Applied Energy 180 (2016) 256–268

Contents lists available at ScienceDirect

Applied Energy

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

Economic and environmental impacts of providing renewable energy for electric vehicle charging – A choice experiment study

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HIGHLIGHTS

- U.S.-wide online survey of Plugin Electric Vehicle owners and lessees is conducted.
- Economic benefit of charging electric vehicles using renewable energy is assessed.
- Choice experiment is used to elicit willingness-to-pay for renewable energy charging.
- Results.
- show significant environmental benefit from emissions reductions.

ARTICLE INFO

Article history:
Received 3 March 2016
Received in revised form 25 July 2016
Accepted 28 July 2016

Keywords:
Willingness to pay
Choice experiment
Charging station
Electric vehicle
Renewable energy

ABSTRACT

This study evaluates the potential economic and environmental benefits available by providing renewable energy for electric vehicle charging at public electric vehicle service equipment (EVSE). Willingness to pay (WTP) for charging an electric vehicle using renewable energy was collected through a U.S.-wide online survey of Plugin Electric Vehicle owners and lessees using the choice experiment method. The results indicate a 433% increase in the usage of charging stations if renewable energy was offered. Results also show a mean WTP to upgrade to renewable energy of $0.61 per hour for Level 2 EVSE and $1.82 for Direct Current Fast Chargers (DCFC). Using Blink public EVSE network as a case study, these usage and WTP values translate directly to an annual gross income increase of 655% from $1.45 million to $9.5 million, with an annual renewable energy credit acquisition cost of $13,700. Simulation results also show significant environmental benefit from emissions reductions.

1. Introduction

Transportation in the developed world is powered predominantly by liquid fuels refined from petroleum. In the U.S. for example, 97% of transportation is powered by petroleum [1]. The high energy density and abundance of these fuels have made them a very effective and relatively affordable transportation energy source. However, motivations for finding alternate sources of transportation energy are numerous, including economic security, mitigation of anthropogenic climate change, and lessening military conflict in the oil-rich parts of the world. These motivations extend to reducing risk to human and environmental health posed by vehicle exhaust, hydrologic fracturing and oil transportation. There are a number of technologies currently at various stages of research and development with the ability to supplement or replace petroleum with a transportation energy source that is renewable, reduced in greenhouse gas (GHG) emissions, and economically feasible. The most currently developed of these technologies include biofuels, hydrogen fuel cells, and plugin electric vehicles (PEVs) powered with renewably generated electricity.

Each of these technologies has its benefits and drawbacks. Most biofuels offer a drop-in replacement liquid fuel requiring little or no modification of the current internal combustion engine technology and fueling infrastructure. However, the land, water, fertilizer, and energy requirements limit feasibility, energy gain, and GHG emission avoidance of biofuels for most feed stocks, for supplementing a majority portion of transportation energy [2]. Algae differs from most feed stocks in that it grows more densely and on inarable land. Meeting U.S. transportation energy needs with corn, canola or switchgrass would require more than 70% of U.S. arable land [2], with the U.S. having more arable land per capita than most developed nations. While algae is a feed stock with great

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http://dx.doi.org/10.1016/j.apenergy.2016.07.121
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potential, current knowledge and technology put algae biofuel production estimates at a low net energy gain of 6% [2] and a cost of $10.87–$13.32 per gallon [3], with these numbers falling towards the center of a wide range of such published values. Corn ethanol and soybean biodiesel currently supplement 5% of U.S. land transportation fuel [1]. However corn ethanol has a low net energy gain estimated at 22% and an estimated 27% GHG reduction [2].

While the prices remain high, a few automotive manufacturers have started leasing hydrogen fuel cell based vehicles in limited numbers. The hydrogen for these vehicles can be sourced from natural gas or electrolysis of water. Relative to gasoline, sourcing from natural gas results in a 21% life cycle GHG reduction, while water electrolysis with grid electricity increases GHG emissions by 25% [4]. Electrolyzing with electricity generated by renewables reduces GHG emissions by greater than 99% [4].

With present technology, all-electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) offer a relatively cost-effective means of transportation with significantly reduced GHG emissions [5,6]. EVs priced for the mass market such as the Nissan Leaf, Ford Focus EV and Smart ForTwo ED are currently limited to a driving range of about 60–85 miles per charge, with high end EVs such as the Tesla Model S traveling greater than 250 miles per charge. PHEVs such as the Chevy Volt and Ford C-Max Energi provide 20–40 miles of electric driving per charge in addition to a gasoline-powered driving range, which is most often similar to that of conventional internal combustion engine vehicles (CVs). For the majority of U.S. drivers, PHEVs offer enough electric driving range for daily commutes, while offering extended range when needed. EVs and PHEVs are collectively referred to as plugin electric vehicles (PEVs). Charge times for PEVs are typically 3–6 h when using 240 V AC Level 2 electric vehicle supply equipment (EVSE). Most EVs can also charge to about 80% capacity in 30 min on Direct Current Fast Chargers (DCFCs). Powered by the average U.S. grid electricity mix, PEVs electric energy life cycle GHG emissions are approximately two thirds that of gasoline powered transportation [4], while the energy costs are below that of gasoline. Powered by renewable energy sources, such as wind or solar energy, the energy life cycle GHG emissions of PEVs amount to less than 1% that of gasoline and with an energy cost still well below that of gasoline [4]. Consumer preference is important in the EV market and in promoting the adoption of EVs [7]. EV charging infrastructure is essential in encouraging the adoption of EVs and enhancing the environmental benefit of EVs [8].

There are many studies on the environment impact of EVs [9–12]. There is also an increasing amount of engineering and science studies that analyze the integration of renewable energy and PEVs from the perspectives of engineering design, environmental impact, and energy planning [13–15]. A few papers use engineering methods to analyze charging from on-site solar in terms of optimal system design [16,17]. However, there are no papers that empirically quantify the economic demand for renewable electric vehicle charging, which is needed for charging companies to evaluate such charging options and thus potentially increase the use of renewable energy.

This study fills the gap in the literature by estimating the willingness to pay (WTP) for and evaluating the potential economic and environmental benefits of a new PEV charging strategy for companies offering public PEV charging. Such companies include utility companies, charging companies, and PEV manufacturers. The new charging strategy evaluated in this study is to provide renewable energy to electric vehicle drivers at public stations, also known as electric vehicle supply equipment (EVSE). A comprehensive search reveals a small number of solar connected public EVSE with no major U.S. public EVSE companies offering widespread renewably powered vehicle charging. Through an online survey and a choice experiment of U.S.-wide PEV owners and lessees the following information was collected:

1. WTP for upgrading their pay-per-use charge event at a public EVSE to renewable energy from wind or solar sources.
2. Would the availability of renewable energy at such EVSE change their EVSE usage frequency?
3. How likely would they choose an EVSE offering renewable energy over one that does not?

Heterogeneity of the elicited WTP is also examined for trends in the data. A case study quantifying the economic and environment benefits available to one of the largest U.S. public PEV charging companies is included.

2. Background and literature review

2.1. PEV drivers and renewable energy

The California Center for Sustainable Energy conducted a survey of Californian PEV drivers. Among other useful data and using the direct ask surveying method, this study provides the stated mean WTP of Californian PEV drivers for public charging powered by standard grid electricity, see Table 1 [18].

Current prices charged at public EVSE provide another source of pricing information. The most common prices from the largest U.S. public charging companies such as Blink and U.S. average residential utilities are shown in Table 2 [19,20,1]. Within this table, where necessary to convert energy-based pricing to time-based pricing, a 6 kW mean charge rate is used for AC Level 2 EVSE and a 28 kW mean charge rate is used for DCFCs, each of which is typical of today's PEVs using the specified charging technology.

At the pre-9/2014 prices, Blink found their nationally distributed customers did 9% of their charge events at public AC Level 2 EVSE and 5% at public DCFCs. The remaining 86% of the charge events occurred at their personally owned EVSE or outlets, paying utility electricity rates. This usage amounts to 77,640 public charge events on 2762 public EVSE in the second quarter of 2013 [21].

One contingency choice experiment based study [22,23] focused on refrigerators examined WTP for the U.S. EPA Energy Star Label, which represents both private (energy cost savings) and public (environmental) benefits. They found a significant positive WTP well in excess of even undiscounted energy cost savings over the life of the appliance. There was a higher WTP among those with environmental concerns and among those who believed consumers can influence market offerings. Combined, these findings indicate a WTP for environmental benefit. Another contingency choice survey [22,23] examined WTP for refrigerators produced by manufacturers that use renewable energy in comparison to those that use conventional energy sources. The findings show a WTP an extra $53.18 to $68.66 for the appliance to be produced by manufacturers powered by renewable energy.

The few studies that have been conducted on PEV drivers and renewable energy have found a higher-than-average interest. A survey of about 1400 PEV owners in California [18] found that 39% of the participants had a photovoltaic (PV) solar system on their home, with another 17% planning on installing PVs in the next year, showing demand for renewable energy. Of those with PVs, about 50% have sized their system to meet the energy demand of their vehicles. Sixty percent of those who have not done so already, plan to expand their PVs in the next year to account for their PEV energy needs, showing demand for charging PEVs with renewable energy.

A more recent U.S.-wide survey [24] of about 1500 individuals consisted of three populations of recent vehicle buyers: CV buyers