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Economic feasibility of residential electricity storage systems in Ontario, Canada considering two policy scenarios

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ABSTRACT

Excessive electricity consumption during peak demand periods has been shown to be expensive for utility companies and can affect the stability of the electricity grid. Shifting peak electricity consumption to off-peak periods has attracted the interest of governments, utility companies, equipment manufacturers and residents. Individual, hourly, household data from Ontario, Canada are used to explore the potential for households to install electricity storage systems by manipulating two financial policy triggers. Results show that households with higher daily and on-peak consumption realize net benefits at lower deviations from the current pricing regimes than do those with lower consumption. Benefits for households can be realized by manipulating either of the policy triggers considered, although the feasibility of these policy decisions is not explored. Repurposed Li-ion batteries require complete subsidy on re-purposing and installation of the system with a \$29 $kWh_{capacity}^{-1}$ subsidy or a differential of 19.5 ¢ kWh^{-1} between on- and off-peak commodity rates for 10% of households to achieve net benefits. Systems with new $ZnMnO_2$ batteries require a \$44 $kWh_{capacity}^{-1}$ subsidy in addition to a complete installation subsidy or a differential of 16.5 ¢ kWh^{-1} between on- and off-peak commodity prices to achieve the same proportion of households with net benefits.

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1. Introduction

Increased peak electricity consumption can cause negative economic, social and environmental impacts. This was experienced during California's energy crisis in 2000 and China's large-scale power shortages of 2004 and 2011, where high costs and power shortages were some of the consequences of inadequate energy supply and demand management [1,2]. Electricity storage systems (ESSs) provide a solution to these issues by charging during off-peak, low-demand periods and utilizing this stored electricity during on-peak, high-demand periods. This strategy of load-shifting improves grid efficiencies and allows for increased flexibility in demand management [3].

At the residential scale, ESSs enable homeowners to reduce household electricity costs and peak energy demand, given a differential pricing scheme between high-and low-demand periods. Battery-based household systems, consisting of a battery and an inverter/charger, reduce the household load during high-demand periods by cycling the battery to take advantage of abundant electricity during low-demand periods [4]. The battery technologies used for ESSs include: lead-acid, nickel cadmium, nickel metal hydride and lithium-ion [5]. Non-battery options for energy storage include: super capacitors, flywheels, compressed air energy storage, super conducting magnetic energy storage and fuel cells [5,6]. Lithium-ion batteries for electric vehicles (EV) are a developing point of interest for residential electricity storage systems. Used EV batteries retain 80% of their initial amp-hour capacity at the end of their vehicle-life and have potential secondary applications [7,8].

Studies have indicated that storage systems can aid in smoothening demand [9,10]. Incentives for householders to invest in ESSs can be found in the cost differential for pricing between low- and high-demand periods under a time-of-use pricing regime in which off-peak commodity pricing is significantly lower than that during on-peak periods. This pricing arbitrage provides economic benefits to the homeowner by reducing electricity costs, while also creating system benefits by reducing the grid demand during peak hours. Ultimately, this allows households to benefit from differences in electricity pricing without the need to change their consumption levels [11].

However, the current costs of residential ESSs present a barrier to implementation. To test how effective ESSs would be to create household and grid scale benefits, policies supporting the implementation of these technologies would be required to decrease barriers (e.g., provide subsidies and incentives to reduce initial

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investment costs, or enact disincentives, such as higher prices, for consumption during peak hours). An additional opportunity to decrease the capital cost of ESSs is through the secondary use of electric vehicle (EV) batteries. These refurbished EV batteries, available at a lower cost, provide a promising prospect for residential storage, and are thus included in this research.

The two scenarios explored in this work are financial incentives to decrease the capital costs of ESS installation and alternative commodity pricing that would encourage ESSs based on net savings from differentials between on- and off-peak price levels considering two promising ESS technologies as identified by the literature. This paper provides a techno-economic assessment of both new battery and second-use EV ESSs to determine the size of the incentives or policy interventions required to generate net household benefits. These net benefits are considered a prerequisite for the creation of a residential ESS market and it is also desired to determine what characteristics are typical of households that may achieve net benefits from installing an ESS. In this article, Section 2.0 provides analysis of existing literature, followed by the methodology in Section 3.0, results and discussion in Section 4.0 and the conclusions in Section 5.0.

2. Literature review

In this section, existing publications on policies stimulating the uptake of ESSs are reviewed, with a focus on existing electricity pricing and ESS development policies in the residential sector.

Economic instruments are frequently the policy tool chosen to influence energy decisions [12]. As noted by Taylor et al., establishing mandatory energy or emissions performance standards or sufficiently high energy costs are potential policy measures to encourage the implementation of ESSs [13]. Peak commodity prices occur at times of peak demand and jurisdictions such as California have implemented a cost structure for these extreme cases known as critical peak pricing (CPP) [14].

CPP events occur only for a limited number of days each year, when the system or market exhibits predetermined cost or demand criteria. Herter et al. found that CPP pricing in California was three times more expensive than on-peak pricing [15]. Currently, three major Californian utilities have implemented a CPP price of over \$1.00 kWh^{-1}, which is much higher than the conventional on-peak summer rate of 10–20 ¢ kWh^{-1} [16]. This is further evidence that greater fluctuations in electricity rates are being implemented to encourage demand-shifting and these alternative regimes exhibit opportunities for electricity pricing arbitrage for households with an ESS. Heymans et al. identified that ESS systems in Ontario were found to be most effective for net savings when off-peak electricity rates were reduced by 75% [17].

Subsidies are another method to stimulate the adoption of new energy technologies such as ESSs. As identified by Taylor et al., the transition of ESSs into the market will not take place if they are not economically beneficial [13]. Heymans et al. recognized through their study that annual savings through residential ESSs were most consistent when auxiliary costs such as regulatory, delivery and debt fees are eliminated; therefore, they identify that incentives are needed for the adoption of ESSs. Their study also determined that the Province of Ontario, Canada would require \$104–155 million for the adoption of a subsidy program [17].

The majority of the research into proposed policies for ESSs involves large-scale systems implemented at the national or sub-national level [13,18–20]. These studies stress the importance of storage implementation for national energy security and for energy efficiency measures [13,19,20]. Additionally, the International Energy Agency (IEA) report on energy storage systems identifies that the deployment of ESSs allows for the supply of multiple energy and power services and helps to support the uptake of renewable energy supply systems [18].

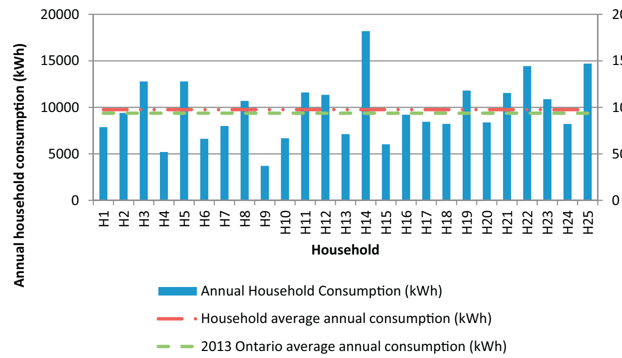

Fig. 1. Annual household consumption with group average and Ontario average.

According to the IEA, government policies have been implemented to encourage adoption of large-scale ESSs in various countries including: Canada (Ontario), China, European Union, Japan, South Korea and the United States [18]. The IEA also identified government initiatives focused on small-scale residential ESSs. First, the procurement model of Ontario's 2013 revised Feed-In-Tariff (FIT) program [21] includes opportunities to incorporate energy storage with renewable energy generation. Second, Germany enacted a subsidy for small-scale ESS projects to promote distributed energy storage to balance the large implementation of small-scale photo-voltaic (PV) projects [18]. These examples highlight the opportunity to integrate small-scale ESSs with renewable electricity generation but these opportunities have not been explored in detail in the existing literature.

The current research in this field and associated development of policies for implementing residential ESSs is limited, thus providing an opportunity to explore the potential for residential electricity storage under time-of-use (ToU) pricing, making use of advanced battery technologies. This work considers options of subsidized ESSs and alternative ToU commodity pricing required to yield net economic benefits to residential households. Additionally, this research incorporates real residential consumption data instead of national or sub-national averages, as the decisions and behavior of individual households will also affect the potential benefits of implementing an ESS [22].

3. Methodology

Hourly smart meter data were obtained from a local electrical utility company, with consent of the householders as part of an on-going smart grid project to assess the interactions of residential electricity consumers with the electricity grid in Milton, Ontario, Canada. These data were obtained for a period of 49 months beginning on January 1, 2010 through to February 6, 2014 and are considered to be the most accurate available data for hourly electricity consumption as the quality is regularly assessed by the electrical utility to ensure proper delivery and billing.

The annual consumption for the participant households averages 9760 kWh and the Ontario average is 9370 kWh [23]. Given the wide range of consumption levels and the similar averages, the households reported here are an appropriate representation of urban households in Ontario, Canada. The distribution of the consumption is shown in Fig. 1 with the group average and Ontario average also plotted for context. The annualized results throughout this work are constructed by aggregating the data from each household and hour over the entire range of data. These values are then divided by the fractional years of data for the individual households to adjust for those with less than the full data complement as

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