal of the project is to define standards and systems for interoperability enabling wide scale adoption of electromobility in a cohesive and repeatable manner. New methods of electric vehicle integration are being assessed over numerous demonstration regions and the policies and strategies at all levels of operation are being evaluated to determine the core elements of a successful approach for deployment of electric transport systems. The initial uptake and success of EV technology in the individual regions will be influenced by the local policies and incentives offered to EV users by authorities and electricity providers. Charging behaviour in particular is of importance when attempting to regulate peak electricity demand and shift charge consumption to the night time when an increased load could make generation more cost effective (6). Variation of the energy tariffs through which EV users purchase electricity is one possible method of encouraging efficient charging habits (7). The primary method of monitoring changes in charge consumption will be through analysis of EV charging events, with data collected through a smart network of charging infrastructure and an
instrumented EV fleet. A comprehensive analysis of this data set will provide insights into the likely effects of mass integration on European energy systems.

**DATA CAPTURE AND ANALYSIS**

One of the central elements of the Green eMotion project is the operation and monitoring of several large scale demonstration trials. These test cases form the initial steps in rolling out electromobility technology in key cities and countries around Europe. The data being collected from the demo regions presents the greatest opportunity to gain an insight into the behaviour and mobility patterns of early stage electric vehicle users. An understanding of the how EVs will influence mobility patterns and energy usage is crucial to providing an effective support framework.

The data collection process gathers information from 10 demo regions spread throughout different countries in Europe. The demo regions involved in the data collection process are:

- Berlin (Germany)
- Stuttgart/Karlsruhe (Germany)
- Bornholm (Denmark)
- Copenhagen-Better Place (Denmark)
- Barcelona and Málaga (Spain)
- Guipúzcoa and Madrid (Spain)
- Strasbourg (France)
- Dublin (Ireland)
- Italy
- Malmö (Sweden)

**Monitored Data**

The data captured by the demo regions can be classified into three different groups; structural, static and dynamic. Structural information is background information that frames the energy scenario in each demo region. This data will help when analysing EV usage patterns and estimating the influence on the grid on a regional basis.

Static data is the list of elements that a demo region is monitoring during each reporting period. Detailed features of each of the monitored elements (EVs, charging points and users) are collected in order to build a comprehensive picture of the available resources. Each vehicle and charge point is given a unique identifier which is reported with each associated event.

Dynamic data is the operational data of the electric vehicles and charge points as monitored by on-board logging equipment, charge post intelligence units and electricity supply chains. These monitoring systems log relevant data for each charge and trip event, building up a detailed database of vehicle and infrastructure usage.

**Vehicle Fleet**

The static data reported by each demo region aims to capture relevant information about the EVs operating within the project. This information includes vehicle technology, type, make and model. During the first year of operation 235 EVs, 598 charge points and 269 individual users were available for monitoring and data collection. At the end of 2011 the Green eMotion fleet comprised 84% cars and 16% commercial transporter vehicles. 70% of the vehicles were pure electric vehicles and the remaining 30% used plug-in hybrid technology. The primary usage of each vehicle is also recorded to allow for comparison of each principal use case. The majority of the vehicles in the fleet were used for commercial purposes, with 65% being used either for business purposes or part of a captive fleet. A further 5% were used for rental purposes. Private use vehicles accounted for 16% of those monitored, with the remainder falling outside of these basic definitions.

**Charging Infrastructure**

The deployment and management of effective charging infrastructure is critical to the success of any electric vehicle initiative. The cost of installing a widespread charging network must be offset by building a system which facilitates the natural expansion of EV fleets. The initial capital cost of the infrastructure can be easily justified if the deployment encourages the uptake of electromobility technology, thereby leading to more efficient and profitable usage models in the longer term. The early stages of charging network roll out address both public perception issues and the practicalities of EV travel (8). As these networks become larger, deployment must be managed in order to ensure that the available resources are installed in proper locations and with sufficient density to provide a cost
effective charging system that fully supports the expansion of electrified transport. The first step in managing this process is to understand the needs and habits of EV users by analysing how the existing infrastructure is utilised. To this end there a number of charge point installations monitored in the Green eMotion demo regions. The most prevalent is on-street charging, accounting for 45% of all 598 monitored installations. Office or workplace chargers account for 35%, while household chargers make up only 17% of the total, with the remainder being in public parking facilities. These figures are consistent with the common approach of leading electric vehicle demand by installing a widespread and visible network of public charge points, while home chargers are provided only to EV users.

PRELIMINARY RESULTS

The following section provides an analysis of the usage patterns observed throughout the demo regions for the various installation types. In addition to the recorded charge point events, numerous vehicles across all regions recorded plug-in and charge events through on-board data collection systems. An assessment of the events, as recorded by the vehicles is also explored.

Charge Point Usage

The timing of EV charge events could have a significant impact on grid demand and efficiency when occurring on a mass scale (9). A large electrified fleet could potentially require considerable increases in grid capacity if charging is not regulated either by smart control or incentivised behaviour. Two key indicators of the potential effects of electrified transport are the timing and magnitude of charge events. These aspects of infrastructure usage are explored below. The distribution of timings across the day and the consumption values are analysed for each major use case. The timings of 9796 individual events were analysed and separated into half-hour time slots. In addition to the timing of each event, the measured power consumption was also analysed. Charging events were further separated into weekday and weekend events in order to reflect the potential differences in commuter and leisure activity. 9095 measured events were used in this analysis.

Workplace Charge Points

The most frequently used charge point installations throughout all demo regions were office based facilities. These units account for 35% of all monitored points and 48% of all recorded charge events. A total of 4720 events were analysed, corresponding to 21,370kWh total consumption. FIGURE 1 displays the charge start time distribution for charge points based in offices of private companies. The primary vertical axis indicates the number of charge events which happened in each time slot, while the secondary vertical axis shows the percentage contribution reached at each interval. It is important to note that the timings recorded for each event do not reflect the presence of any managed charging facilities. While the values recorded ideally indicate the beginning of power delivery to the vehicle, the majority of installations have no technical facility to distinguish between plug-in time and the beginning of the charging process. There is a considerable peak at the early part of the day, with 30% of all events occurring between 7.00am and 9.30am. This is easily explained by the arrival of commuters to the workplace and plugging in at available facilities. Events at these locations are almost entirely confined to working hours, with 98% of events occurring before 7.00pm. FIGURE 2 shows that 78.7% of all office based charge point events consumed less than 5kWh. The average consumption per charge event was 4.4kWh, based on data from 2866 reported values. There was a considerable amount of variation in the readings, with a standard deviation of 4.2kWh, indicating a wide range of measured values. Weekend use of these facilities shows considerably larger consumption, due in part to the charging of heavier commercial vehicles. The average time for a charge event was 339 minutes, again with considerable variation. These events have a significant influence on overall trends, indicating that workplace charging has considerable implications for energy management.
Although office based charging units recorded the highest number of individual events, the household charge points were the most heavily employed. While only 17% of monitored units are located in homes, the associated charging events make up 40% of all recorded values. The total energy consumption was 23,553kWh. The average consumption per charge was 5.9kWh. Again there was considerable variation in the data with a standard deviation for this sample of 5.2kWh. The average charge time was 137 minutes, with a standard deviation of 122 minutes. Even considering this large variation, this indicates that charge times are not usually long enough to account for complete recharging of vehicle batteries. FIGURE 3 shows the charge time distribution for household points in all demo regions. In contrast to the office use case, the peak occurs in the early evening, with 30% of events beginning between 5.30pm and 8.30pm. This suggests that users have a tendency to plug in the EV immediately after arriving home, even at peak time.
In the absence of managed charging this behaviour could have a significant negative impact on grid demand management, increasing peak load if done en-masse. Approximately 20% of home charge events began during off-peak hours. While beginning charge events during evening peaks is undesirable, the potential exists to have a highly efficient managed solution by leveraging smart charging technology, ideally postponing charging until the period of inactivity observed in the early part of the day.

The consumption level breakdown for household charge points is shown in FIGURE 4. These events are characterised by higher consumption levels than other locations, with a larger percentage of charges falling into the 5-9kWh range. This pattern is also reflected in the higher average consumption level noted above.

![CHARGE START TIME DISTRIBUTION](image)

**FIGURE 3** Charge Time Distribution for Household Charge Points

![CHARGE POINT CONSUMPTION](image)

**FIGURE 4** Energy Consumption Levels for Household Charge Points.
The installation and operation of public access charge points is a pivotal factor in the roll out of EV infrastructure. A widely deployed public network addresses concerns such as range anxiety and serves to increase the visibility of the technology and promote electromobility as a commonplace and viable transport alternative. A comprehensive infrastructure installation can thus lead the demand for EVs and help to stimulate the market by reassuring and attracting potential users. The usage statistics from public charge points are of particular interest when planning future deployments. On-street charge points represent 45% of all monitored assets in the project. However, the associated charge events make up only 7% of the total recorded. The usage levels for public access points are the lowest of all charge point types. FIGURE 5 shows the distribution of charge start times for charge points designated as being on-street or in public access car parks. A large peak in activation can be seen in the early morning. 20% of all recorded events took place between 7.30am and 9.00am. The remaining events have a normal distribution around 12.00pm, with an isolated peak at approximately 8pm. The charge points were almost entirely dormant between midnight and 6.00am and 98% of all charge activations took place prior to 9.00pm.

FIGURE 6 displays the consumption break down for the public charge points. Similar to other installation types, the majority of charges consumed less than 10kWh. Approximately 20% of events recorded consumption in the 5-9kWh band. The average time spent charging was approximately 2 hours, less than at other charge point types. The variation in the recorded values was also less, indicating that users spend less time using public infrastructure than at home or work. The total energy consumed by all public charge events was 3139kWh. The average consumption was 4.8kWh, with a standard deviation of 4.4kWh. Two-thirds of all events recorded consumption of less than 5kWh. In the case of charge points located in public access parking facilities (48 instances) 95% of all events consumed less than 5kWh.
Vehicle Charge Events

In addition to monitoring the usage of charging stations, many of the vehicles throughout the demo regions are equipped with data loggers capable of recording information about charging events through interfaces with the on-board systems. We provide a breakdown of plug-in time and consumption by vehicle use case. The two scenarios with appreciable amounts of available information were “business use” and “private use”. The commercial use case included EVs which were designated as being part of a captive company fleet. It should be noted that the data coming from the vehicles cannot be directly matched to the data from the charge points in the previous section i.e. the analysis is not considering the same data set from two individual measurement sources, but two separate data sets representing different events. Again, when reporting the timing of events, many data loggers were not capable of distinguishing plug-in time from the beginning of vehicle recharging.

The total energy consumption during the 3251 events recorded was 22,922kWh. The average charge time was almost 4 hours. However, there was considerable variation in these readings. The mean energy consumption from the grid was 7.38kWh, with a standard deviation of 5.21kWh. As mentioned in the previous sections, the maximum value recorded was seen when charging a commercial vehicle. The greatest distance achieved between charging events was 148km, while the average was only 36km, suggesting users recharge often rather than allowing vehicle batteries to be significantly depleted.

As with the charge point data set, the weekend data shows slightly increased consumption levels compared to weekdays. The exception to this is with private use vehicles, where low consumption charge events prevail over weekend periods. The figures below explore this trend further.

Charge Events for Fleet Usage

Electric vehicles represent an opportunity for operators of large fleets to achieve significant savings while operating an environmentally friendly vehicle pool. EVs are ideally suited to the travel patterns seen in many business use cases, comprising short regular journeys or scheduled activity. For these reasons, it is envisaged that a considerable portion of initial sales of EVs will be to the commercial sector, both for passenger and freight vehicles. This section analyses the charging patterns of vehicles designated for business use in the demo regions. These account for an appreciable portion of all monitored events and represent a total consumption of 14,490kWh. FIGURE 7 shows the distribution of plug-in times for business use EVs. As might be expected, there is a heavy concentration of charge events during working hours, beginning at 7.30am. 75% of all charging events happened prior to 5.30pm, with an additional 20% plugging in before 9.30pm.
When considered along with the information displayed in FIGURE 8 it can be seen that these vehicles are consuming relatively large amounts of energy during peak hours. Over 20% of the measured charge events recorded consumption of between 10-14kWh, with a further 10.5% exceeding these levels. The average consumption was 7.25kWh with an average charge time of just under 4 hours.

When considered along with the information displayed in FIGURE 8 it can be seen that these vehicles are consuming relatively large amounts of energy during peak hours. Over 20% of the measured charge events recorded consumption of between 10-14kWh, with a further 10.5% exceeding these levels. The average consumption was 7.25kWh with an average charge time of just under 4 hours.

CHARGE EVENTS FOR PRIVATE VEHICLE USAGE

Potentially the most important use case for EVs is the private, domestic scenario. This manner of usage represents the mass scale consumer market. The ultimate goal of the Green eMotion project is to define and begin implementing the framework for mass scale roll out of EV technology, particularly for the consumer use case. Accordingly, information from private usage vehicles could provide insights into the likely behaviour and use patterns in any future large scale market. There were 453 recorded events with a total consumption of 3771kWh. The average plug-in time recorded was approximately 3 hours with an average of 38.8 hours between charge events. The mean consumption from the grid was 8.3kWh, higher than the business use case and consistent with the same patterns observed between office and household chargers.

FIGURE 7 Plug In Time Distribution for Business Use Electric Vehicles.

FIGURE 8 Energy Consumption Breakdown for Business Use Electric Vehicles.

Charge Events for Private Vehicle Usage
In contrast to the patterns observed for commercial usage, the plug-in times for private vehicles, shown in FIGURE 9, occur predominately outside of business hours. 70% of measured charge events began between 6.00pm and 6.00am. There is a noticeable peak in the early evening, again suggesting that users tend to connect the vehicles to the power supply immediately at the end of the daily commute. This peak accounts for almost 30% of all charge events, showing a large concentration of vehicles connected to the grid at peak time. 20% of plug-in events began between 10.30pm and 2.30am, indicating that an appreciable number of users were conscious of the benefits of managing charge consumption.

The energy figures associated with these charge events show higher consumption levels than the commercial use case, with an appreciable percentage of events in the excess of 10kWh. It should be noted that the sample for the private use scenario was much smaller than that for the business use case with only 343 private EV charge events recording consumption levels. Despite this some obvious trends can be seen, mainly the more pronounced variation between weekday and weekend charge patterns. Weekday charge events show higher consumption levels, while the largest percentage of weekend charge events are in the lowest 0-4kWh range. This would suggest that weekend charging behaviour is characterised by shorter charge events and lower overall energy usage.
Travel Patterns

Predicting and managing the influence of electric transport on electricity supply networks does not depend solely on the energy consumption levels of the vehicles. While an analysis of trip distance and frequency gives an insight into likely energy usage, from a demand management perspective it is also important to know when that energy will be required from the grid (10). Thus, an analysis of travel timing and vehicle availability is necessary to determine the likely time frames for vehicle recharging (11). When combined with the usage level analysis from the previous section it is possible to estimate the amount of energy required and also the probable timing of energy demands.

An analysis of 8469 individual trips was performed, assessing the time at which travel began in any given day. The level of travel activity for each vehicle was assessed, on the basis that high concentrations of trips being undertaken mean that vehicles are unavailable for charging. Conversely, during periods of low travel activity, vehicles can generally be assumed to be available for charging in some location. There was a notable absence of any travel in the early morning, for all use cases, indicating that night time charging is a realistic and practical option for many EV users.

The majority of trips undertaken were for short distances. 52% of all recorded trips were of less than 5km in length, while 90% were below 30km. This indicates that users make regular short trips spread across the day. The average trip distance was 8.7km, although there was considerable variation observed in the measurements. The total driven distance analysed was 68,609km. Weekend patterns were mostly similar to weekday, with a slightly higher number of short journeys at weekends. This is consistent with the charging patterns observed in the previous section which show charge events of shorter duration and lower consumption over weekends. The EVs were rarely driven close to the limits specified for a single charge, with less than 4% of journeys being over 50km. Deeper analysis of vehicle use cases revealed similar patterns for both business and private usage scenarios, both of which matched with the aggregated case.

DISCUSSION

The usage rates for the various charge point types provide an interesting first insight into infrastructure use patterns. Despite the large percentage of monitored on-street chargers in the project, only a very small portion of recorded events can be attributed to public infrastructure, indicating very low usage rates. Household charge points on the other hand, experienced heavy usage, recording both the proportionally highest number of events and the greatest energy consumption per event. Charge posts located in offices and workplaces were used frequently and represent a considerable portion of all power consumption seen.

Charging events recorded by on-board systems within the EVs showed similar patterns with fleet vehicles charging slightly more often, with lower consumption than private vehicles. While this dataset potentially represented a very different set of charging events, the general patterns observed are consistent with those from the charge post measurement system.

The initial charge point usage patterns observed in this analysis provide an insight into the behaviour of early EV users across a range of scenarios. The trends presented above represent the manner in which infrastructure is used without any incentivised behaviour other than environmental or energy concerns of the individual. The effects can be seen in the analysis of charging times where large numbers of events are observed during peak energy times. While this may be unavoidable in some business use cases and indeed where charge facilities are provided in the workplace, the habits are also evident for home chargers and private use vehicles. This would suggest that much of the charging behaviour recorded is determined only by individual needs and not influenced by any larger concerns such as demand management. In the absence of information to distinguish plug-in time from charge delivery the main observation which can be made from this information is that there is very real potential to optimize EV charging and electricity generation through smart management of energy delivery to EVs. In particular the private use case lends itself to this ideal scenario where energy providers can control and manage charge delivery in response to real time grid conditions.

There was appreciable variation in the datasets returned from each of the demo regions. As each region continues to develop more advanced technical systems for data collection and measurement the quality and quantity of information available to Green eMotion will increase. This will allow deeper analysis of use cases, regional trends and also lend greater levels of confidence to the statistical analyses and subsequent conclusions. An in depth analysis per region will provide an
indication of the relative effects of local policies and incentives have on charging behaviour and energy usage. This further analysis can be combined with the use case analysis presented here to determine detailed energy use and travel pattern information about local EV fleets.

CONCLUSION

Electric vehicles can provide a means of establishing cleaner transport networks and potentially more efficient energy generation systems. Achieving these goals requires in depth knowledge of the effects of EV integration on both systems in order to predict and control energy demand when operating on a massive scale. Considerations such as local energy mix, policies and incentives will influence both the primary use of the EV and charging equipment. This information will be valuable when predicting and planning for future energy demands. Further differences in usage patterns may be identified through regional analysis of EV fleet data, taking into consideration local policy and energy tariff information. This analysis will provide deeper insights into the likely effects of a large EV fleet and also possible methods for regulating EV energy demands through policy and infrastructure planning.

REFERENCES


5. Green eMotion: www.greenemotion-project.eu.


