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Electricity costs for a Level 3 electric vehicle fueling station integrated with a building

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HIGHLIGHTS

- Electricity cost for Level 3 electric vehicle refueling at a building is determined.
- Sharing of demand charges between drivers and a building provides largest savings.
- Savings are eliminated when maximum building and vehicle refueling demand coincide.
- Savings potential is primarily created for electric vehicles, not the building.
- Refueling operation can result in a utility rate switch that increases building costs.

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ABSTRACT

Despite the potential environmental benefits, plugin electric vehicles (PEVs) face challenges associated with driving range and long refueling times. Level 3 electric vehicle service equipment (EVSE) is capable of refueling PEVs quickly, but may face economic challenges, such as high utility demand charges. The current study extends prior work to determine if lower utility costs can be achieved by integrating Level 3 EVSE with a commercial or industrial building. Models are developed to simulate travel patterns using real travel data, building demand based upon real building data, and subsequent refueling of Level 3 compatible PEVs to evaluate cost implications of integrating public fast charging into real buildings operating under current electric utility rate structures. Two types of Level 3 refueling station operations are considered (conventional and valet parking). By integrating EVSE with a building, savings can be produced if lower cost energy is accessed, and by the sharing of demand charges between the PEV drivers and the building. These savings were determined to be much more significant to the refueled PEVs than any examined building. The dynamics of building electricity consumption have a large effect on overall demand charge cost reductions, with high load factor buildings providing the smallest savings. Lower load factor buildings may experience a larger benefit, but only if the maximum building demand does not coincide with the refueling of PEVs. In general, savings tend to disappear or turn into losses when valet parking is active and PEV traffic is moderate to high. Increasing building size reduces the risk of peak building and PEV refueling demand coinciding, maintaining savings for PEVs. However, the relative value of the savings due to integration disappears for larger buildings. Installing multiple EVSE can provide a cost benefit under conventional parking, but nearly always increases costs under valet parking. Increasing EVSE power always reduces savings, or increases losses. Finally, if multiple utility rates exist, EVSE integration can result in a rate switch for small buildings, significantly increasing utility costs for the building.

1. Introduction

Plugin electric vehicles (PEV) fueled by low carbon or renewable electricity sources reduce both greenhouse gas and pollutant emissions [1]. Barriers to widespread adoption include range, refueling time, and availability of electric vehicle supply equipment (EVSE) [2–4]. Research focused on Level 1 EVSE (3.3 kW output) and Level 2 EVSE (up to 14.4 kW output but typically 6.6 kW) [5] has shown that the viability [6] and environmental benefit [7] of PEVs can be increased through the use of public EVSE. In addition, Level 3 (or DC fast charging: up to 240 kW but typically 44–120 kW [5]) can

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Nomenclature

Abbreviations

DC	direct current
EVSE	electric vehicle supply equipment
NHTS	United States National Household Travel Survey
PEV	plugin electric vehicle
SCE	Southern California Edison
TOU	time of use

Equation variables

φ_i	Shapley value for member i
N	coalition of n participants
S	any coalition of participants that form a subset of N
$\upsilon(S)$	cost incurred by coalition S

refuel a depleted PEV up to 80% state of charge in a fraction of the time required by Level 1 or 2, potentially reducing concerns regarding range, refueling time, and EVSE availability. Also, other work has shown that only a fraction of total installed EVSE needs to be public [6]. Much research has been performed to determine the best location, operation, and impact of EVSE.

Optimal EVSE siting models have been developed. Specifically for Level 3 EVSE, work that determines optimal placement along travel routes where lower power EVSE are not viable [8] were studied in [9]. [10] explored the optimal mix of public Level 2 and 3 EVSE located along a travel route. Other work concerned with the optimal placement of EVSE within cities have been developed in [11–21].

Once EVSE sites and layout have been determined, other research has examined how to control PEV refueling to improve grid performance [22,23], minimize electricity cost [24], or both [25,26]. If special EVSE with bi-directional capabilities are installed, a PEV battery can be discharged for the purposes of supplying electricity in support of improving the performance of a building [27–29], micro-grid [30–32], or macro grid [33] as well as reducing the need for electric energy storage in systems with high renewable penetrations [34]. Other work has focused on pricing methods for public EVSE to minimize cost of operation [35], improve customer access to EVSE [36], improve return on work place EVSE investment while remaining cost competitive with gasoline vehicles [37], improve overall grid operation [38], and developing refueling algorithms that reduce the impact of local distribution circuits [39].

The refueling of PEVs introduces new challenges to operating and maintaining the electric utility grid network [40]. Grid reliability [41,42] and voltage stability [43,44] may be reduced in regions with high PEV use. In addition, research on the impact of PEV refueling in residential areas has shown that grid equipment upgrades will be needed if Level 2 EVSE is used and refueling is uncontrolled [45,46]. On the other hand, unscheduled PEV refueling may only increase peak demand by 1% for some regions in the United States [47]. Also, PEV refueling loads have the potential to be aggregated and controlled during off-peak periods to improve grid performance [22,48,49] and reduce grid emission factors [50].

Currently, PEVs comprise a tiny fraction of all vehicles on the road today and Level 3 EVSE make up only 8.5% of all publicly available EVSE (70% is Level 2) [51]. Much of the current literature suggests that improving PEV refueling infrastructure will lead to increased PEV adoption. While PEV adoption is positively correlated with EVSE availability, improving refueling infrastructure does not guarantee an increased number of PEVs on the road [52]. In addition, at an early stage of PEV adoption, investment in Level 3 EVSE is not profitable [53]. The reasons for using Level 3 EVSE along travel corridors are clear (e.g., to enable longer and more convenient travel). However, the viability of using Level 3 EVSE to power our most frequent trips, such as shopping, going to a restaurant (a few commonly suggested locations for Level 3 EVSE [54]), or work travel, has not yet been fully determined. In addition to understanding optimal placement, control, and dispatch of public Level 3 EVSE, the economics of operation must also be evaluated when deciding whether or not to invest in this technology.

Prior work that examines a public Level 3 EVSE stations powered through a dedicated utility meter has shown that the cost to purchase electricity under real utility rates can be prohibitively expensive when demand charges are applicable and PEV traffic is low, or if no parking management occurs [55]. This work also showed that demand charges become relatively small when a large number of PEVs are refueled, i.e., when a demand charge is shared by many customers. While that work examined the utility cost associated with a public Level 3 EVSE station, the results suggest that integration of the EVSE with a building (or installing the Level 3 EVSE on the same utility meter as a building) will lower the cost to refuel PEVs due to the sharing of demand charges between the PEVs and building, even when PEV traffic is low.

This current work is an extension of the work presented in [55], and attempts to answer the question of whether integration of Level 3 EVSE with a building leads to lower PEV refueling costs? Fig. 1 shows a schematic of the scenario considered in the prior work [55], where the EVSE is powered through a dedicated utility meter, and in the current work, where the EVSE and a building share the utility meter. The models developed in [55] that describe PEV travel patterns based on the U.S. National Household Travel Survey (NHTS) [56] and possible EVSE operation scenarios that span most types of public EVSE operation are used to produce an electrical demand load profile for Level 3 EVSE. This load profile is then combined with a building energy model using real building data for summer and winter [57] to produce a combined building and EVSE load. The cost of supplying electricity to this combined load is then determined using utility rate models based on rates for Southern California Edison. The combined utility cost is then split between the EVSE and building through calculation of the Shapley value. Finally, the results with building integration are compared to the results without building integration as presented in [55]. The primary contribution of this work is to address the question of whether the cost to refuel PEVs can be reduced by integrating EVSE with a building, and how such integration affects building energy costs. This analysis assumes that any PEV that can be refueled using Level 3 EVSE is refueled if possible, providing the most supportive (optimistic) case for public Level 3 EVSE.

The paper is organized as follows: Section 2 describes the models and methods used in this work, including the PEV travel model, Level 3 station operation strategy, building energy model, electric utility rate structures, and cost allocation method. Section 3 reviews the cost of electricity for each studied building prior to EVSE integration. Section 4 presents the results from analyzing the integration of the various buildings with Level 3 EVSE operated