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Electric storage in California's commercial buildings

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HIGHLIGHTS

- We model distributed energy resources (DER) at commercial buildings in California as a MILP.
- Consider EVs/stationary storage, which can be used by an EMS for demand response.
- Minimize energy costs and CO_2 emissions for 139 representative commercial buildings.
- Report on the aggregated cost and CO_2 savings for the state of California.
- Show the basic interactions between DER technologies (PV, EVs, CHP, etc.).
- That EV adoption is basically driven by cost measures and not CO_2 reduction goals.

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ABSTRACT

Most recent improvements in battery and electric vehicle (EV) technologies, combined with some favorable off-peak charging rates and an enormous PV potential, make California a prime market for electric vehicle as well as stationary storage adoption. However, EVs or plug-in hybrids, which can be seen as a mobile energy storage, connected to different buildings throughout the day, constitute distributed energy resources (DER) markets and can compete with stationary storage, onsite energy production (e.g. fuel cells, PV) at different building sites. Sometimes mobile storage is seen linked to renewable energy generation (e.g. PV) or as resource for the wider macro-grid by providing ancillary services for grid-stabilization. In contrast, this work takes a fundamentally different approach and considers buildings as the main hub for EVs/plug-in hybrids and considers them as additional resources for a building energy management system (EMS) to enable demand response or any other building strategy (e.g. carbon dioxide reduction). To examine the effect of, especially, electric storage technologies on building energy costs and carbon dioxide (CO_2) emissions, a distributed-energy resources adoption problem is formulated as a mixed-integer linear program with minimization of annual building energy costs or CO_2 emissions. The mixed-integer linear program is applied to a set of 139 different commercial building types in California, and the aggregated economic and environmental benefits are reported. To show the robustness of the results, different scenarios for battery performance parameters are analyzed. The results show that the number of EVs connected to the California commercial buildings depend mostly on the optimization strategy (cost versus CO_2) of the building EMS and not on the battery performance parameters. The complexity of the DER interactions at buildings also show that a reduction in stationary battery costs increases the local PV adoption, but can also increase the fossil based onsite electricity generation, making an holistic optimization approach necessary for this kind of analyses.

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1. Introduction

In the past years considerable progress in battery technology has been made. This led to significant improvements in the technical characteristics and costs of batteries [1]. This improvement has amplified their field of application. High performance batteries found their way into the automotive field, where they are forming

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the core of advanced propulsion technologies such as hybrid, plug-in hybrid or pure electric power train systems. They also increased their relevance as stationary energy storage devices for power systems applications. Stationary batteries, whose application field used to be limited to islanded networks and buildings without grid connection, can now become more relevant for energy management in buildings and microgrids with e.g. installed Photovoltaic (PV) [2].

This paper analyses the effect of this progress on local power system applications including both stationary and mobile battery storage, using the Distributed Energy Resources Customer Adoption Model (DER-CAM) [3–6]. DER-CAM is a mixed integer linear program (MILP) that defines optimal adoption and use of distributed energy resources (DER) in a microgrid or building complex in order to minimize costs or CO_2 emissions. A microgrid is a group of interconnected loads and DERs within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. More detailed information on microgrids can be found in [7]. Berkeley Lab has been developing the DER Customer Adoption Model (DER-CAM) for more than 10 years and its basic mathematical formulations are documented for example in [6,15]. Its optimization techniques find both the combination of equipment and its operation over a typical year to minimize the site's total energy bill or CO_2 emissions, typically for electricity plus natural gas purchases and for amortized equipment purchases. This model outputs the optimal distributed generation (DG) and storage adoption combination and an hourly operating schedule, in addition to the resulting costs, fuel consumption, and CO_2 emissions. This work uses the latest DER-CAM version, which enables EVs and looks into the interaction of electric storage with other DERs as e.g. photovoltaic (PV) or combined heat and power (CHP) in commercial buildings and microgrids, assuming different technical characteristics for future years. Thus, the main objective of this paper is to determine the economic and environmental impact of building connected electric cars and stationary storage in California. For this purpose, the California End-Use Survey (CEUS), which holds approximately 2700 building load profiles for the commercial sector in California [16] was used as basic input data. These hourly load profiles are needed to make optimal decisions on the operation of the DG equipment and EVs, which influence the optimal DG investment capacities because DER-CAM considers amortized investment and operation costs. A subset of 139 representative building load profiles for buildings with electric peak loads ranging between 100 kW and 5 MW are used as input for DER-CAM. These 139 buildings account for approximately 35% of total statewide commercial sector electric sales [4]. These load profiles, combined with technology costs and performance data, will serve as input for DER-CAM, and DER-CAM will then determine the optimal adoption of DER and usage of stationary and mobile storage on a building level in 2020. DER-CAM will act as simulated building energy management system (EMS), which can use the EVs connected to the buildings for load shifting. To take into account potential improvements of battery technologies, the robustness of the results with respect to changes in storage specific parameters, such as charging and discharging rates and efficiencies are analyzed in detail, and the interaction with other DERs is shown.

Several papers analyze the effect of renewable energy sources and EVs on the power grid and electricity prices. The possibility of providing macro-grid ancillary services and storage capabilities by usage of plug-in hybrid electric vehicles (PHEVs) is analyzed in [8]. Refs. [9,10] analyze the impact of EVs on the macro-grid load and electricity prices. Ref. [11] looks into different battery technologies suitable for renewable technologies as PV and also how these technologies can be assessed on a technical level by Simulink [12] or Homer [13]. In contrast, this work and DER-CAM uses a building-centric economic and environmental approach since buildings establish the link between EVs and the wider macro-grid and looks into the cost and CO_2 benefits for buildings adopting DERs in California. This building-centric approach implies that every single building is optimized individually based on the building owners expectations and views. Furthermore, many DERs in a building will be influenced by EV batteries. Also, stationary storage in buildings attracts more research attention, which can create competition between mobile storage and stationary storage. On the other hand, when mobile storage is not suitable for EV usage anymore, it can be recycled and used as stationary storage in buildings, where the battery specifications can be relaxed. This post-vehicle ''battery-to-grid'' application of EV batteries attracts the attention of researchers and the California Energy Commission (CEC), which may also create opportunities for EV batteries [14]. The DER-CAM building-centric approach allows us to use it as EMS emulator and the building can use the mobile storage and stationary storage for tariff-driven demand response. By using EVs connected to the buildings for energy management, the buildings could arbitrage their costs. However, with this approach we do not optimize storage technologies in isolation and treat all possible building DERs as equal options. In this way it is possible to model interactions and competition between DER technologies and interesting effects can be seen. For example, [17] shows that PV and stationary storage can be in competition depending on the optimization strategy (costs versus CO_2). Voltage and Var support is not considered in this work, but currently under design in DER-CAM. Also, this work assumes a deterministic view of the future and does not consider uncertainty in e.g. driving patterns. Thus, the results presented in this work should be interpreted as an average or benchmark case given planned behavior or driving patterns. A full stochastic based version of DER-CAM is currently under development.

The paper is structured as follows:

- Section 2 shows the basic methodology of DER-CAM and focuses particularly on aspects related to the adoption and use of electric storage capacities.
- Section 3 presents the input data used for the analysis, focusing especially on techno-economic specifications of electric storage technologies.
- Section 4 illustrates and discusses the results of the analysis.
- Section 5 draws conclusions.

2. Methodology

2.1. DER-CAM

DER-CAM is a mixed-integer linear program (MILP) written and executed in the General Algebraic Modeling System (GAMS). Its objective is typically to minimize the annual costs or CO_2 emissions for providing energy services to the modeled site, including utility electricity and natural gas purchases, plus amortized capital and maintenance costs for any DG investments. The approach is fully technology-neutral and can include energy purchases, on-site conversion, both electrical and thermal on-site renewable harvesting, and partly end-use efficiency investments. Its optimization techniques find both the combination of equipment and its operation over a typical year that minimizes the site's total energy bill or CO_2 emissions, typically for electricity plus natural gas purchases, as well as amortized equipment purchases. It outputs the optimal DG and storage *adoption* combination *and* an hourly *operating schedule*, as well as the resulting costs, fuel consumption, and CO_2 emissions. Furthermore, this approach considers the simultaneity of results. For example, building cooling technologies are chosen such that results reflect the benefit of electricity demand displacement by heat-activated cooling, which lowers building peak loads and, therefore, the on-site generation requirement, and also has a