Submission to
Commission for Energy Regulation

on

Electric Vehicles

The future of the Charge Point Infrastructure in Ireland

in response to

CER Open Consultation call CER/16/286
of 14th October 2016

by

Dr. Thomas Conway

Lecturer, ECE Dept.
University of Limerick,
Limerick
V94 T9PX,
Ireland.

Tel +353 61 202628
Email thomas.conway@ul.ie

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Contents

Chapter 1

Executive Summary

1.1 Introduction

This chapter provides an executive summary of the submission stating the authors conclusions and recommendations based on his own research, work and experience in the area of electric vehicles (EVs). These are summarized in three sections:

- The authors suggestion of what the purpose of the public charge point infrastructure in Ireland should be.
- Response to CER request for other party views.
- Suggestions and recommendations on the future direction of the future public charge point infrastructure in Ireland to achieve the suggested purpose. This covers the areas of *funding*, *ownership* and *future development*. The detailed justification and rationale behind these suggestions and recommendations are described in chapter 2 of this submission.

1.2 Purpose of the public charge point infrastructure in Ireland

It is the authors opinion that the purpose of the public charge point infrastructure should be:

`to enable transport electrification by allowing the average motorist to undertake their long range journeys using a battery EV by recharging their vehicles battery at regular intervals along the route.`

1.3 Response to CER request for other party views.

1.3.1 1. Funding of the EV trial:

`a) The CER requests respondents views on the ESB eCars proposal regarding funding in relation to the additional expenditure on the trial.`

The authors opinion is that the additional expenditure requested is largely justified on the basis that the trial has been very extensive and visible. It has done much to bring the attention of electric vehicles to the Irish public and helped enable in the commercial availability of electric vehicle in Ireland.

However, it should be conditional on the making available of a database of all the data gathered to the general public (including the academic community) to allow research and analysis.

1.3.2 2. CER objectives in relation to EV policy:

`a) Do you agree with the CERs objectives for EV policy?`
`b) Are there other objectives the CER should consider?`
`c) Do you consider conditions should be attached to the ownership of the assets? if so, what kind of conditions should be added?`

The authors opinion is that the broad objectives (page ii, ESBN Electric Vehicle Pilot & Associated Assets Consultation Paper; Ref: CER/16/286) are appropriate, but that a clear overall mission objective is lacking. If the overall mission objective was something like *"to enable transport electrification in Ireland"*, then the more specific objectives could follow from that and adjust over time to address changes in technology, financial constraints, geopolitical changes,world events, etc.

The objectives also appear to lack reference to quality of service issues and the public good. They appear indirectly to make the assumption that the EV charging service would be a commercially viable entity and its not immediately clear that this is the case.

Indeed the pilot project report (CER16286b ESB eCars Pilot Project Report) on page 119 states "*If however a flat fee is used to access public charging, then it is likely that EV owners will try to maximize the use of public charging in order to justify the cost of the flat fee".* Clearly this makes financial sense to maximize operator income. It is interesting in this context to note that the ESB eCar charging proposal of late 2015 indicated a significant flat fee component. However, it would also incentivize the operator to make home charging less accessible.

Its the authors opinion that home charging and indeed workplace charging need to be maximized to make transport electrification a realistic long term option and that users should only need to access public charging when absolutely necessary i.e. for long trips. This is because the provision of public charging infrastructure is inherently more costly that using home charging.

There needs to be significant conditions attached to the ownership of the charge point assets particularly if they are to become property of a private commercial organization. These should concern, for example:

- Nationwide charging infrastructure coverage.
- Charge point reliability targets.
- Quality of service requirements.
- Pricing control.
- Interoperability, ICT functionality and public application interfaces (APIs).

1.3.3 3. ESB eCars Proposal:

`a) Do you agree with the ESB eCars proposed four options?`
`b) Are there other ownership models the CER should consider?`
`c) What is your recommended option?`
`d) Under your recommended option how would CER ensure that the current value of the assets is adequately reflected?`

It is the authors opinion that only the first ESB eCars option:

`Assets become part of the Regulated Asset Base: With future opex covered from DUoS and arrangements made for users of the system to purchase electricity from a supplier(s). In addition, the CER may opt to support additional Capex to support future expansion (ESB would not earn any regulated return on the portion of any assets whose creation has already been funded by the CER through the R&D Opex allowance)`

is at all a viable option for the foreseeable future.

The other options appear to imply the commercially viability of a public charging infrastructure and that market forces would regulate it (i.e. Unregulated User Prices). With the current uptake rate of electric vehicles in Ireland, this does not appear realistic and indeed may never be the case.

An alternative view of the public charging infrastructure would be that of a public service and that the assets be held in public ownership. The author would suggest that the option of the public charging infrastructure assets be considered part of the transport system in a similar manner to roads, bridges, etc.

This may be beyond the remit of the CER, but is perhaps something they could discuss with other government departments.

1.4 Recommendations for the future public charge point infrastructure in Ireland

1. **Funding**

    (a) Charge point usage should be costed to the user on a time occupied basis proportional to the available power level. For example, the author would suggest:

    - Type 2 Charge point (AC): Bill user at $2\times$ standard unit rate i.e. with a nominal residential unit rate of 18 cent per kWHr, a 22KW AC charge point should be billed at factor of $2 \times$ 22KW $\times$ 18 cent per kWHr = 7.92 Euro per hour or 13.2 cent per minute for the time the user is parked at the charger.
    - Type 3 Charge point (DC Fast Charge): Bill user at $4\times$ standard unit rate i.e. with a nominal residential unit rate of 18 cent per kWHr, a 45KW DC charge point should be billed at factor of $4 \times$ 45KW $\times$ 18 cent per kWHr = 32.4 Euro per hour or 54 cent per minute for the time the user is parked at the charger.

    with a 2 minute identification/connection setup period and 2 minute disconnection period allowed. See section 2.3.2 for a detailed discussion.

    (b) The electricity generating utilities should contribute to the costs of building and maintaining the public charge point infrastructure as the widespread adoption of electric vehicles will provide increased electrical energy usage and benefit their business. This could perhaps be achieved via the Public Service Obligation (PSO) mechanism.

    (c) Small or no registration/fixed charge.

    (d) Some government funding to support the system until a critical mass of electric vehicles adoption is achieved. Perhaps funding from carbon taxes revenue might be an appropriate method.

2. **Ownership**

    (a) Ideally be owned and operated by an electric utility. In this case the ESB eCar organization would be the preferred organization. However, some independent regulation should be required.

3. **Future Development**

    (a) Public charge infrastructure be redeployed and enhanced along routes rather than in destinations points such as car-parks, shopping centers, etc.

(b) Enhance the reliability with backups and redundancy and guaranteed quality of service.

(c) Implement a booking system with a nominal booking cost as this significantly improves the capacity of the system.

Chapter 2

Analysis & Justifications

2.1 Introduction

The use of electric vehicles (EVs) is widely regarded as a desirable alternative to internal combustion engine (ICE) vehicles for many reasons from climate change concerns to urban air quality levels. The battery only electric vehicle (BEV) is the more desirable in this regard as there are no tailpipe emissions in use. Plugin hybrids (PHEV) are useful in their ability to avoid tailpipe emissions for some of their use cases and their overall improved efficiency.

A key limitation of battery electric vehicle has always been, and still is, their limited range from a single battery charge **AND** the significant time taken to recharge.

However, the vast majority of journeys made by the average motorist are within the range of existing electric vehicles. The problem lies with the small percentage (2%) of trips that cannot be completed on a single charge. As battery capacities increase, the percentage of journey lengths achievable increases but the fundamental problem is not eliminated.

In the authors opinion, the key to battery electric vehicle adoption is the addressing of the small number of long range journeys that cannot be achieved on a single charge. This can be achieved in a number of ways and a non exhaustive list might include:

1. Recharging with distributed charge points
2. Range Extenders, petrol, diesel, compressed natural gas, etc
3. Conventional petrol/diesel car rental for rare long journeys.
4. Battery Swap
5. Fuel cell type sources e.g metal air cells
6. Overhead wires, embedded wireless charging in the roads, ...

The capability to recharge with distributed charge points is a desirable option for the average motorist, as this reduces their vehicle capital costs and provides the ability to make the rare longer journeys. It also allows for complete electrification of the transport system with the ultimate aim of eliminating the use of fossil fuels, and eliminating tail pipe pollution.

The use of range extender could be viewed as a transient solution. The Plugin Hybrid Electric Vehicle (PHEV) could be viewed in this manner, and a variety of such vehicles are commercially available. They have the advantage of eliminating the range problem while using the existing petroleum infrastructure. However, they do still produce some tail pipe pollution. They also have the disadvantage of requiring the full ICE equipment and full EV/Battery equipment resulting in an expensive and complex vehicle.

The other methods listed are more speculative and do not yet show a clear trajectory for an affordable adoption on a large scale.

2.1.1 Authors Background

The author has had an interest in electric vehicles for a number of years and has constructed an experimental electric trike as well as and experimental conversion on a existing car. He currently owns a first generation Nissan Leaf battery electric vehicle as his only domestic vehicle and is registered with the pilot ESB eCar charge point network and has used the pilot charge points on a number of occasions.

In his academic role as a lecturer in the ECE Dept of the University of Limerick, he lectures and researches in the areas of power electronics and electric vehicle transportation. He has recently conducted research on the public charge point system in Ireland and has developed a computer model for analysis of the overall system performance. The appendix contains a preprint of the manuscript he has submitted for publication by the IEEE, which is currently under peer review. He is also competed work on DC fast charger power electronics and has built and tested a 8 KW fast charger with a CHAdeMO interface.

2.2 Purpose of the Public Charge Point Infrastructure

Before considering, aspects such as ownership, funding and so forth, it is important to identify clearly what the purpose of a public charge point infrastructure should be. In the authors opinion, the essential purpose of this infrastructure should be to *overcome the range limitation of battery powered light electric vehicles.* This requires that it possesses the following attributes. It should be:

- Extensive

- Reliable, Robust and Efficient
- Secure and Safe
- Public

2.2.1 Extensiveness.

The charge point infrastructure should enable unhindered travel throughout the whole country. Research by the author on the deployed charge point network of early 2016, indicates that the charge point locations have been well chosen to provide countrywide coverage under reasonable assumptions on the available ranges of commercially available electric vehicles. This is quite an achievement for a pilot program and should be highly acknowledged. The availability of larger capacity batteries will further help in this regard. However, many large (rural) areas are supported by a single charge point and failure of these can significantly limit the network.

2.2.2 Reliability, Robustness and Efficiency.

The author has personnel experience of using a BEV as his only car over two years and has undertaken research into the Irish charge point infrastructure. This experience and research work has convinced him that reliability and robustness are extremely important aspects of a charge point network. The key limitation of BEVs is the limited range and the charge point infrastructures key objective should be to alleviate this.

The charge point network, must be reliable as it is absolutely needed when the BEV user is running low on remaining battery energy and cannot complete their journey without recharging. Interestingly, this appears most acute on the motorway network as there may be a considerable distance to travel, even to exit and turn around. The BEV drivers trick of travelling slowly (say around 50kph) to maximize remaining range is also potentially unsafe in a motorway context.

The authors paper preprint in the appendix considers the effect of non operational charge points on the network performance in terms of leaving users stranded, which is the biggest fear of the BEV driver. His work shows clearly the effect of charge point faults, and this is an area that requires detailed consideration.

Commonly used techniques in other fields requiring high reliability can be employed. These would include built in test functionality, redundancy in the charge points units themselves, multiple independent charge points co-located and real-time communications to alert users of charge point faults. For example, it would be sensible to have at least a reliable type 2 AC charge point co-located with each fast DC charger and even an outside domestic 13A socket as a final backup to prevent stranding users.

Once such reliability and robustness were implemented and operational, considerations of efficiency can be addressed. The authors work in this area shows that the ability for users to book charge points would be an important method for improving the efficiency and capability of the system. He has extended some of his work to produce data for this submission and this data is show in Fig. 2.1.

This data shows an estimate of the capacity of the deployed (early 2016) charge point system in Ireland with and without the capability to book charge points. The effect of increasing battery energy capacity is also shown in this data. This data assumes all the charge points are operational.

The figure shows that without the ability to book or reserve charge points and with typical battery energy capacities of around 24 kWHr, the current charge point system might be expected to support somewhat less than 1,000 vehicles. This increases above 3,000 as the typical battery energy capacities increase to 30 kWHr and upwards which is the current trend[1], and over 10,000 with 40 kWHr capacities.

With booking through an intelligent reservation system, the same charge point infrastructure can achieve over an order of magnitude increase in vehicles supported. This work shows the critical importance of an advanced ICT system in addition to the physical charge points.

2.2.3 Security and Safety.

To achieve the goal of enabling electric vehicle adoption on a large scale, the public charge point infrastructure needs to meet the needs of an average motorist. In this regard, issues such as the security and safety of the general public need to be considered particularly in locating charge points. Presently, some are are located at in-town car-park locations and sometimes in poorly lit areas. It is important that consideration be given to users who may be vulnerable persons such as the aged or solo drivers. These would be strangers at these locations and unfamiliar with the surroundings and may be there at night.

The authors recommendation would be to move such in-town and remote charge points towards peripheral locations with high traffic throughput such as motorways services, and large petrol stations with night attendants.

2.2.4 Public Service.

In the authors opinion, the *public* aspect is important. In this regard, the primary objective should be to provide a service to the public. The service is to enable long distance travel with electric vehicles.

[1]The author cautions the reader against making projections based on future battery capacities claims. Its quite a considerable task to build reliable production grade battery cells and the claims of many research papers and companies announcements have proved excessive in the past.

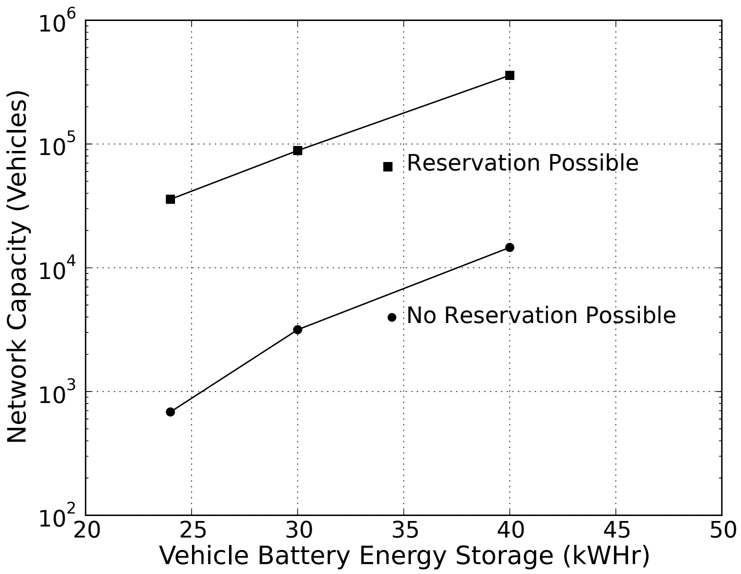

Figure 2.1: Estimated Network Capacity as a function of EV Battery Storage improvement.

Its also useful to consider what the public charge point infrastructure should NOT be aiming to achieve.

Being a public service, it should be essentially available to members of the public on an equal accessibility basis. For example, there is an issue on how people living with communal parking facilities can charge their electric vehicles from home. A typically example would be a private apartment block with gated communal parking spaces. While public charge points could be viewed as a solution, this would be in effect dedicating public infrastructure for largely the private use of one or few individuals. It would be difficult to justify public spending on this particularly on a large scale. Its the authors opinion that the issue of electric vehicle charging in communal style private parking is one that needs a specific solution. This may need legislation to allow or force management companies of these buildings to facilitate private electric vehicle supply equipment. Future planing regulations might also be considered in this regard.

Many existing charge points have been located in town center car parks, along town center street parking and in retail center or supermarket parking lots. This would have made sense in the early phase of electric vehicle adoption particularly as a visual display to introduce the general public to the concept. Its the authors opinion that going forward, this is less effective use of such equipment. Its unlikely that the average motorist will risk driving such a long distance to these locations that they absolutely have to recharge there or be stranded. More often, these charge points are used for opportunity charging and somethings used as parking spaces.

If electric vehicle adoption increases and as higher battery capacities become available, it would make sense to redeploy the in-town charge points to locations along major routes.

2.3 Detailed Justifications for Recommendations

2.3.1 Funding

The question of who funds the development, expansion and maintenance of the public charge point infrastructure is an important aspect to address as it will not function and expand without a viable funding model. Initially, "seeding" or "priming" by governmental sources may be required but the natural expectation would be that the infrastructure is funded in the long term by those would benefit from it.

While the present current public charge point infrastructure in Ireland has been developed through a combination of European Union, Irish governmental and commercial semi-state ESB, its now a point where a sustainable funding model should be put in place.

The beneficiaries of the public charge point infrastructure include the following:

- EV Owners
- Electric Utilities
- Society as a whole

The EV Owners are the obvious beneficiaries as they would directly use the service provided by the infrastructure. A point of usage billing model would be appropriate and a proposed model is described in section 2.3.2. The revenue raised from users should be expected to provide a significant portion of the long term capital and operating costs for the network.

Less obvious, are the Electric Utilities in the country as a whole. The Electric Utility that provides the electrical energy to the public charge points should bill at an appropriate rate for that electrical energy. However, the presence of a public charge point infrastructure enables the adoption of electric vehicles in general. Most of these vehicles will be charged most of the time from the owners residential supply and often at night. Thus the widespread adoption of electric vehicles would increase the market for electrical energy, particularly at night which could help the grid peak balancing. The increased demand for electrical energy thus benefits all the electric generating utilities and it would be reasonable that they would make a financial contribution to the development and running costs of the public charge point infrastructure.

The environmental benefit of electric vehicles particularly for air quality in urban areas is a clear benefit for society as a whole. This should justify state support for public charge point infrastructure.

The author has make some preliminary revenue calculations based on the model used in the paper preprint shown in the Appendix. These have been done using the proposed charge point billing model of chapter 1 using the assumption of a retail unit price of 18 cent per kWHr, and that the public charge point infrastructure is only used for trips beyond the EV range (about 2% of trips).

The results are shown in Fig. 2.2. Broadly speaking, the revenue generated from the public charge point infrastructure is an order of magnitude below that of the revenue accruing to the private charging energy supplier (e.g. residential energy supplier for home charging).

For the public charge point infrastructure owner, the revenue must cover the cost of the electrical energy supplied as well as the capital and operating costs of the infrastructure. The author has made a rough estimate of the capital and operating costs of the existing (early 2016) infrastructure as about 1.25 million Euro per annum. While, the margins on electrical energy supply is not readily known to the author, it would appear that numbers of electrical vehicles in the order of 25,000 would at least be required to make a stand alone charge point infrastructure commercially viable.

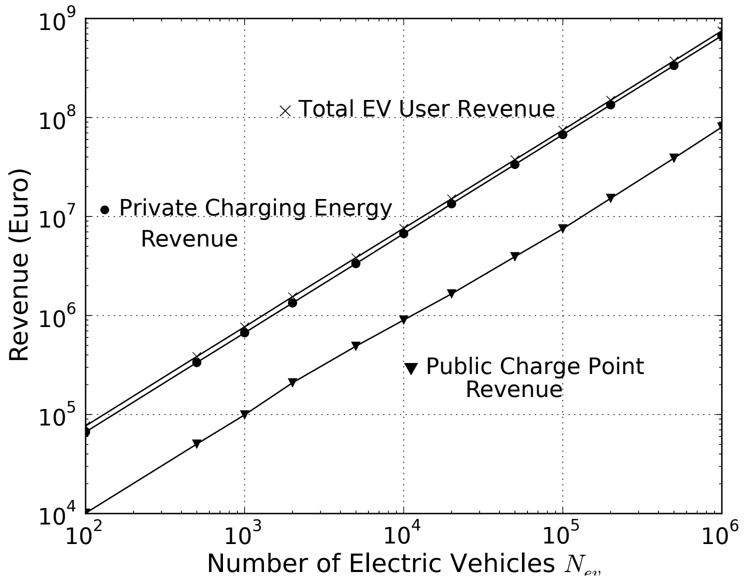

Figure 2.2: Estimated Generated Revenue as function of EV number adoption.

However, the data also shows that a significant amount of revenue accrues to the energy suppliers. For example, if 5% of that revenue funded the charge point infrastructure, then roughly 5,000 electrical vehicles would be required to make the charge point infrastructure commercially viable.

2.3.2 Billing for charge usage

The proposed billing model for charge point usage is based on a number of observations and experiences. With the view that the function of the public charge point infrastructure is to enable long journeys to be possible for the average motorist, the use of charge points should be discouraged for users who do not strictly need them from blocking users who absolutely need them.

The objective of a scaling factor over the residential unit price of electrical energy is to encourage users to charge their electric vehicles at their own home or from private supply points (e.g. work) whenever possible. It also reflects the basic cost of electrical energy and an additional amount to contribute to the capital and operating costs of the charge point infrastructure. The higher costs associated with DC fast charge points should be reflected in the higher scaling factor for these versus AC charging posts.

The rationale for billing per time and the charge point power rating is that the product of these factors represent the potential rated energy that the charge point can deliver and determine the cost of the charge point and electrical connection provisioning. For example, a two point 22KW charge point needs a 3 phase 44kW connection with the associated cable, civil works and distribution point connection all capable of continuous 44KW operation. Charaging a vehicle using a 3.3KW on board charger is under utilizing the 22KW available resource provisioned.

This billing model will incentivize users who frequently use the infrastructure to purchase the higher on board charger power rating and DC charge ports options for their EV model. It would also encourage EV manufacturers to develop such higher power on board chargers for their vehicles. Indeed, one manufacturers already sells a model with a 22KW on board charger that can use the full capability of the common 22KW rated charging posts.

Its also well known that the maximum power acceptable for charging typical EVs drop as the battery becomes increasing charged. Typically, the charge rate significantly drops above the 80% state of charge level and fully charging to 100% can take a significant length of time as the charging power drawn from the charge point drops.

The proposed billing model incentivizes users (particularly for DC fast charge points) to limit their charging to the faster charging region of up to 80% and then vacate the charger to allow for another user. Again, this provides an incentive to maximize the use of the installed infrastructure.

Billing for the time the vehicle is occupying the charge point space is important to ensure that only those absolutely need to recharge would use the infrastructure. Unfortunately, its not uncommon to see existing charge points blocked for hours by an EV whose owner is gone and the vehicle is fully charged.

In the future, variable rate electrical energy unit pricing is likely to be adopted, e.g. higher unit rates at peak demand periods. The suggested billing model could incorporate such dynamic pricing models.

2.3.3 Electricity Generating Utilities

As the authors preliminary revenue calculations show, the electricity generating utilities would be a big beneficiary of mass adoption of electric vehicles due to increased demand for their product. With the public charge point infrastructure being a key enabling technology to allow such mass adoption of electric vehicles, it seems reasonable that they should contribute to its capital and operating cost. This could perhaps be achieved via the Public Service Obligation (PSO) mechanism.

2.3.4 Standing charges

The authors opinion is that the application of standing charges, flat charges, etc, while appealing to utilities, is not appropriate for a public charging infrastructure. This is for a number of reasons:

- Fixed or standing charges creates an incentive for the user to view the service as "already paid for" and use the service even when not absolutely necessary.
- Fixed or standing charges reduces the incentive for the supplier to maintain and rapidly repair faulty charge points.
- All users paying fixed or standing charges mean those who rarely use the infrastructure would be subsidizing the high useage users.
- Persons who rarely drive long distances would be put off by large standing charges and these are the exact people that electric vehicles should be appealing to.
- Complicates internationalization as foreign vehicles, tourists, etc will not have paid such standing charges.

2.3.5 Government funding/subvention

Society as a whole would benefit from the mass adoption of electric vehicles, particularly in the air quality in urban areas. This would suggest that some state funding would be appropriate in subsidizing the public charge point infrastructure.

The level and sourcing of such funding is beyond the scope of this document and the funding of road development and maintenance, road tax, fuel duties, vehicle registration taxes and so forth, is somewhat opaque in the Irish context. However, perhaps a contribution from carbon taxes might be considered, given the environmental credentials of electric vehicle adoption.

2.3.6 Ownership and Operation.

With Ireland being a small country, and given the uptake of electric vehicles so far and expected uptake in the short to medium term, it would make sense for a single integrated public charge point infrastructure with a single owner.

Based on the experience and research work of the author, it is clear that the public charge point infrastructure must be robust in both its electrical energy aspect and ICT aspect.

In the electrical energy aspect, proper provisioning, installation and safety of charge points and DC fast chargers is very important as well as the consistency of supply (i.e minimization of outages). The author believes that it is well recognized that the grid in Ireland has been well managed and is regarded as being very reliable and world class.

The ESBs role in the grid and work to date in deploying the current charge point infrastructure has been very good. The research work of the author (see Appendix) indicates that the deployed infrastructure is extensive and supports the whole Irish Republic.

The actual charge point equipment itself has been somewhat less reliable. While mostly anecdotal evidence from users, it has been observed that in a number of locations charge point equipment has been out of operation for significant periods of time, (weeks or even months). The author has experience of an AC charge point being non operational for more than a month. While full high powered DC chargers are complex pieces of equipment, the author would have expected the AC charge points to have been highly reliable as they don't have high power handling conversion circuits.

Its unclear to the author the reason for such reliability issues. However, his high level modelling of the charge point infrastructure in Ireland indicates that high reliability is a key attribute if widespread EV adoption is to occur.

The communications and IT back-end is also a critical aspect for the key function of the charge point infrastructure, i.e. to enable long distance travel to be achieved with EVs. This is perhaps an area that ESB eCars had less experience in initially and it would be expected that there would have been a learning curve here. The existing ESB eCar team has clearly done much work in this area and recently have begun to add charger occupancy information to their online applications.

The authors opinion and research work indicates that such ICT functionality will be of crucial importance in the proper functioning of a charge point infrastructure particularly if EV numbers increase to large values (10,000s). It is important that this be properly funded and developed as the history of large scale ICT projects in general have often shown poor performance, cost and time overruns. In this regard, the ESB eCar organization will clearly have developed a significant experience in the ICT back-end and it would be sensible to build on this institutional knowledge gained.

Thus, it would make technical sense for the ESB to take full ownership of the current assets and maintain and develop them further. They have the experience in acquiring and commissioning them, locating and provisioning them and would have sufficient critical mass to negotiate and manage maintenance contracts.

However, the financial rationale for the ESB is less obvious. In their CER proposal of the 5th Oct, option 4, they propose ownership and operation on a commercial basis. Its not clear to this author, that operation of the public charge point infrastructure on a commercial basis is likely to be viable in the short to medium term, given the number of electric vehicles in use in the Irish republic.

Furthermore, the funding for capital and operations of the infrastructure needs careful consideration. Based on revenue estimates outlined in section 2.3.1, a combination of EV users charge point billing, electric generators contribution and state subvention would be a better model in terms of achieving the desired outcomes.

2.4 Conclusions

This document provides suggestions on the future direction of the public charge point infrastructure in Ireland based on the authors own experience and research activities.

In moving forward, a clear view by society in general is needed on what the purpose of such a public charge point system is. It does not appear to the author that further development and operation of the public charge point infrastructure purely on a commercial basis is feasible or indeed desirable at the present time.

The author suggests that a more holistic view of the overall expected outcomes be considered and perhaps done in consultation with other government stakeholders such as transport and environmental departments.

Finally, the author hopes the experiences, discussion and data presented in this document are helpful in highlighting some of the issues involved and contributes to policy in this area.

`Thomas A. Conway`

`24 Nov 2016, Limerick, Ireland`

APPENDIX 1

Preprint of submitted paper currently under peer review.

`Also available at: http://arxiv.org/abs/1607.06965`
`Errata Note: The two middle labels on Fig.6 of the manuscript should be reversed.`

On the effects of a centralized computer routing and reservation system on the electric vehicle public charging network.

Thomas Conway *†

July 23, 2016

Abstract

One solution to the limited range of battery electric vehicles is the provision of a public charging infrastructure to enable longer journeys. This paper describes a simulation model of a centralized computer routing and reservation system based on the current charging infrastructure deployed (early 2016) in Ireland using the Irish population density and a trip length distribution. Monte Carlo simulations show quantitatively the effects of EV on-board charger power rating and the advantages of a routing and reservation systems on a country wide scale in terms of the number of electric vehicles that can be supported. The effect of charge point fault rates based on the currently deployed charging infrastructure is also assessed.

*Contact: Dr. Thomas Conway Lecturer, ECE Dept University of Limerick National Technology Park Limerick, Ireland. Tel +353 61 202628, Email thomas.conway@ul.ie

1 Introduction

The advantages of electrified transportation are well known since the 1900's. Battery powered electric passenger cars and light commercial vehicles are presently being manufactured and sold to the general public in many countries. The technology of electric vehicles (EVs) is well developed and mature. Modern battery electric vehicles can meet the needs of the majority of users most of the time. However, the small percentage of trips that exceed the available range, present a stumbling block to their widespread adoption by consumers. This *'range anxiety'* [1][2] needs to be addressed if EV adoption rates are to increase.

One possible solution is the deployment of a charging infrastructure, available to EV users, to allow recharging of the vehicle battery at intermediate points during their trip [3]. Therefore, it is of considerable interest to evaluate the performance of such infrastructure and determine its potential in addressing long trip requirement of EV users. Prior work using stochastic models network models [4] and recently intention aware routing models [5] show improvements in journey times using prior history statistics. Deterministic central planning has been proposed previously with data presented for a grid road network with stations randomly deployed [6].

In this paper, the Republic of Ireland is taken as a case study, as already a comprehensive network of public charge points have been deployed [7]. A simulation model of the presently deployed charging infrastructure is developed in section 2, based on the geographical population density, a trip length probability distribution function and a routing algorithm that allows for reservation of charging points and minimization of travel time. Monte Carlo simulations are run based on a specified number of EVs with metrics calculated to show the performance of the system on a countrywide scale.

The results show the importance of the onboard charger power rating which would be intuitively expected. They also show the key importance of providing a charge point reservation systems in addition to the physical charge points. Such a reservation system together with an optimizing routing algorithm is shown to provide a significant improvement in the number of EVs that can be supported under minimum average trip speed specifications.

While average trip speed is important, the concept of 'range anxiety' is really related to the chance of being stranded, i.e. running out of battery energy and being unable to recharge. In this paper, the effect of charge point faults is also considered. This is the case of arriving at a charge point with a deeply depleted battery energy level only to find the charge point is not functional. If it is not possible to travel to another charge point, then the EV is considered stranded and the user is unable to complete their trip. The probability of this occurrence must be comparable with current levels of trip failure, such as mechanical breakdown, if extensive adoption of EVs is to occur.

In this paper, a system simulation model is described in section 2. The results of Monte Carlo simulations on this model are presented in section 3.

2 System Simulation Model

The simulation model employed assumes that a specified number N_{EV}, of EVs are deployed and that each one will make a trip, all starting at the same time. The start location of the trip is chosen from a geographical population density map of the country as described in section 2.1. The length of the trip is randomly chosen from a trip length probability distribution function as developed in section 2.2. The destination location is then chosen based on the population density map of locations that are the chosen trip length distance from the start location.

Using a typical EV specification detailed in section 2.3, a routing algorithm is run for each trip. If the trip length is less than the available range, then no recharging is required and the trip is assumed to be achievable with the normal vehicle speed. Otherwise, the routing algorithm chooses a route using charge points to ensure the trip can be completed. The arrival time and charging time at each charge point is calculated and a database entry made of this information. Subsequent trips being routed use this reservation database to ensure that any charge point is not allocated to more than one EV at any given time. As more trips are routed and charge points reserved, it may become necessary for EVs to wait at a charge point, thus decreasing the average trip speed for that vehicle. The routing algorithm may chose a longer distance trip through other charge points with less waiting if the overall achievable trip time is less. After processing N_{EV} trips, the trip statistics are calculated.

2.1 Population Distribution

A population distribution model for the Republic of Ireland is developed based on data from the 2011 Irish census [8]. The data is used to create a geographical map of the population density. Fig. 1 shows the population density based on 1 km by 1 km area blocks.

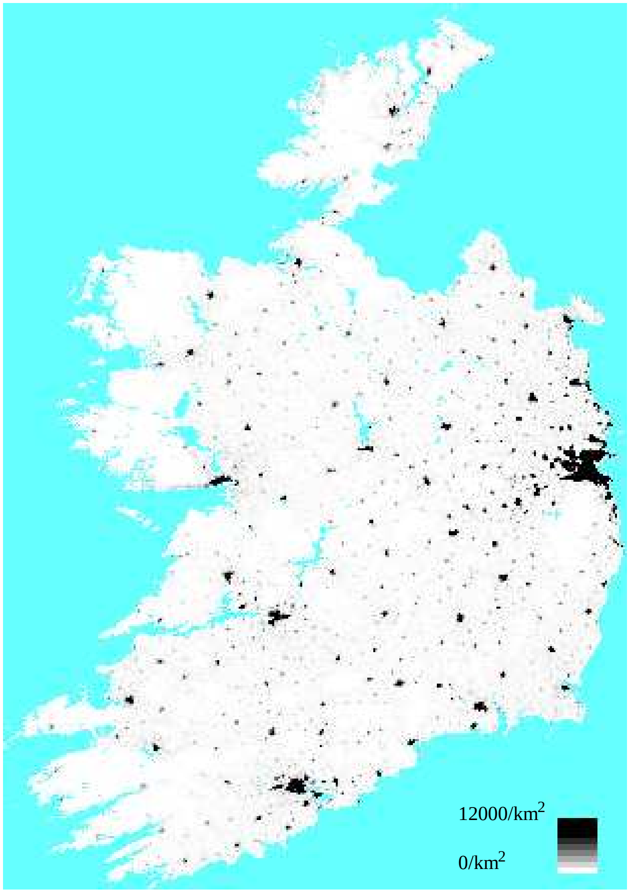

Figure 1: Population density map based on 2011 census data from [8]

The 2011 Irish census further reports "1.36 million households having at least one car". This number is taken as the potential maximum adoption of electric vehicle ownership for the purpose of the developed model. Hence a 20% electric vehicle adoption rate is interpreted as $N_{EV} = 272000$ electric vehicles. The users of these vehicles are assumed, for the purpose of the model, to be distributed in the same manner as population density.

2.2 Journey Distribution

The distribution of journey distances is a key factor in the analysis of electric vehicle usage models. The Irish central statistics office report that "On average, each private car travelled 16,736 kilometers in 2013" [9], but the distribution of journey distances is not available. However, an extensive survey by the US Federal Highway Administration is available based on the 2009 National Household Travel Survey (NHTS). Data extracted from this survey [10], provides the distribution shown in Fig. 2. This data shows an average journey length of 8.9 miles (14.2 km) per trip with less than 1% of trips being over 100 miles (161 km). The empirical probability density function in the journey length (y) in km

$$p(y) = 1.2059ye^{-2.7733y^{0.33}} \tag{1}$$

is developed based on this data and yields an average journey length of 16.7 km with 1% of trips over 161 km. The annual travel distance of 16736 km indicates an average of 2.74 trips per day.

2.3 Electric Vehicle Characteristic

While there are a number of electric vehicles available with different characteristics, the parameters in table 1 are taken as representative of

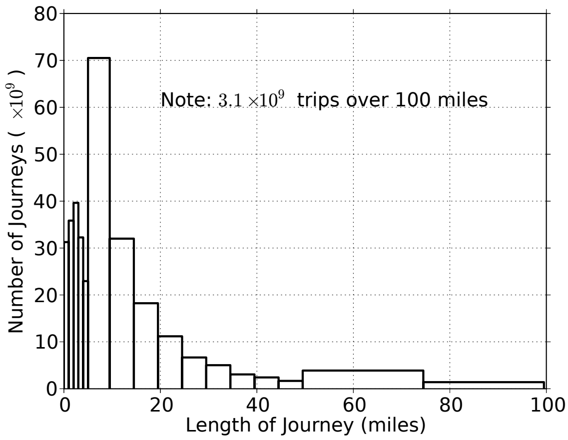

Figure 2: US journey distance distribution from [10].

a typical family sized electric car at the present time. As a baseline scenario, it will be assumed that the user has the ability to charge at their home and their work location to 100% at the 6.6kW rate using level 2 charging.

Parameter	Value
Battery Capacity	24 kWhr
Average Speed	90 kph
Max Range	110 km
DC charge rate (to 80%)	45 kW
AC charge rate (to 100%)	6.6 kW

Table 1: Typical electric vehicle parameters.

With these characteristics, starting from a 100% charge then travelling until 20% of the battery energy remains, a journey distance of $110km \times 0.8 = 88km$ would be viable without charging. Based on the distribution in Eqn. 1, only about 2% of journeys would require charging, en route.

For short trips, where no charging is required an average speed of 90 kph, is assumed. With a maximum charging rate of 45 kW, a 20% to 80% recharge time of 19.2 minutes is required and a distance of 66 km can be travelled between recharges. At 90 kph, the time travelling between charges is 44 minutes. This results in a lower effective speed of 62.7 kph if no waiting at charging facilities is assumed and the maximum charge power that the vehicle can take is available.

With 22 kW charging availability, the lower effective speed is 47.6 kph.

The effective speeds represent the limitation imposed by the charging requirement. Speeds below these values represent limitations imposed by the finite charging infrastructure, a useful metric in assessing the quality of deployed infrastructure.

2.4 Charge Point Allocation Algorithm

The charge point allocation algorithm uses a database of available charge points consisting of their physical location, maximum power capability and their reservation schedule. A request for a journey route is handled upon the arrival time of a reservation request.

The allocation algorithm processes each reservation request by performing a breadth first search of all reachable charge points. The departure time from the charge point (including travel, charging and waiting times) is used as as a metric. To avoid infinite loops, any charge point considered is removed from the subsequent available list of charge point locations for that journey. Any consideration of a charge point that is within range of the final destination results in a viable route for the trip. The search paths are extended until all viable routes are found. The best route in terms of the earliest arrival time is chosen. Note that once any viable route is found, an overall arrival time is known. Paths with a departure time later than the best time so far can be pruned with no loss of optimality. This achieves improved computational times by avoiding extension of paths that can never be the optimum.

If a successful route is achieved, then the charge points on that route are reserved for the relevant times, otherwise a failure to route is declared.

The routing algorithm works on the basis of taking location to location (or point to point) lengths ignoring the limitations of the road network. A scaling factor of 0.85 is applied to all the vehicle ranges to provide for some mitigation of the routing algorithm point to point assumption. For example, with a fully charged battery and allowing the battery energy to reach 20%, the typical EV range from section 2.3 would be 88 km, but this is scaled to 88 km$\times$0.85 or 74.8 km as the maximum achievable point to point range before the first recharge event. With a maximum allowable discharge of 20% and recharging to 80% at each recharge event, the maximum point to point distance between charge points is 110km $\times$ $(0.8 - 0.2) \times 0.85$ or 56 km.

In a real deployment, a more realistic routing based on commercial navigation software could be employed [1], but this is beyond the scope of this study.

2.5 Fault Model

While the reliability of the electric grid is generally very high in Ireland, there are many reasons why public charge points may be non-operational at a particular time, ranging from telematics issues, blocked access, vandalism, etc. In the worst case, the fault may be unknown to the charging utility or may just have occurred when the EV driver arrives expecting to recharge their vehicle. Using the charge point allocation algorithm of section 2.4, the EV is always expected to have a 20% remaining capacity upon arrival at any charge point.

To evaluate the effect of charge point unavailability, simulations are run by initially assuming all charge points are operational. The charge point allocation algorithm is run with each trip needing recharging being allocated charge point which is reserved for the corresponding EV.

A simple fault model is then assumed whereby a fraction of charge points are assumed to be unavailable due to faults. In this work, each individual charge point fault is assumed to be independent. The probability of a fault is denoted p_f.

Any trip that includes a faulty charge point is stopped at the first faulty charge point in its trip route. The charge point allocation algorithm is run with the start location being the first faulty charge point, the destination location being the original destination for that trip and the initial battery capacity being the battery energy remaining on arrival at the first faulty charge point. All faulty charge points are marked as non-operational during the algorithm run. If it is not possible to reach any other operational charger, then the trip is considered to have failed i.e. the EV is counted as stranded.

More detailed work on failure mechanisms is needed to evaluate the independent fault assumption used here. For example, circuit breaker events may disable a bank of chargers deployed adjacent to each other. However, the independent fault assumption is used for simplicity in this study.

3 Simulation Results

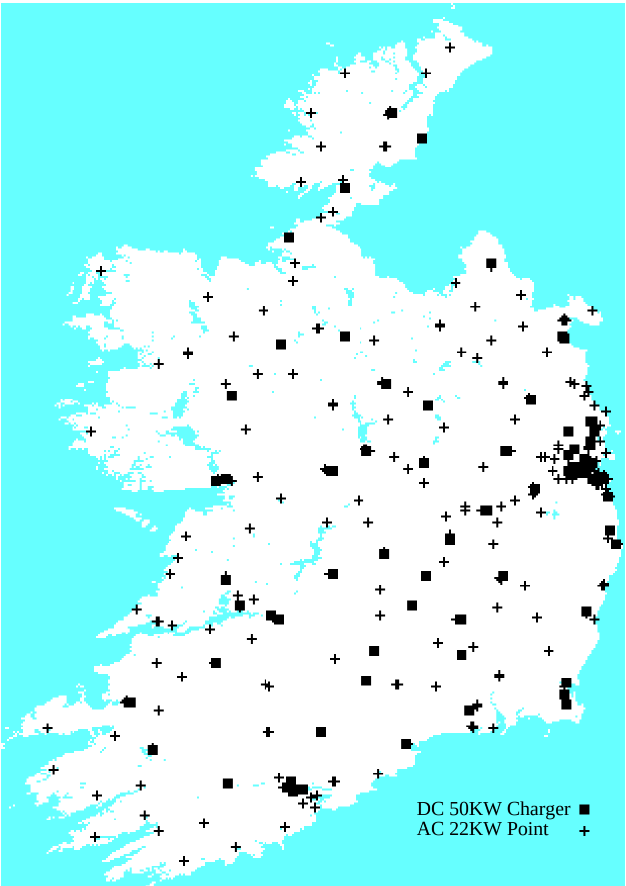

Figure 3: Location of public charge points on 11 Jan 2016

The baseline scenario consists of taking the current distribution of level 2 and level 3 (fast chargers) available in Ireland. It is assumed that it is possible to reserve their usage. Based on data downloaded [11] on 11 Jan 2016, there were 72 DC chargers, 1 of which was not operational. There were 636 Type 2 AC charge points of which 49 were not operational. Fig. 3 shows the location of these chargers. For simplicity, the DC chargers were assumed to be 50 KW chargers units and the Type 2 AC charge points were assumed to be 22 KW 3 phase 230V units. All the charge points are assumed operational at the start of the simulation.

3.1 Baseline Results

Two set of simulations are run. The first assumes that the charging rate at the 22 KW AC charge points is limited by the vehicle on board charger to 6.6 KW, while the second assumes that the full 22 KW is available to charge the vehicles battery. The resulting data are shown in Fig. 4. This figure shows the fraction of total trips meeting various conditions. In all cases, at least 10^7 sample trips were generated for each data point in the Monte Carlo simulations.

The first condition is that charging is required to complete the journey. This happens in about 2% of all the cases. Such a number would be expected based on the journey distribution as in section 2.2.

When charging is required the average speed is reduced due to the charging time as well as waiting times. The figure shows the fraction of total trips that resulted in an average speed below 60 kph, 40 kph and 10 kph. In these simulations, no trips were impossible.

From the figure, an average speed above 60 kph is not achieved in about 1 in 500 trips which are about 10% of the 1 in 50 trips that require recharging even with a very low number of vehicles. As most of the charge points are 22 KW, this result is not surprising.

Considering an average speed above 40 kph, all

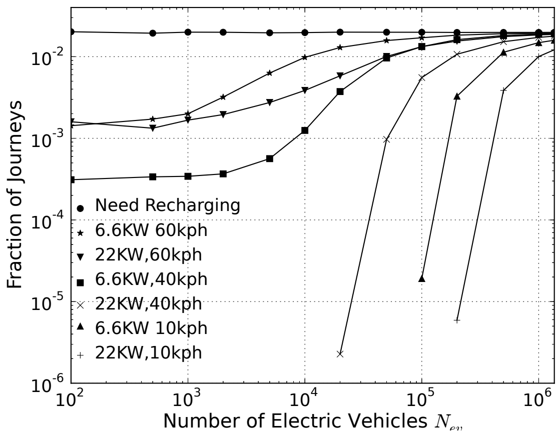

Figure 4: Simulated baseline speeds for existing public charging infrastructure.

trips were able to exceed this under the assumption that 22 KW on board charging was possible. This was the case for supporting more than 10000 electric vehicles. Naturally, the limitation of the 6.6 KW on board charging significantly increases fraction of trips that fail to achieve 40 kph. However, this data does show that the deployed infrastructure is extensive; potentially supporting more than 10000 electric vehicles for trips over the whole country. It also shows that employing 22 KW on board charging is a key factor in improving the achievable average speed.

Above the 20000 electric vehicles, the limitation of the infrastructure (waiting times) begins to dominate. Above 200000 electric vehicles, many are beginning to hit average speeds below 10 kph.

Choosing an acceptable probability of failing to achieve 40 kph as 10^{-4}, then the capacity of the currently deployed infrastructure would be about 36000 vehicles. This represents 2.6% of the 1.36 million households having at least one car.

While an average trip speed of 40 kph seems low, it should be recalled that this is a worst case value. For many non-professional drivers who take few long distance trips, many of which may be leisure travel, a guarantee of this as worst case speed may be acceptable and enough to alleviate the range anxiety associated with battery electric vehicles.

3.2 Financial Costs

The ability to support up to 36000 with the existing infrastructure (assuming 22 KW on board charging with a routing and reservations system) allows estimates of the financial cost per user to be calculated. Based on the costs reported in [7], the average installation costs of DC chargers and 22 KW AC charging posts were about 48K Euro and 12.5K Euro respectively with annual maintenance costs of 6K Euro and 350 Euro. Taking the existing infrastructure of 72 DC chargers, 636 22 KW AC charging posts and with an assumed lifespan of 20 years, then with 36000 users, the annual cost per user would be 34 Euro per annum.

If all the charge points were DC chargers, then the annual cost per user would increase to 165 Euro per annum.

While these figures exclude overheads and the cost of the proposed routing and reservations system, they are reasonable in comparison to the EV prices in the order of 30K Euro.

Presently the existing infrastructure has been subsidized on the basis of encouraging EV adoption, but ultimately, the EV users would be expected to pay. If financial charging of EV users started when an EV adoption rate of say 10% of the potential 36000 users was reached, the annual cost of 340 Euro per annum would be required. This amount would likely be acceptable to most users particularly if a guaranteed quality of service was provided.

3.3 Effect of Reservations

The prior simulations assumed that trips were reserved in advanced. The allocated charging times accounting for waiting times, to minimize the overall journey time. However, this is not currently available. It is of interest to consider the impact of such a reservation feature on average journey speeds. Assuming 22 KW on board charging the effect of such a feature can be assessed.

Fig. 5 shows the data in the case of a reservation algorithm that minimizes waiting times against the case where each journey is planned based only on minimizing travel and charging time, i.e. without consideration of waiting times due to other users. There is a severe deterioration in the fraction of trips that fail to achieve an average speed above 40 kph. This is the case even for relatively small numbers of vehicles being electric. It occurs because many users chose the same charge point, resulting in long waiting periods. Even with only 2000 vehicles, about 1% of trips that need recharging fail to achieve the 40 kph level.

With an acceptable probability of failing to achieve 40 kph as 10^{-4}, then the capacity of the currently deployed infrastructure with no reservation system would be about 700 vehicles. Clearly there is an important need for a reservation infrastructure to be deployed to maximize the utility of the physical charge point infrastructure.

The employment of a reservation and routing infrastructure also allows for the implementation of a demand driven financial costing model to allocate the financial cost of providing the physical electrical charging infrastructure to EV users [12]. For example, fast DC chargers can be priced at a higher rate than 22 KW AC charge points to reflect the additional costs of the DC chargers. Indeed, some EV users may be happy to pay a higher rate for peak time use of fast DC charger while others may be prepared to accept a longer trip time (e.g. using only 22 KW AC charge points) in return for lower costs.

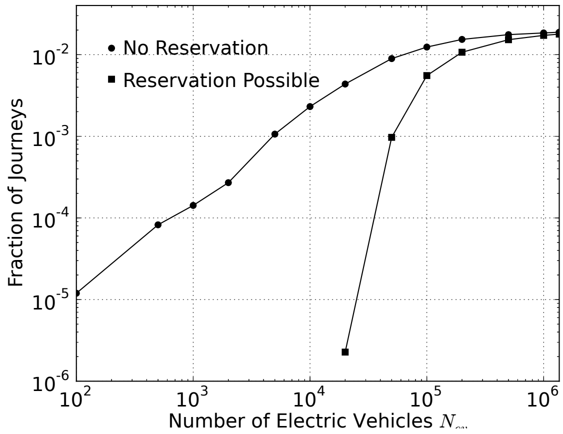

Figure 5: Simulated baseline speeds for existing public charging infrastructure with and without reservation provision for average trip speed above 40 kph.

3.4 Fault Simulation

In the case of charge point faults, the most serious problem is a vehicle being stranded and unable to complete its trip. The probability of a vehicle being stranded in this manner is not related to the number of electric vehicles in the system, but only the probability of a charge point fault p_f.

With the installed base of 708 charge points, if 50 were non-operational (as was the case on Jan 11, 2016), then this would suggest a charge point fault probability of $\frac{50}{708}$ or about 7%.

Hence sequences of simulations are run for charge point fault probabilities in the range of 1% to 30% as described in section 2.5.

The primary cause of stranded vehicles is arriving at a charge point to find it non-operational and having insufficient battery energy left to travel to another charger. With the routing algorithm from section 2.4, the worst case battery level on reaching a charge point is set as 20% capacity. This corresponds to an available point to point range of about 18 km.

Based on the charge point location distribution, there are 3 charge points that have no neighboring charge points within this radius. Hence a fault at any of these would result in vehicles being stranded there with a probability of order p_f. Otherwise, at least two non-operational charge points would need to occur as neighbors. This has probability of order p_f^2. Thus, the probability of a stranded vehicle p_s can be estimated as

$$p_s \approx p_c p_f \frac{3}{708} + O(p_f^2) + \ldots, \qquad (2)$$

where p_c is the probability of recharging being required ($\approx 2\%$) and ... represent third and higher order terms in p_f .

As an example of improving the charge point infrastructure, three additional charge points were added to the model, one each co-located at the three identified charge points with no neighbors in the 18 km radius. Simulations with these additional charge points are also run.

It is also possible to modify the routing algorithm parameters to increase robustness of the system. The original reserve level for the battery energy was chosen as 20% but increasing it to 28% would ensure that sufficient reserve energy is available to avoid being stranded in the case of a single faulty charge point.

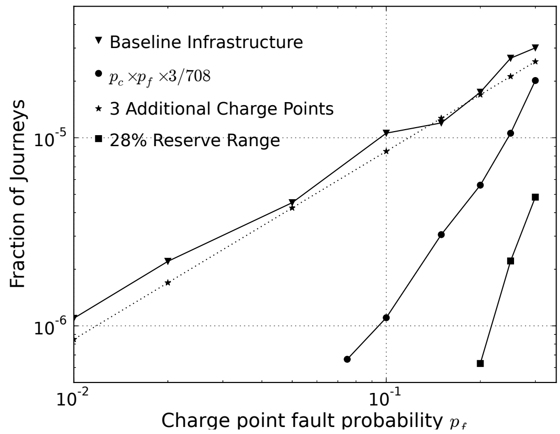

Figure 6: Fault simulation results.

Fig. 6 shows the result of fault simulations. The baseline case of the existing infrastructure shows a stranding probability of about 10^{-5} for a fault probability of 10%. The baseline case is close to the first term of Eqn. 2, indicating that the three charge points identified are a significant source of stranded EVs in the model.

With the addition of just three additional charge points, Fig. 6 shows almost a factor of ten improvement in the stranding probability to about 10^{-6} for a fault probability of 10%.

Choosing an acceptable probability of being stranded of 10^{-6}, then the baseline case would require a fault probability of less than 1%. With the additional three charge points, the tolerable fault probability would be about 9%.

The increase in the battery reserve energy level to 28% with the baseline infrastructure shows an even more significant improvement of the system robustness. A fault probability of more than 20% still achieves a probability of being stranded below 10^{-6}. However, increasing the reserve level reduces the maximum allowable distance between charge points. The increase to 28% resulted in a fraction of about 1.5×10^{-5} trips not being possible to route in the first instance. In a real deployment a location dependent reserve level could be adopted which would address this issue.

These results show that charge point fault probability and the charge point location distribution are key factors in the stranding probability of EVs for long trips using a recharge infrastructure. The robustness of the recharge infrastructure can be increased by adding redundancy at existing charge points, even if they are low power charge points just to reduce the probability of stranded vehicles. The use of a routing and reservation system can also significantly improve the system resilience to charge point faults. For example the allocation of a higher battery energy reserve when high risk charge points are being used can significantly improve the system robustness.

4 Conclusions

In this paper, a model of the complete charge point infrastructure deployed (early 2016) in Ireland is built using the Irish population density. The assumed trip length probability density function is based on a US survey (as this data was not available for the Irish case). The population density and trip length distribution are used to create a set of trips based on the number of EVs assumed present. These trips are then routed through the deployed charge points when the trip length exceeds the range of a typically EV presently available.

The results of these simulations show that with the typically EV, that the deployed charge point infrastructure is extensive and can support electrified travel across the whole country. With the majority of charge points being 22kW AC sources, the effect of the on-board charger power rating is a limiting factor in the vehicle. Manufactures are working on this [13]. At least a 22kW power rating appears desirable.

The second key factor is the provision of a routing and reservation system, which is not presently available to EV users in Ireland. Without this, the number of EVs that the system can support is limited. As measured by average trip speed, even with the assumption of 22kW onboard charger power ratings, the present infrastructure could potentially support about 36000 EVs based on achieving an average trip speed below 40 kph with a probability of 10^{-4}. This is under the assumption of a routing and reservation system as described in section 2.4. Without such a system, the equivalent number support is less than 1000.

The third factor that needs to be accounted for is the effect of charge point faults. The worst case scenario for the EV user is the chance of being stranded at a faulty charge point, thus being unable to complete the journey at any speed. Using a fault model that assumes faults in each charge point are independent, the system simulation can be used to assess the impact of faults rates on the fraction of EVs being stranded. The simulation results show the importance of charge point distribution with low fault rates to reduce the probability of stranding EV and the ability of an intelligent routing algorithm to improve the robustness of the system to charge point faults.

Overall, the simulation model and results in this paper show quantitatively the effects of EV on board charger power rating, the major advantage of a routing and reservation on a country wide scale, and the effect of charge point fault rates based on a currently deployed charging infrastructure.

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