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Exploring the potential synergy between micro-cogeneration and electric vehicle charging

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HIGHLIGHTS

- Potential synergy between micro-CHP and electric vehicle charging was investigated.
- Overnight EV charging (Level 1) increases micro-CHP revenue by $200–$300 per year.
- Level 2 EV charging is less effective and creates at best 50% of Level 1 benefits.
- Revenue creation was consistent for full range of electricity consumption profiles.
- Robustness of concept and strong micro-CHP/EV charging synergy were proven.

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ABSTRACT

The economic viability of micro-cogeneration (micro-CHP) systems strongly depends on the value of the co-produced electricity. In case electricity produced by the micro-CHP is used inside the house ('behind the meter'), the electricity has the same value as the price otherwise paid to the utility. If the electricity cannot be used inside the house and needs to be exported to the grid, it generally has a much lower value. For jurisdictions that do not have an active support for micro-CHP, this value could range from zero to at most the whole-sale market price.

The primary function of most micro-CHP systems applied in residences is to provide heat for space heating and sometimes also for domestic hot water. The micro-CHP system generally operates under a heat-load following control strategy, which causes the system to run more in winter and during the night. A large fraction of the electricity is thus produced at times when the electric load of the house is low, requiring substantial amounts of electricity to be exported with low or zero revenues.

Electric vehicles (EVs) consume considerable amounts of electricity. EVs are mostly driven during the day and charged at home during the night. The recharging of EVs could thus be a way to drastically increase the own use of electricity produced by the micro-CHP and to boost the profitability of the system.

A simulation study was performed to explore the potential synergy between electric vehicles and micro-CHP systems by combining the results of the whole building simulation program TRNSYS and NRCan's Plug-in Electric Vehicle – Charge Impact Model (PEV-CIM). Detailed measured profiles of residential electricity consumption were used to determine the economics of a micro-CHP system applied in a single detached house in Ottawa, Ontario, Canada.

EV charging showed to have a great potential to improve the profitability of micro-CHP systems. Level 1 charging significantly reduced electricity exports and created substantial additional micro-CHP revenues of $200–$300 per year for common daily driving distances. Significant economic benefits were found over the full range of residential non-HVAC electricity consumption, clearly proving the robustness of the concept and the existence of a strong synergy between micro-cogeneration and overnight electric vehicle charging.

1. Introduction

The economic viability of micro-cogeneration (micro-CHP) systems strongly depends on the value of the co-produced electricity. In case electricity produced by the micro-CHP is used inside

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the house ('behind the meter'), the electricity has the same value as the price otherwise paid to the utility. If the electricity cannot be used inside the house and needs to be exported to the grid, it generally has a much lower value. For jurisdictions that do not have an active support for micro-CHP, this value could range from zero to at most the whole-sale market price.

The primary function of most micro-CHP systems applied in residences is to provide heat for space heating (SH) and for domestic hot water (DHW). The micro-CHP system generally operates under a heat-load following control strategy, which causes the system to run more in winter than in summer, and more during the night when the temperature difference with the ambient environment is larger than during the day. A large fraction of the electricity is thus produced at times when the electric load of the house is low, requiring substantial amounts of electricity to be exported with low or zero revenues.

Electric vehicles (EVs) have the potential to substantially reduce transportation related emissions and oil dependency. EVs consume considerable amounts of electricity and are mostly driven during the day and charged at home during the night. The recharging of EVs could thus be a way to drastically increase the own use of electricity produced by the micro-CHP and to boost the profitability of the system.

This article presents the results of a simulation study into the potential synergy between micro-CHP and electric vehicles. First, the simulation method and inputs are described. Then results are given for a base case without EV charging, followed by those for a number of EV charging scenarios. The article ends with conclusions on the potential benefit of EV charging for micro-CHP economics and recommendations for further research.

2. Method

2.1. Overview of study

A simulation study was performed to investigate the potential synergy between electric vehicles and micro-CHP systems. In this study, results of the whole building simulation program TRNSYS [1] regarding the operation of a micro-generation system applied in a single detached house in Ottawa, Ontario, Canada were combined with results for electric vehicle charging from the Plug-in Electric Vehicle – Charge Impact Model (PEV-CIM) [2] developed by Natural Resources Canada. Detailed measured profiles of residential electricity consumption [3] were used to determine the baseline economics of the micro-CHP system. Subsequently, the potential improvement of the profitability of the micro-CHP system was evaluated for scenarios in which it was also providing (part of the) power required to recharge electric vehicles with different driving and charging characteristics. Finally, a sensitivity study was performed to investigate the influence of the amount of excess micro-CHP available on the economic benefit of overnight EV charging.

2.2. Micro-CHP simulations

A detached house situated in Ottawa, Ontario, Canada was simulated in TRNSYS [1] using standard weather data [4]. The house had a space heating load of 77 GJ/year, which is equal to that of the average Canadian detached house [5]. The annual load for domestic hot water (DHW) was 17 GJ.

The heating loads for SH and DHW were met by an Internal Combustion Engine (ICE) based micro-cogeneration system. Fig. 1 displays a schematic overview of the total micro-CHP system.

The ICE is the core of the micro-CHP system and the main heating source for the house. It provides its heat to a 284-L DHW storage tank through an immersed heat exchanger. The 284-L tank

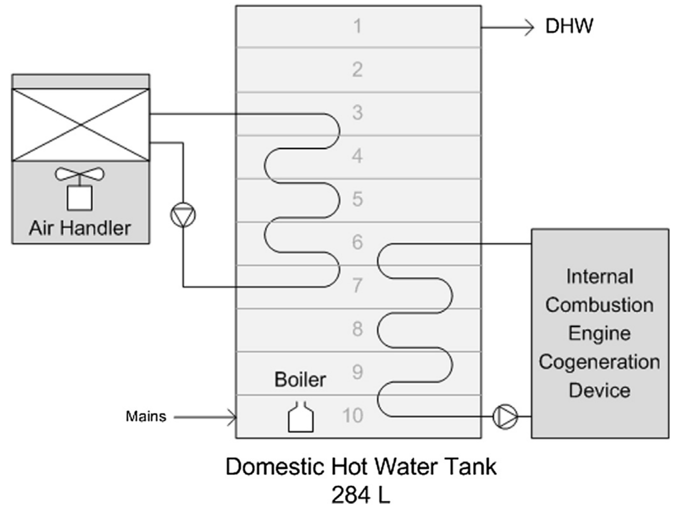

Fig. 1. Schematic overview of the integration of the ICE-based micro-CHP unit, the DHW storage tank and the air handler.

is one of the bigger standard size tanks. It was selected for this study to balance the desire for increased heat storage potential for the micro-CHP system with a reasonable space requirement when installed in a house. A second heat exchanger in the tank allows heat to be extracted for space heating through a hot water-fed air handler. The ICE is operated in a heat load following mode. It is activated when the temperature of the water in the storage tank falls below 54 °C and runs until the water temperature reaches 90 °C. The storage tank is also equipped with a back-up heater ('Boiler' in Fig. 1) to provide additional heat in case the ICE is not able to keep the DHW water at the desired temperature level.

An ICE with an electrical capacity of 2 kWe and a thermal output of 5.4 kWth was selected for the micro-CHP system, because the thermal output of the ICE would be a good match for the total heat demand for SH and DHW. The storage tank in the system would allow the ICE to run for extended periods, thus maximizing performance by reducing cycle losses. The main characteristics of the micro-CHP system are given in Table 1.

In IEA/ECBCS Annex 42, a model for a combustion-based micro-cogeneration device was developed and implemented in several whole building simulation programs [6]. The model was recently calibrated against data of a 6 kWe ICE system [7]. However, no calibration for a 2 kWe device could be found in the literature. As the micro-CHP system was configured to run in long operating cycles, the dynamic behaviour of the system would be less important than its steady state performance. It was therefore deemed acceptable to create a 2 kWe model by adjusting the parameter set of the 6 kWe device to give steady state results conform the values presented in Table 1, while keeping the dynamic behaviour (start-up and cool-down periods) similar to that of the 6 kWe unit. This

Table 1
Characteristics of the micro-CHP device and the back-up burner ('boiler').

	Fuel	Capacity (kW) or efficiency (%HHV)
Micro-CHP (ICE)	Natural gas	
Electric power		2.0 kW
Electrical efficiency		23%
Thermal power		5.4 kW
Thermal efficiency		62%
Back-up burner	Natural gas	
Thermal power		29 kW
Thermal efficiency		85%

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