Energy Policy 49 (2012) 355–364

Contents lists available at SciVerse ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

The impact of electrified transport on local grid infrastructure: A comparison between electric cars and light rail

Agathe Grenier, Shannon Page *

Department of Environmental Management, Lincoln University, P.O. Box 84, Lincoln 7647, Christchurch, New Zealand

HIGHLIGHTS

- ► The impact of electric vehicles and light rail is assessed at the local grid level.
- ► Electric vehicles will likely be clustered in certain parts of a city.
- ► Local grid capacity may be exceeded even with low penetration of electric transport.
- ► Electric vehicles have a smaller impact on the grid due to load shifting options.

ARTICLE INFO

Article history:
Received 6 March 2012
Accepted 17 June 2012
Available online 10 July 2012

Keywords:
Electric vehicles
Light rail transit
Peak demand

ABSTRACT

This study examines the impact on the local electricity grid should electric vehicles (EVs) or a light rail transit (LRT) system be introduced to the city of Christchurch, New Zealand. Spatial analysis highlighted that EV owners would not be evenly distributed throughout the city, and the initial stages of a proposed LRT network would cover only a limited area. Therefore, a few local power substations would have to provide the majority of additional power for both electric transport modes. Without management of EV charging patterns, one of the local substations would be overloaded if more than 2.6% of the Christchurch light vehicle fleet were EVs. The power demand from a LRT system would not overload the local grid given current demand levels. However several substations would need an upgrade 4 years earlier than current plans.

A comparative analysis shows that despite the power demand from an EV fleet being higher than the demand from a LRT system (on a equal passenger kilometre per day basis), demand side management methods would allow shifting EV charging off peak time whereas a LRT system would still contribute significantly more to peak load.

1. Introduction

Given the uncertain future of fossil fuel availability, climate change and associated regulations on CO_2 emissions, new technologies that reduce the current dependence on fossil fuels are appearing on the market. Such technologies include increased renewable electricity generation as well as new transport systems. A potential way to reduce fossil fuel dependence in the transport sector is to shift towards electrified transport modes. These transport modes include public transport (electric light/heavy rail, trolley and electric buses) and private electric vehicles. This shift is all the more beneficial in a region where the majority of electricity generation is from non-fossil fuel resources.

National and local governments have been promoting both EVs and public electric transport. For example, in Paris and London, EV charging infrastructure and incentive programmes have been announced (The Canadian Press, 2011; Mayor of London, 2009). In New Zealand, the city of Wellington operates an electric rail network, and the city of Auckland is undertaking a rail electrification programme (Joyce, 2009). In addition, electric vehicles have been promoted by electricity retailers/generators such as Meridian Energy using the Mitsubishi iMiEV cars (Shaw, 2009). In 2010, 74.2% of NZ electricity generation came from renewable sources, (predominantly hydro), and new generation is projected to come largely from renewables (MED, 2011a, b). This puts New Zealand in a good position to reduce its dependence on fossil fuels for transport by switching to electrified modes, provided risks from daily/seasonal variability can be managed, particularly given potential climate change effects on hydro and wind electricity generation (Renwick et al., 2010).

Increasing the amount of electric transport will require not only more electricity to be generated, but also consideration of where and when power is required. Indeed, electricity generation, transmission and distribution infrastructure are under increased

* Corresponding author. Tel.: +64 3 325 2811; fax: +64 3 325 3845.
E-mail address: shannon.page@lincoln.ac.nz (S. Page).

0301-4215/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enpol.2012.06.033

pressure during peak times, when demand is significantly higher compared to the daily average load. For New Zealand, peak demand occurs during the winter months between 6 pm and 8 pm. Electricity providers are required to deal with increasing peak power demand and adapt their infrastructure accordingly. The growing demand may not occur evenly across an area; therefore the geographic distribution of demand must be estimated to identify specific local infrastructure upgrades required. When examining the potential impacts of electrified transport, consideration should therefore be given to the local grid infrastructure as well as to the total energy and regional power demand.

2. Goal and overview of paper

This research provides a geographic and time based power load profile for an electric vehicle (EV) fleet and a light rail transit (LRT) system. By identifying where and when increased power demand will occur, local power distribution providers can identify which areas will require infrastructure upgrades and when they may be needed. Should widespread electric transport be the chosen alternative, such information would help local authorities anticipate potential additional costs due to growing demand.

The following section of this paper reviews previous studies in which the impact of electric transport on the grid has been examined. Section 4 of this paper explains the overall method, in which the case study of Christchurch is described and the procedure in which the impacts on the grid are evaluated and compared. Sections 5 and 6 provide the power demand estimation for the EV fleet and LRT system respectively, as well as the identification of the impacted local power infrastructure. The impacts of both are compared in Section 7. The implications on policy making are discussed in Section 8 with Section 9 providing final conclusions.

3. Review of electric transport studies and their impacts on the grid

A significant amount of research worldwide has been done on EV energy and power demand on a national and regional scale. These studies are country specific. For example, in New Zealand, Duke et al. (2008) estimated that a 2 million EV fleet would require an additional 1350 MW of wind generation, providing an additional 4900 GWh per year. This would be a significant increase in the total installed capacity of 9667 MW in New Zealand, which in 2010, generated 43,401 GWh (MED, 2011). In Ontario, Hajimiragha et al. (2010) analysed the feasibility of utilising grid off-peak potential for charging plug-in hybrid electric vehicles (PHEVs). They concluded that 6% of the total vehicles in Ontario and 12.5% in Toronto could be PHEVs without any additional transmission or power generation investments beyond those currently planned. Hajimiragha et al. (2010) identified the need to study technical problems such as overloading distribution feeders in more details.

Some studies have examined the impact of EVs on a more local level by focusing on distribution issues. In New Zealand, Duncan et al. (2010) undertook an analysis based on a distribution network infrastructure model to analyse how EV charging could affect power quality. Their analysis revealed that 15% of the NZ national fleet could be EVs without a need for an infrastructure upgrade. A similar study by Lambert (2000) has been conducted in California by collecting data from residential appliances and EV chargers. The study concluded that power quality (total harmonic distortion) should not be a cause for concern. The main cause for concern is the overloading of the distribution transformer with widespread use of EV chargers. The study recommend planning services to consider real current load value (kVA) and power factor to base their analysis (Lambert, 2000). In Europe, Perujo and Ciuffo (2010) estimate both the impacts of EV uptake on the Milan (Italy) area electric grid in terms of power demand based on market penetration studies. Perujo and Ciuffo (2010) concluded that without appropriate regulation on vehicle to grid behaviour, EV could heavily impact the daily electric power demand, especially in a high uptake scenario where more than 20% of light vehicles are EVs. A study by Mullan et al. (2011) has been undertaken to assess regional power supply and transmission in Western Australia. The authors concluded that even without controlling charging times, a 200,000 EV fleet (10% of the current local fleet) could be charged on the local grid before there is any significant impact on local peak demand. They also suggest that EVs would be clustered, and how it would be more difficult to predict where they will be charged during the day as opposed to the night time where the home would be the obvious location for private EVs.

The issue of non-even distribution of EVs and the resulting impact on the local distribution network has been identified by a number of studies. Schirmer et al. (1996) undertook a predictive analysis of EV distribution in Southern California using GIS (Geographic Information System). They noted that the use of even one single charger could potentially double a household electrical demand. Furthermore they concluded that although generation and transmission infrastructure could sustain an increasing demand from EV charging, it is likely that EV owners will be spatially clustered, creating a disproportionate load on some local power substations. This issue has also been examined by Mohseni and Stevie (2009) for several North American cities considering the need for new electric capacity, the timing of that capacity need, and the potential spatial clustering of EVs using a statistical procedure. They concluded that the main risk in EV uptake lies with the utilities' abilities to successfully manage local distribution issues, time of use pricing, charging venues, and infrastructure management. It was also shown that the uptake of EVs in the near term was unlikely to pose risks to utilities, but infrastructure additions should not be ignored for too long when a robust EV market eventuates.

With respect to time of use, Rahman and Shrestha (1993) showed that off peak generation must be looked at as well as distribution capacity. EV charging could induce a new peak in electricity demand and jeopardise the load management programme currently in use. Denholm and Short (2006) in the U.S. looked at the benefits from optimally dispatched EV charging to ensure EVs are charging when the electricity price is at the lowest. They conclude that up to 50% of EV penetration with optimal dispatch would increase the per capita electricity demand by around 5–10%, depending on the region evaluated but would require no new electric generation capacity.

The electricity demand profile from an EV fleet is different from an electric LRT system in a number of ways. The energy demands for a LRT system are lower per passenger km travelled. Newman and Kenworthy (1999) report the average energy per passenger kilometre of rail travel for cities in Europe (electrified rail) to be 0.49 MJ/pkt (140 kWh/pkt). For the same cites, the (liquid fuelled) energy required for car travel is 2.62 MJ/pkt (727 Wh/pkt). Although an electric vehicle requires less energy than a traditionally fuelled vehicle (as shown in Section 5), an electric rail (or LRT) system requires the least energy per passenger kilometre travelled. When considering the effect on the electricity grid, the fact that a LRT system requires power during morning and evening peak times makes the impact potentially larger than an EV fleet. Much of the research on LTR is currently focused on reducing energy and power demand using regenerative breaking and onboard batteries/supercapacitors.