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Environmental Energy
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Disclaimer

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The added economic and environmental value of plug-in electric vehicles connected to commercial building microgrids[1]

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ABSTRACT

Connection of electric storage technologies to smartgrids or microgrids will have substantial implications for building energy systems. In addition to potentially supplying ancillary services directly to the traditional centralized grid (or macrogrid), local storage will enable demand response. As an economically attractive option, mobile storage devices such as plug-in electric vehicles (EVs) are in direct competition with conventional stationary sources and storage at the building. In general, it is assumed that they can improve the financial as well as environmental attractiveness of renewable and fossil based on-site generation (e.g. PV, fuel cells, or microturbines operating with or without combined heat and power). Also, mobile storage can directly contribute to tariff driven demand response in commercial buildings. In order to examine the impact of mobile storage on building energy costs and carbon dioxide (CO_2) emissions, a microgrid/distributed-energy-resources (DER) adoption problem is formulated as a mixed-integer linear program with minimization of annual building energy costs applying CO_2 taxes/CO_2 pricing schemes. The problem is solved for a representative office building in the San Francisco Bay Area in 2020. By using employees' EVs for energy management, the office building can arbitrage its costs. But since the car battery lifetime is reduced, a business model that also reimburses car owners for the degradation will be required. In general, the link between a microgrid and an electric vehicle can create a win-win situation, wherein the microgrid can reduce utility costs by load shifting while the electric vehicle owner receives revenue that partially offsets his/her expensive mobile storage investment. For the California office building with EVs connected under a business model that distributes benefits, it is found that the economic impact is very

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limited relative to the costs of mobile storage for the site analyzed, i.e. cost reductions from electric vehicle connections are modest. Nonetheless, this example shows that some economic benefit is created because of avoided demand charges and on-peak energy. The strategy adopted by the office building is to avoid these high on-peak costs by using energy from the mobile storage in the business hours. CO_2 emission reduction strategy results indicate that EVs' contribution at the selected office building are minor.

INTRODUCTION[2]

This paper focuses on the analysis of the optimal interaction of EVs with a microgrid, which may include photovoltaic (PV), solar thermal, stationary batteries, thermal storage, and combined heat and power (CHP) systems with and without absorption chillers. Definitions of a microgrid can be found at Microgrid Symposium 2005-2010, and Hatziargyriou et al. 2007. In previous work, the Berkeley Lab has developed the Distributed Energy Resources Customer Adoption Model (DER-CAM) (Stadler et al. 2008). 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[3], typically for electricity plus natural gas purchases, as well as amortized equipment purchases. It outputs the optimal Distributed Generation (DG) and storage adoption combination and an hourly operating schedule, as well as the resulting costs, fuel consumption, and carbon emissions. Figure 1 shows a high-level schematic of the complex building energy flows as modeled in DER-CAM, including the connection of electric vehicles. Since finding the best economic or environmental solution is infeasible by trial-and-error searching, an analytic approach considering the whole set of possible technologies is necessary. To assess the impact of EVs connected to buildings in 2020, an office building in Pacific Gas & Electric (PG&E) service territory is investigated with DER-CAM.

2020 EQUIPMENT OPTIONS, TARIFFS AND BUILDING ANALYZED

The menu of available equipment options, their cost and performance characteristics, the applicable PG&E tariffs for the office building and the EVs are shown in Table 1, 2, 3, and 4. Technology options in DER-CAM are categorized as either discretely or continuously sized (more information can be found at Stadler et al. 2009). As is

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[2] Please note that this paper does not assess the impact on the whole economy nor does it reflect the whole CO_2 reduction potential of EVs. This paper focuses on the impact on microgrids only.

[3] In this work we always minimize the total energy bill of the microgrid considering a CO_2 tax.

typical for Californian utilities, the electricity tariff has time-of-use (TOU) pricing for both energy and power (demand charge). Demand charges are proportional to the maximum rate of electricity consumption (kW), regardless of the duration or frequency of such consumption over the billing period. The demand charge in $/kW is a significant determinant of technology choice and sizing of distributed generation and electric storage system installations (Stadler et al. 2008). This paper analyses a San Francisco Bay Area office building with electricity and gas load profiles based on the California Commercial End-Use Survey (CEUS). The office building has a peak electricity demand of 373 kW, and yearly electricity and natural gas consumption of 1.677 GWh and 0.713 GWh, respectively. The EVs can be charged at home at night for $0.062/kWh plus any CO_2 tax (PG&E E-9).

ELECTRIC VEHICLES MODELING

EVs belong to employees who commute every weekday from home to the office building and back. The EV modeling is based on previous DER-CAM work from Momber et al. 2010 and was extended to be able to model also the impact of a CO_2 pricing scheme. The model allows the EV batteries to transfer electricity to the office and vice versa, and DER-CAM delivers the optimal charging and discharging schedule. The building energy management system (EMS) can use this additional battery capacity to lower its energy bill, and/or carbon footprint; and whenever possible, economically attractive energy from a renewable energy source or CHP system at the office building could be used to offset EV charging at home. It is assumed that the EV owner will receive exact compensation for battery degradation caused by the office building and be reimbursed for the amount of electricity charged at home and later fed into the office building. The occurring monetary charging and discharging losses as well as the decay will be covered by the building. Also, we assume that the car owner receives a connection payment of $80/year ($5 per kWh of battery capacity), which is paid by the building as an incentive to connect to the building in principle.

DESCRIPTION OF SIMULATION RUNS

To assess the interaction between EVs and the office building, a total of 24 simulations were performed. These runs are a) a *do nothing* case, where all energy is purchased from the utility, b) an *EV only* case, where EVs are the only investment option, c) an *EV&PV* case with EV and PV as possible investment options, d) an

EV&PV& stationary battery case, with EV, PV, and stationary batteries as options, e) an *everything* case with all possible DER technologies enabled, and finally f) e*verything except EV* as possible options. All these cases were performed with a CO_2 tax level of \$0/tCO_2, \$41/tCO_2, \$123/tCO_2, and \$273/tCO_2.

RESULTS

Figure 2 shows that the cost reduction by option *EV-only* is always much smaller than what could be achieved by the whole portfolio of DER technologies when CO_2 taxes are applied. Please note that the *do-nothing* and *EV-only* cases are almost identical in Figure 2. Also, the effect of EVs on CO_2 emissions is marginal or even negative when not used in combination with other carbon reducing technologies because of the very flat hourly marginal carbon emissions and battery inefficiencies (Mahone et al. 2008). This inefficiency problem can be clearly seen in Figure 3. Without any other carbon reducing technology in the investment portfolio, EV capacity always decreases with increasing CO_2 taxes. With other possible DER technologies the initial staring point in Figure 3 is lower and will only increase with very high CO_2 prices. Figure 4 clearly indicates that *EVs-only* cannot be used to decrease CO_2 emissions, regardless of the level of CO_2 tax. This is also based on the very flat hourly marginal carbon emissions and battery inefficiencies. It needs at least one carbon reducing technology, e.g. PV to be able to reduce the CO_2 emissions. However, most interesting is the finding that only with natural gas fired CHP systems can the best cost and CO_2 results be reached (see frontier *everything* in Figure 4). For each scenario and each month, the net transfer of electricity is from the residential building to the office building. In almost all cases EVs leave the office building with the minimum battery state-of-charge (SOC) of 32% (see Table 4). The PV panels and CHP technologies installed in the office building are never used to transfer energy to the residential building, even when high carbon taxes make PV more attractive. In such instances, PV is used to displace the building electricity consumption, but the charging and discharging losses make it economically unattractive to use office building PV to charge EV batteries and then to use it in the residential building. In some runs, EVs batteries absorb electricity from PV or CHP during the morning or early afternoon and send it back to the office building a few hours later, and therefore reducing the on-peak related demand and energy costs (see Figure 6).

CONCLUSIONS

Although EVs can be charged at home for only $0.062/kWh, the charging and discharging losses and battery degradation compensation increases the real cost seen by the office building. However, EVs are effectively used by the EMS to mitigate demand charges. But since EVs connection schedule only approximately matches the building load profile, the shaving potential remain small, as shown in Figure 5. On the other hand, PV and stationary batteries more closely follow the load profile, and therefore, PV panels and stationary batteries, which are available 24 hours a day, are more efficient at mitigating demand charges (see Figure 6). Finally, since the marginal CO_2 emissions from the macrogrid remain relatively constant throughout the day, no massive CO_2 reduction can be expected by charging EV batteries at home during the night and discharging them during office hours at the office building. If the macrogrid CO_2 emissions would show a bigger difference between day and night hours, there would be a greater potential for CO_2 emissions reduction due to EVs.

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Figure 1. Schematic of the Energy Flow Model used in DER-CAM

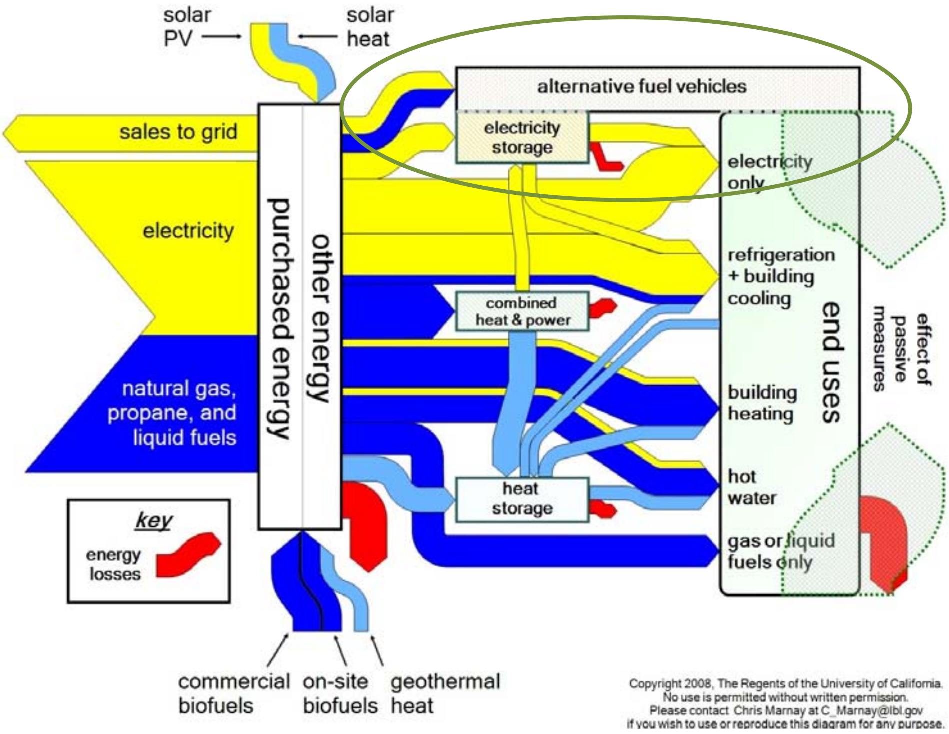

Table 1. Available Equipment Options in 2020, Discrete Investments

	capacity (kW)	installed costs (US$/kW)	installed costs with heat recovery (US$/kW)	variable maintenance (US$/kWh)	electric efficiency (%), (HHV)	life-time (a)
ICE[4]-small	60	2721	3580	0.02	0.29	20
ICE-med	250	1482	2180	0.01	0.30	20
GT	1000	1883	2580	0.01	0.22	20
MT-small	60	2116	2377	0.02	0.25	10
MT-med	150	1723	1936	0.02	0.26	10
FC-small	100	2382	2770	0.03	0.36	10
FC-med	250	1909	2220	0.03	0.36	10

Source: Stadler et al. 2009

Table 2. Available Equipment Options in 2020, Continuous Investments

	thermal storage	absorption chiller	solar thermal	photo-voltaics	stationary battery
intercept costs (US$)	10000	93912	0	3851	295
variable costs (US$/kW or US$/kWh)	100 US$/kWh	685 US$/kW[5]	500 US$/kW	3237 US$/kW	193 US$/kWh
lifetime (a)	17	20	15	20	5

Source: Stadler et al. 2009

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[4] ICE: Internal combustion engine; GT: Gas turbine; MT: Microturbine; FC: Fuel cell; Technologies with heat recovery can utilize waste heat for heating or cooling purposes.

[5] In kW electricity of an equivalent electric chiller.

Table 3. Estimated PG&E Commercial Energy Prices for Office Building in 2020

Electricity	Summer (May – Oct.)		Winter (Nov. – Apr.)	
	electricity (US$/kWh)	**demand (US$/kW)**	**electricity (US$/kWh)**	**demand (US$/kW)**
non-coincident	na	10.27	na	5.76
on-peak	0.16			
mid-peak	0.14		0.11	
off-peak	0.13		0.10	
fixed (US$/month)	118.28			

summer on-peak: 12:00 – 18:00 during weekdays
summer mid-peak: 08:00 – 12:00 and 18:00 – 21:00 during weekdays
summer off-peak: 21:00 – 08:00 during weekdays and all weekends and holidays
winter mid-peak: 06800 – 21:00 during weekdays
winter off-peak: 21:00 – 08:00 during weekdays and all weekends and holidays

Natural Gas	
0.042	US$/kWh
64.48	fixed (US$/month)

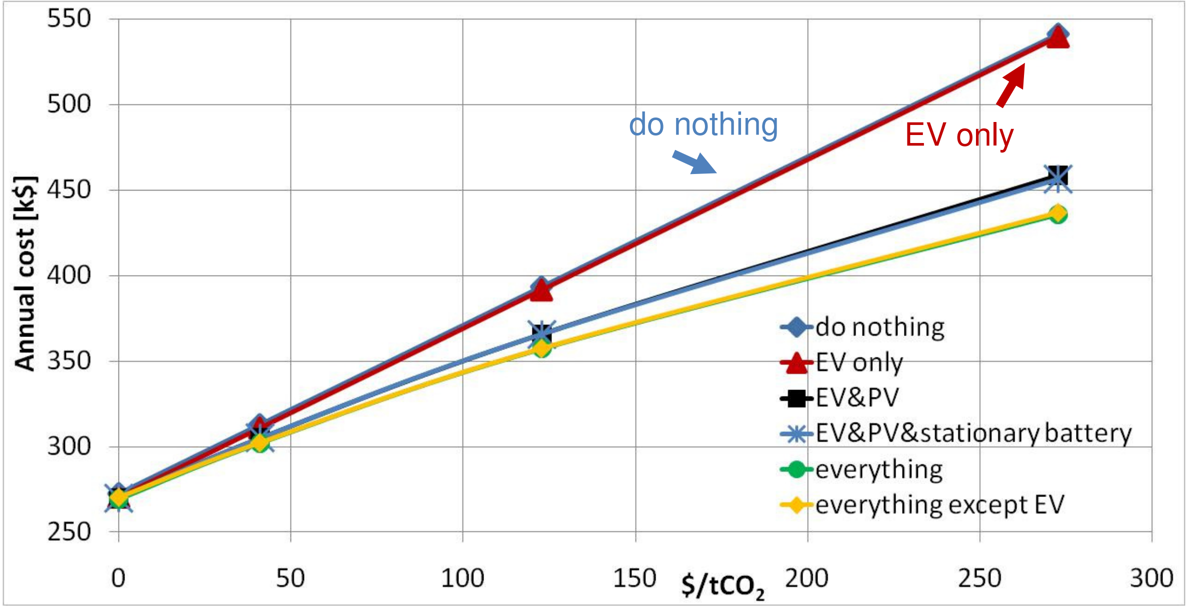
Source: PG&E Tariffs and own calculations

Table 4. EV Schedule and Battery Specifications

EV-building connection period	9am – 6pm
EV-home connection period	8pm – 7am
EV battery state-of-charge (SOC) when arriving at the building	73%
EV battery SOC when leaving the office building	>=32%
EV battery charging efficiency	95.4%
EV battery discharging efficiency	95.4%
EV battery hourly decay	0.1% [of stored electricity]
EV battery capacity	16 kWh
Maximum EV battery charging rate	0.45 [1/h]

Source: Momber et al. 2010 and own assumptions

Figure 2. Annual Building Energy Costs[6] vs. CO_2 Tax for the 24 Runs



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[6] Including amortized capital costs for investments.

Figure 3. EV Capacity vs. CO_2 Tax

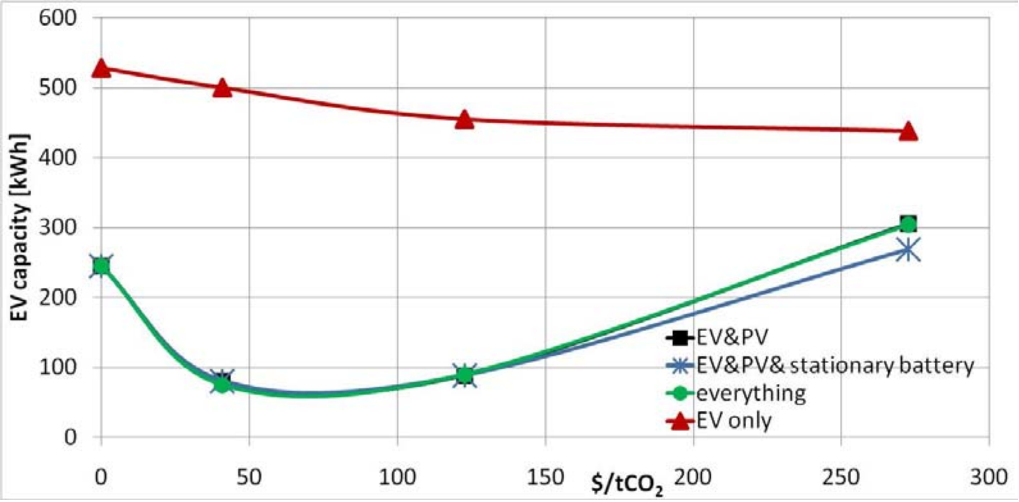

Figure 4. Annual Building Energy Costs and CO_2 Emissions subject to CO_2 Tax

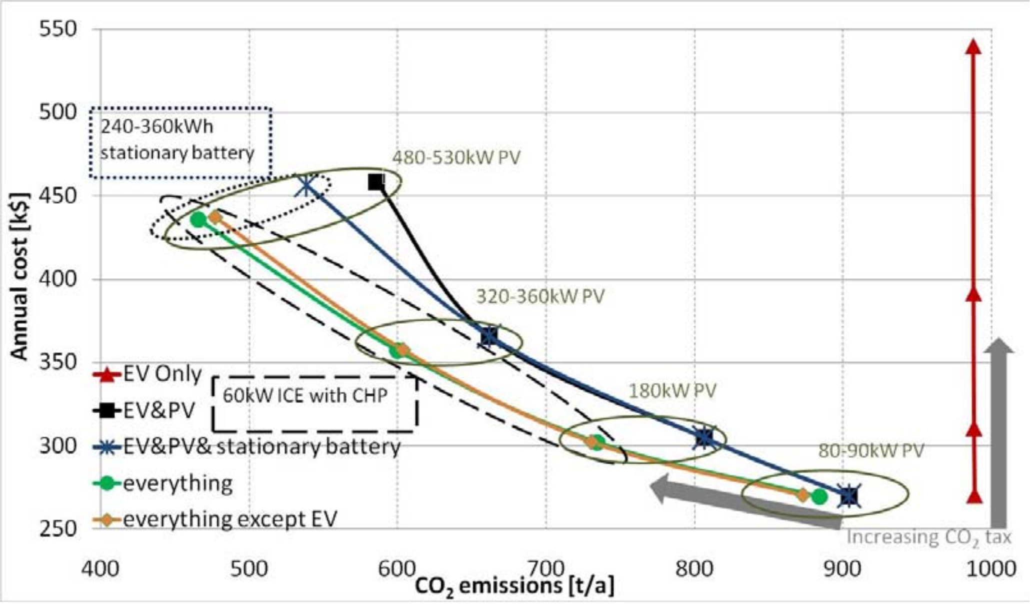

Figure 5. Diurnal Electricity Pattern for a July Weekday, CO_2 Tax of \$41/tCO_2, *EV only* case

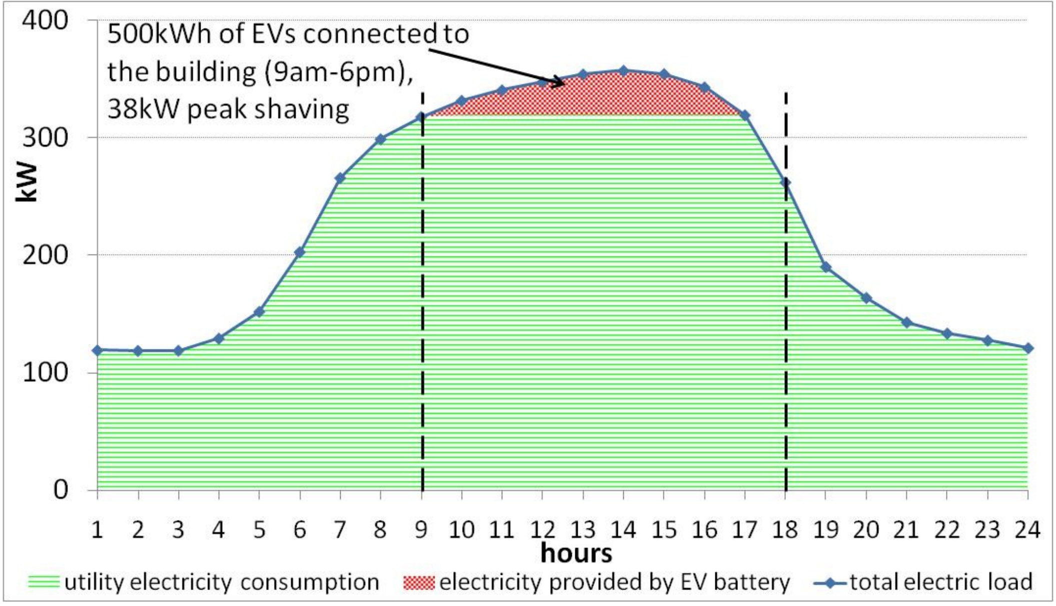

Figure 6. Diurnal Electricity Pattern for a July Weekday, CO_2 Tax of \$273/tCO_2, *EV&PV& stationary battery* Case