Modeling of Plug-in Electric Vehicles' Interactions with a Sustainable Community Grid in the Azores

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ABSTRACT

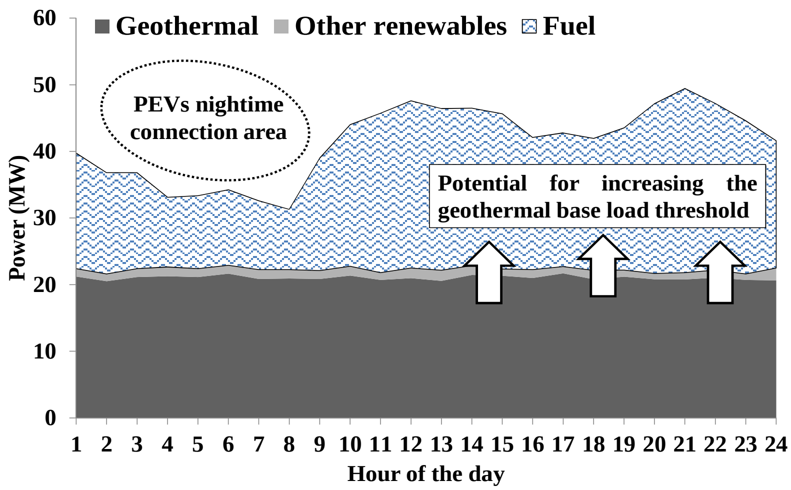
This paper extends ongoing Integrated Community Energy Systems (ICES) analysis on the Azores Archipelago conducted by the MIT Portugal Program. A key technology for ICES are microgrids, systems capable of sustaining electricity, heat and cooling supply and of islanding during macrogrid outages. Additionally, past research results have suggested that plug-in electric vehicles (PEVs) can play an important role in the energy management of microgrid systems. PEVs can be considered as mobile storage devices and are direct competitors of conventional storage and stationary generation sources. Understanding the interactions between PEV batteries and microgrids, together with the role of demand response as a strategy for energy management, constitutes the main contribution of this paper. The case-study put into practice is the Azorean island of São Miguel. The analysis of the economic and environmental impacts of PEV interactions with services buildings microgrids is performed by using an extended version of the Distributed Energy Resources Customer Adoption Model (DER-CAM). The cost minimization optimization results show that PEVs are typically used to transfer low cost electricity from the residential building to the services buildings to avoid high demand and volumetric energy charging during expensive day hours. Office and Health facilities seem to constitute attractive options for economically-sound PEVs adoption. Additionally, GHG emissions reduction potential exists, mainly due to reduced utility purchases by investment in additional PV and battery storage.

Introduction

The Green Islands Project, part of the MIT Portugal Program, aims to provide the people of the Azores with a fully-functional sustainable energy system, which should be able to satisfy the growing energy demand of populations by maximizing the use of local resources and promoting energy autonomy in the archipelago. Integrated in the Green Islands framework, the New Energy Systems project explores innovative methods and tools suitable to the design of Integrated Community Energy systems (ICES) in the Azores. Its main purpose is to demonstrate that an adequate mix of technologies under the appropriate management strategies could contribute to develop ICES, in which supply and demand can meet dynamically. Previous work (Mendes, Ioakimidis, & Ferrão 2011) has suggested the Distributed Energy Resources Customer Adoption Model (DER-CAM) as a viable tool for this purpose. It features a robust and flexible mixed-integer linear optimization algorithm and can be used for exploring ICES design modeling. ICES are to be conceived in a way that they can meet energy needs economically, attaining at the same time beneficial environmental impacts. In that sense, the adoption of not only renewable energy systems but also of highly efficient distributed generation sources such as fuel cells and microturbines, coupled with innovative energy storage solutions, including Plug-in Electric Vehicles (PEVs) are options to consider. Key technology to ICES are microgrids, locally controlled and organized groups of electricity generation, storage and concurrent loads (normally under 1 MW) that operate together in a grid-connected fashion through a single point of common coupling and being able to isolate from the main grid (the macrogrid). From the technical point of view in this paper, PEVs are perceived as an additional distributed asset in forms of mobile storage of electricity, eventually available in a microgrid system. Recent research (Momber et al. 2010; Stadler et al. 2010, 2011, 2012) has been demonstrating the operation of PEVs in combination with stationary storage and electric distributed resources such as PV, internal combustion engines, microturbines and fuel cells. Mobile storage can directly contribute to tariff driven demand response in commercial buildings. PEVs connected to the buildings inner electricity system can aid in the energy management of the facility, i.e. PEV batteries can transfer electricity to the commercial building and vice versa. The building energy management system (EMS) can use this additional battery capacity to lower its energy bill and to some extent the carbon footprint. Also, whenever possible, economically attractive energy from a renewable energy source or CHP system at the building could be used to offset EV charging at home. It is important to note that technically, the link between a microgrid and an electric vehicle can create a win-win situation, wherein the microgrid can reduce utility-related costs by load shifting while the electric vehicle owner receives revenue that partially offsets the investment in mobile storage. Preliminary work done for certain types of buildings (Momber et al. 2010; Stadler et al. 2010, 2011) has suggested that the economic impact is limited relative to the costs of mobile storage for the site analyzed, i.e. cost reductions from electric vehicle connections for car owner are modest in principle. In Stadler et al. 2011 the results show also that demand charges in $/kW (monthly or daily) as well as the on-peak energy costs are determinants for the technology choice and sizing. In developed countries, the transportation and electric power sector contribute to the large majority of CO_2 emissions, and in this context, PEVs correspond to a transportation technology which deserves proper consideration due to its great potential for reducing vehicle emissions and oil dependence. Vehicles are parked about 93%-96% of their life time (Turton & Moura 2008) constituting an idle asset with associated maintenance, insurance and parking costs. By connecting PEVs to the grid, a dispatchable power provision resource may be created to assist in its stabilization. PEVs could be charged in principle during off peak hours with cheaper base load or intermittent renewable generation and be used as a storage system during the day parking hours or during low demand times especially to match the demand during expensive peak hours from both the volumetric and demand charging point of view. However, in this work we do not assume such strategies and let DER-CAM decide to find the optimal charging and discharging strategy depending on the objective function (costs versus CO_2). Such a vision considers then, bidirectionality of energy flows between PEVs and the grid. The Portuguese Azores´s archipelago is located in the Atlantic Ocean, about 1,500 km west of Portugal and 3,900 km east of the USA. São Miguel is the largest of the nine islands, with about 140 000 inhabitants. The islands are very dependent on fossil fuels import, which represents 90% of the total primary energy needs in the archipelago. In the case of São Miguel, there is substantial use of renewable energy for electricity generation, such as geothermal (42%) and in a less extent small hydro and biomass (5%), being the remaining 53% of the electricity produced by burning fuel-oil. In the overall, there is still a large dependence of total primary energy on oil (87%) with

53% of these used in electricity production and 47% used solely in the transportation sector, in the form of diesel and gasoline. Diesel and gasoline vehicles on the island are over 50 000 units.

Figure 1. Daily Electricity Generation Profile in the Island of São Miguel (An Example May Day).



Source: Adapted from SOGEO 2010.

This study looks at the whole cycle of potential optimal interactions between PEVs and building complexes of different typologies in the Azorean context as a strategy to increase the use of renewable energy sources, which are available (geothermal and hydro) but that are not currently used at its full potential due to technical difficulties in balancing the electrical grid. The integration of PEVs in the island's electrical system brings the possibility of increasing the usage of the existing geothermal resource by enhancing its base generation load (see Figure 1). Additionally, in systems such as São Miguel, strongly dependent on fossil fuel imports, PEVs have the particular importance of reducing the carbon footprint associated with the fuel consumption of the vehicles fleet. Also, typically lower driving distances in which island inhabitants incur, are fit to current PEV battery technology limitations. The approach can consider off-peak charging at home during the night and energy transfer to and from the commercial buildings during the day while the PEV owners are at work and connected to the commercial building. However, DER-CAM will decide on what source and building to use for charging. In other words, a certain state of charge (SOC) is required when leaving the commercial building and DER-CAM can decide if the commercial building and maybe an installed PV system will charge the PEV or if the PEV will be charged at the residential building during off-peak hours. This paper aims at the validation of the economic and environmental rationales of such exchanges. The case study is based on real data from a selected neighborhood in the island of São Miguel, the Azores. Additional services buildings load data as well as updated technology specifications have been collected from Portuguese energy services companies.

Methodology

This chapter describes the methodological developments to make use of the DER-CAM tool, an optimization program initially created by researchers from the Lawrence Berkeley

National Laboratory (LBNL) (Momber et al. 2010; Stadler et al. 2012,). Particular attention is also made to the technical approach as well as to the case-study description.

Problem Formulation

DER-CAM finds the total energy costs (TEC) minimizing combination and operation profiles of a set of distributed generation technologies that meet a building's heat and power loads over a typical year. The tool solves a mixed integer linear program, which is written in the General Algebraic Modeling System (GAMS[1]). In this work, DER-CAM is used to find the optimal charging and discharging schedule for PEV batteries. The PEV approach followed in this paper assumes that the vehicle owners will receive monetary compensation for battery degradation caused by the increased charging/discharging cycles by the services building EMS. DER-CAM considers that the owner is reimbursed for the amount of electricity charged at home and later fed into the services building. If the PEV owner charges its vehicle at the building, he/she needs to pay for the electricity. DER-CAM's cost minimization[2] objective function is expressed below in equations 1, 2, 3 and 4. To the summed-up technology, electricity, fuel, demand response and battery degradation costs, sales to the macrogrid operator are subtracted. Particularly, the models that define the cost of energy exchanges with the PEV and the accelerated battery degradation are described by equations 3 and 4. Please note that the following code just describes the commercial building optimization, which serves as host for PEVs. A detailed description of the mathematical formulation can be found at Stadler et al. 2012.

$$C_{total} = C_{DG} + C_{elec} + C_{fuel} + C_{DR} + C_{evbat} - \sum_m \sum_h S_{m,h} \tag{1}$$

$$C_{elec} = \sum_m \sum_h \left(C_{fix_m} + C_{\text{var}m,h} + C_{EV\,m,h} \right) \tag{2}$$

$$C_{EV\,m,h} = P_{EV} \cdot \left(\frac{E^{r \to c}{}_{m,h}}{\eta_c} + E^{c \to r}{}_{m,h} \cdot \eta_{dc} \right) \tag{3}$$

$$C_{evbat} = E_{EV} \cdot CL \cdot RC_{bat} \tag{4}$$

C_{total} are the total annual energy costs (TEC) of the commercial building, (USD),

C_{DG} are the total capital costs for distributed generation technologies, (USD),

C_{elec} is the total sum of electricity costs at the commercial building, (USD),

C_{fuel} is the total sum of fuel costs (including fuel for distributed generation in the commercial building), (USD),

C_{DR} is the total sum of demand response-related costs, (USD),

[1]GAMS is a proprietary software product used for high-level modeling of mathematical programming problems. It is owned by the GAMS Development Corporation (http://www.gams.com) and is licensed to Instituto Superior Técnico.

[2]An environmental objective function is also available in DER-CAM and has been used in the past. Previous research (Stadler et al. 2011; Stadler et al. 2012) has shown that PEV adoption is mainly driven by cost reduction objectives rather than by environmental improvements. Although the main focus is on cost reduction optimization, the authors still pay attention to environmental improvements in these papers.

C_{evbat} corresponds to the total sum of PEV battery degradation costs, (USD), caused by additional usage due to the commercial building managements system

$S_{m,h}$ is the total amount of electricity that is sold to the macrogrid, (USD),

C_{fix}, C_{var} are the fixed, variable electricity costs (volumetric, demand charges), (USD),

$C_{EV\,m,h}$ are the total amount of electricity costs associated with PEVs, (USD),

P_{EV} is the price at which electricity is being exchanged with the PEV and the building, (USD/kWh)

$E^{r\rightarrow c}{}_{m,h}$ corresponds to the electricity flow from residential building to the car, (kWh)

$E^{c\rightarrow r}{}_{m,h}$ is the electricity flow from the car to the residential building, (kWh)

η_c and η_{dc} are the dimensionless PEV battery charging and discharging efficiencies,

E_{EV} is the total annual electricity exchange between PEVs and the commercial building, (USD),

CL is the dimensionless capacity loss factor,

RC_{bat} is the replacement cost of the PEV battery, (USD),

m and h are to the month (1..12) and hour (1..24) equation indices.

Additionally, area constraints for the maximum possible PV and solar thermal adoption are considered[3]. This constraint has a significant impact on DG adoption and operation and can drive up building energy costs. This work also reports on the environmental impact of the connection of PEVs to services buildings. The marginal GHG emissions when the PEVs are plugged in at residential buildings for charging are tracked as this is necessary to be able to calculate the proper GHG emissions changes in the services buildings. For improved emissions analysis, the authors use in DER-CAM appropriately balanced composite greenhouse gases (GHG) emission factors in CO_2 eq. units, which take into account emissions from the three most relevant GHG, CO_2, N_2O and CH_4 respectively. This is done through evaluation of global warming potential indexes for each emitting air pollutant[4].

Case-Study Definition

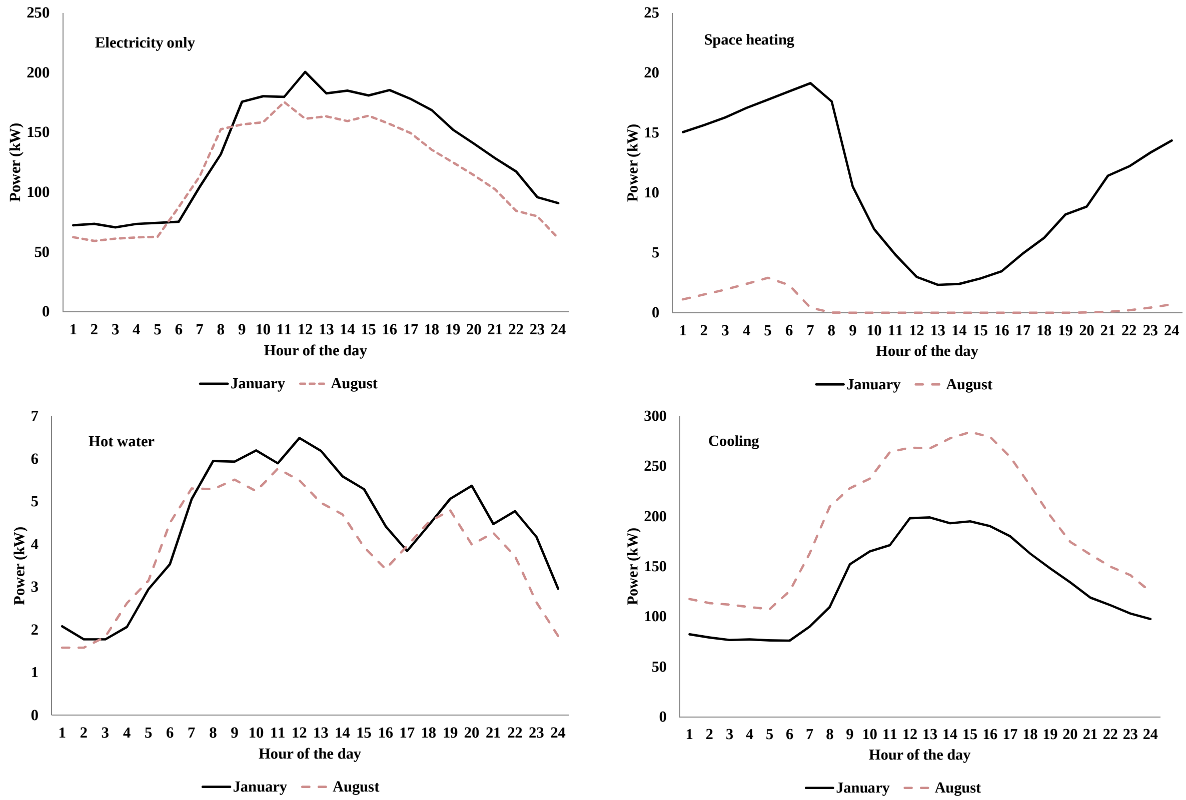
In this case-study of São Miguel, the main island of the Azores, it is considered that the inhabitants of a residential neighborhood in the Azores are available for switching their diesel and gasoline-fueled cars to PEVs. A scenario is analyzed where these PEVs are used for daily transportation to work. PEV owners can charge their vehicles at the residential building at special PEV charging tariffs. When connected to the service/commercial buildings, the buildings' EMS can use the mobile storage units for energy management purposes. The focus is on four types of services multi-building complexes: Educational, Health, Office and Lodging. Offices and Education facilities are mainly daily loads, with typically higher costs with on-peak energy charging. Health and Lodging building complexes are significantly more stable loads during the 24h period but for instance Health has massive electricity-only critical requirements. In this analysis it is assumed that: 1) PEVs can be charged at home from 20h to 7h and that the vehicles remain parked at work from 9h to 18h. 2) No car leaves home with the battery state-of-charge (SOC) under 72% and when leaving the services buildings, all cars have at least 32% of battery SOC left to make it home. Services buildings load data was obtained through

[3]Education, lodging and offices: 2500m^2, health facilities: 5000m^2, residential neighborhood: 1000m^2.

[4] Global warming potentials: CO_2=1, CH_4 =21 , N_2O=310.

collaborative research with a Portuguese energy services company, which includes large volumes of information from services buildings energy audits, for multiple typologies and different sizes. The energy simulation software tool Visual DOE 4.1.2 was used to access each one of the specific building models and obtain the required hourly reports, inputs to DER-CAM. Figure 2 shows some examples of the typical load profiles used in this work.

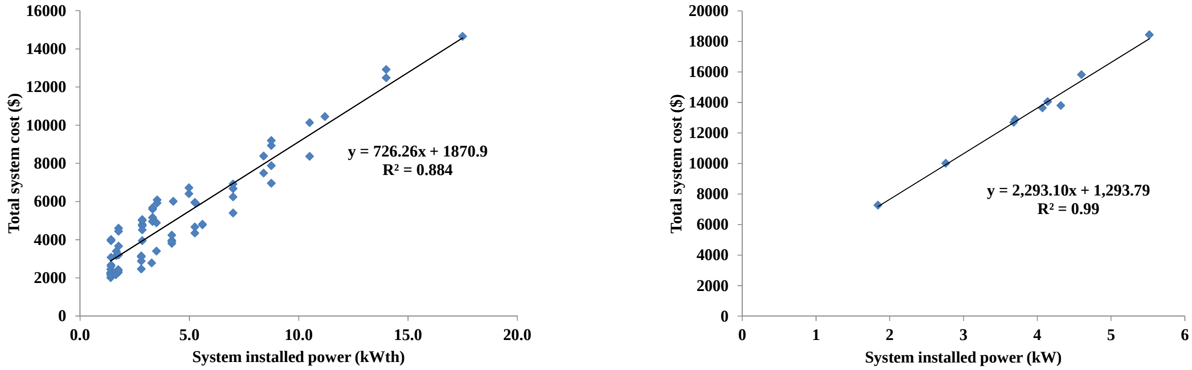
Figure 2. Example daily load profiles based for the health facility.



The DER-CAM model was used to identify optimal technology combinations that guarantee the system self-sufficiency at minimum costs. The technology-choice optimization considers that the critical loads of each building complex are to be satisfied in the event of a macrogrid failure, i.e. they are able to operate as isolated systems if needed. This constraint will influence the results and force DG technologies into the solution to sustain a grid disturbance.

The solar energy technology turn-key costs assessment for updating cost data with Portuguese market prices is shown in Figure 3. In the case of solar thermal, the cost curve was designed based on 85 different suppliers. The photovoltaics regression relies on data of 9 suppliers only; however a high R^2 provides statistical confidence for using the resulting cost equation. The electricity tariffs considered in this work were collected from EDA, the Azorean utility. Time-of-use tariffs are used for all typologies. In the case of the residential neighborhood, installed power meter varies from the large majority of the standard 3.45kVA to a few houses with 17.25kVA. The residential tariff in use is the standard low-voltage with three period TOU (BTN tri-horária) with volumetric energy costs ranging from 0.11$/kWh during off-peak periods to 0.23$/kWh in the most expensive hours. The service (commercial) buildings are served with the medium voltage four period TOU tariff with daily demand on-peak charging (MT tetra-horária). Volumetric costs range between the 0.08$/kWh and the 0.18$/kWh throughout the 24h of the day. The daily demand charge of 0.47$/kW applies from 9:30 to 11:00h and from 17:30h to 20:00h during the winter and from 9:00 to 11:30h and from 19:30h to 21:00h during summer time. Natural Gas is inexistent in São Miguel. Instead, channeled liquefied petroleum gas (LPG), namely butane, is provided to a wide range of customers at a tariff whose maximum value is set by the governmental authorities. Residential customers can have it at a cost of 0.14$/kWh. For bigger installations such as services buildings, the volumetric cost per kWh lowers to 0.13$. A PEV energy exchange tariff of 0.06$/kWh is put into use. Such a tariff is still not implemented in Portugal, however it is assumed a scenario where PEVs can exchange cheap electricity from must-take renewable generation during off-peak periods. The technical and economic details of the equipment which is available in DER-CAM runs, including the PEV batteries characteristics, are displayed in Tables 1 to 4.

Figures 3a and 3b - Regression Analysis of Turnkey Costs for Solar Energy Thermal and Photovoltaics Installations in the Portuguese Market Context



a) solar thermal   b) PV

Table 1 - Technical and Economic Characteristics of DG/CHP Technologies Considered in the Commercial Building Optimization (Goldstein et al., 2003 and Own Calculations)

	ICE		MT		FC	
	S	M	S	M	S	M
Capacity (kW)	60	250	60	150	100	250
Capital cost ($/kW)	3580	2180	2377	1936	2770	2220
Maint. cost ($/kWh)	0.02	0.01	0.02	0.02	0.03	0.03
Electrical Efficiency (%)	29	30	25	26	36	36
Heat to Power Ratio	1.73	1.48	1.80	1.40	1	1
Lifetime (years)	20	20	10	10	10	10

Notes: all technologies with CHP capabilities and running on LPG. ICE - Internal Combustion Engine, MT - Microturbine, FC - Fuel Cell. S – Small-sized equipment, M - Medium-sized equipment. Besides CHP, only-electricity technologies are also considered in DER-CAM runs. Technology costs are rounded for presentation.

Table 2 - Technical and Economic Characteristics of the Solar and Storage Technologies

	ES	TS	ST	PV
Fixed cost ($)	295	10000	1871	1294
Variable cost ($/kW or $/kWh when referring to storage)	193	100	726	2293
Maintenance cost ($/kW or $/kWh when referring to storage)	≈0	≈0	0.50	0.25
Lifetime (years)	5	17	20	20

Source: Own calculations and Stadler et al. 2012. Notes: ES - Electrical Storage (Lead-Acid), TS - Thermal storage, ST - Solar thermal, PV - Photovoltaics. Technology costs are rounded for presentation.

Table 3 - Energy storage parameters.

	ES	TS
Charging efficiency	0.9	0.9
Discharging efficiency	1	1
Decay	0.001	0.01
Maximum charge rate	0.1	0.25
Maximum discharge rate	0.25	0.25
Minimum State of Charge	0.30	0.00

Source: Stadler et al. 2011

Table 4 - EV battery specifications.

Charging efficiency	0.95
Discharging efficiency	0.95
Battery hourly decay (related to stored electricity)	0.001
Battery capacity (each vehicle)	16 kWh

Source: Stadler et al. 2012

Notes: ES - Electrical storage (Lead-Acid), TS - Thermal storage. All parameters are dimensionless. The decay is relatively high due to lifetime of lead-acid batteries assumed at its upper end, when the decay increases rapidly.

The first technology adoption results will provide the authors with the amount of mobile storage (therefore with the number of PEVs) that would optimally connect to the services buildings complexes and thus that could be charged during the night at the residential neighborhood. It is assumed that this amount of mobile storage will be adopted by customers as an alternative to their conventional vehicles. This shift from diesel and gasoline-fired vehicles has also environmental consequences, which are taken into account and depicted in the final part on this paper.

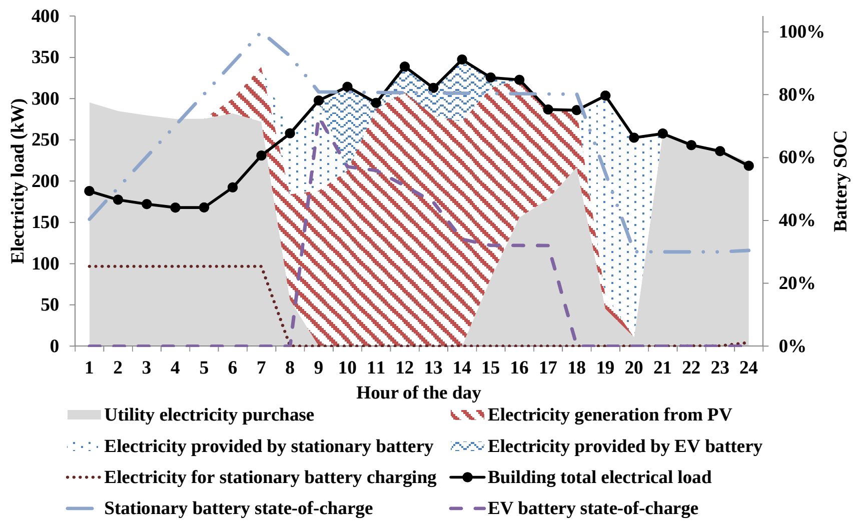
Results and discussion

The graph in Figure 4 shows the electrical load diurnal optimization pattern on a November week day for a lodging facility in São Miguel.
This is a building typology mainly characterized by stable load operation due to both nightly and daily activities at the site. DER-CAM selects to purchase 360kW of PV panels at Portuguese market prices and 967kW of electrical stationary battery storage with the main goal of avoiding electrical utility consumption during peak and mid-peak times[5]. Most of the available space for solar installation is used. PV is generating electricity from 6h to 19:30h, although in the early hour of the day, still under an off peak period, PV is minimally used for charging of stationary batteries in the morning. During peak periods, when the most expensive volumetric rates operate, which are in this time of the year from 9h to 11:30h and 19:30h to 21h, there is no or almost no utility purchase. Besides energy volumetric cumulative costs, a strong reason for this is to avoid expensive demand charges at peak hours. Stationary and mobile storage aid PV with supplying

[5]Additionally, a 20kW switch is purchased to take the 25% base and 5% peak critical loads of the system.

electricity needs from 8h to 4h. Utility electricity is mostly used for charging the stationary storage during the night, from 1h to 7h, when this is economically attractive. The 16 employee PEVs used during this day leave the facility with minimal battery SOC of 32%. This configuration allows for the lodging facility to economize approximately 31k$ from the original 345k$ total energy costs and saving also around 214t of CO_2eq. of GHG emissions. It is important to notice that reductions on emissions do not necessarily come from PEVs, but from the increased purchase of PV. As recent research from DER-CAM team (Stadler et al., 2012) had suggested, PEVs and stationary storage can be related to increases in CO_2 emissions at the site since they have charging and discharging efficiencies. The total emissions however, can be reduced as seen in this case (see table 5).

Figure 4 - Optimization Results for a May Week Day for a Lodging Building Complex in São Miguel, Cost Minimization Strategy



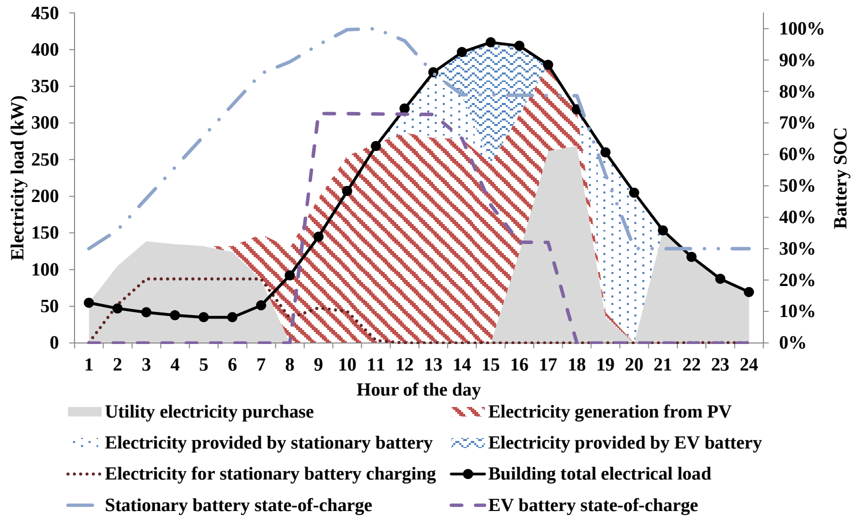
Notes: EV – electrical vehicles, PV – photovoltaics, SOC – battery state-of-charge. The represented battery SOC refers only to the periods of service building connection.

Figure 5 exhibits the case of the electrical diurnal profile during an August week day for an education multi-building complex in São Miguel. In this situation, DER-CAM suggests the purchase of 871kWh of stationary storage along with 323kW of PV[6] which makes use of only part of the available space for solar technologies. PV is extensively used throughout the day from 6h to 19h. This happens because, in this case, PV can provide the full electrical requirements during the morning peak hours, from 9h to 11:30h while stationary storage is also used to cover mid-peak hours from 11h to 14h and the peak period from 19:30h to 21h. This stationary battery capacity is fully charged by utility electricity and PV during night and early morning off-peak hours, respectively; 40% of this capacity is used from 11h to 15h while the remaining 60% during the final peak periods of the day, from 18h to 21h. That day the mobile storage is used when the electrical load of the building reaches its peak, from 13h to 17h. PEVs battery energy is used down to the minimum SOC of 32%. The total amount of PEVs used in this facility is 20 units, corresponding to 318kWh. PV covers the rest of the mid-peak period. Utility electricity is

[6] A 36kW static switch is additionally purchased. The critical loads of the facility correspond to 25% of the base and 5% of the peak loads. Please note that the critical load requirement and high LPG prices forces also stationary storage to be able to ride through a macrogrid disturbance.

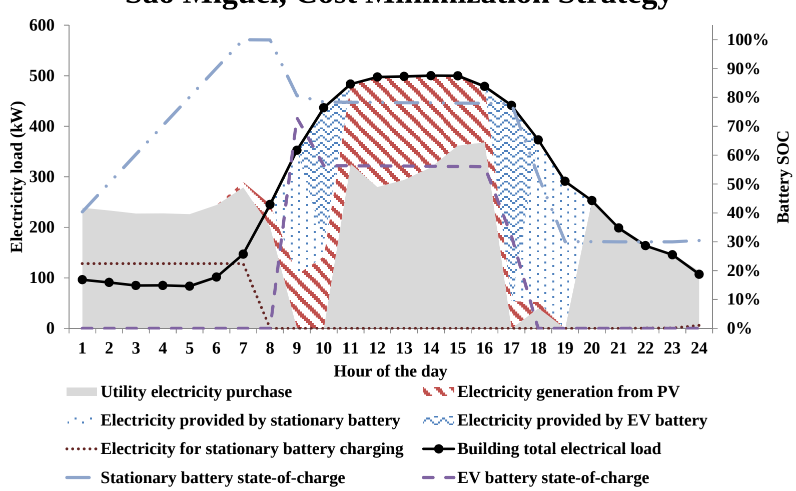
purchased exclusively during night hours with off-peak low volumetric rates. There is significant economic gain with PEV adoption for this facility. The benefit compared to the base case is of almost 45k$ while GHG emissions reduction accounts for some 229t of CO_2eq. annually. Also, since this is a natural gas-intensive building complex, in this particular situation, emissions at the site are slightly reduced due to adoption of a large amount (205 kWth) of solar thermal. Please see Table 5 for more detailed information on GHG emissions.

Figure 5 - Electrical Load Profile of an August Week Day for an Education Building Complex in São Miguel, Cost Minimization Strategy



Notes: EV – electrical vehicles, PV – photovoltaics, SOC – battery state-of-charge. The represented battery SOC refers only to the periods of service building connection.

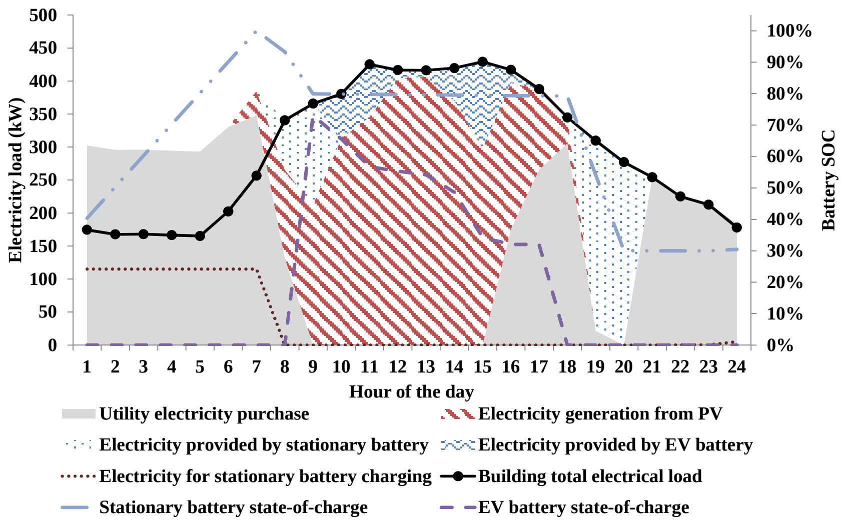
Figure 6 - Electrical Load Profile of a March Week Day for an Office Building Complex in São Miguel, Cost Minimization Strategy



Notes: EV – electrical vehicles, PV – photovoltaics, SOC – battery state-of-charge. The represented battery SOC refers only to the periods of service building connection.

With Figure 6, the authors depict another diurnal electrical profile; this time applicable to a typical medium-sized Portuguese office complex in São Miguel. DER-CAM recommends the purchase of 351kW of PV and a substantial amount of 1.3MWh of stationary battery storage[7]. This highly electricity-demanding facility uses a combination of PV, stationary and mobile storage to curtail its morning peak period and avoid highly expensive demand charges for the site, since during these hours peaks reach almost 500kW. PV is providing part of the energy during mid-peak periods along with some utility purchase, while from 16h to 20h both mobile and stationary storage do the job of avoiding higher electricity costs, again. In the end, microgrid technology adoption and PEV usage of 41 employee vehicles (655kWh) leads to a remarkable reduction in total annual energy costs from 473k$ to 401k$. GHG emissions decrease by 208t of CO_2eq. to approximately 794t of CO_2eq. per annum. Please note that this reduction is due to the combination of all technologies and not only PEVs. DER-CAM considers all distributed energy resource technologies at the same time, reporting on the cumulated impact of all technologies.

Figure 7 - Electrical Load Profile of a September Week Day for a Healthcare Facility in São Miguel, Cost Minimization Strategy



Notes: EV – electrical vehicles, PV – photovoltaics, SOC – battery state-of-charge. The represented battery SOC refers only to the periods of service building connection.

The last example is a multiple building healthcare facility in São Miguel. The pattern in Figure 7 corresponds to a typical September week day. Quantities of 1.2MWh of stationary storage, along with 551kW of PV panels are recommended for purchase[8] by DER-CAM. More that 75% of the available space for solar technologies is occupied. PV is essentially used at its most with the objective of not purchasing utility electricity during highest consumption and highest volumetric rate hours. From 6h to 7h, PV and utility purchase is initially used to charge electrical stationary storage. An amount of 371kWh of EV batteries energy, corresponding to around 23 employee cars is progressively used troughout the day, from 9h to 12h and 13h to 16h. Eventually, the PEVs leave the building with minimum battery SOC of 32%. Stationary storage covers the whole final day peak period. Microgrid technologies adoption, including PEVs, by the

[7]An additional switch of 59kW, which seamlessly isolates the microgrid from the main grid, is purchased. The sensible loads of the office facility correspond to 40% of base and 10% of peak loads. This also drives the stationary storage adoption.

[8]A switch of 45kW is also purchased. Critical loads of the health building complex are the highest, being that 70% of the base and 10% of the peak are sensible to its proper operation. This also drives the stationary storage adoption.

healthcare facility leads to a final decrease in annual costs of 61k$ and to a high reduction of 35% (330t CO_2eq.) in total GHG emissions to 605t of CO_2eq..

Table 5 compares the results of the services buildings investment optimization runs with the initial base case (BC) situation (where no investment takes place) for a typical year, in terms of total annual energy costs (TEC) and building complex operation-related GHG emissions.

Table 5 - Results for the Cost Minimizing Runs of Microgrid Adoption with PEVs for the Services Buildings in São Miguel

Building complex	Annual TEC (USD)	Reduction in TEC, compared to BC		Annual GHG emissions (kg CO_2eq.)		Change in annual GHG emissions, compared to BC				Total PEVs usage by the services facility	
	Invest run	Total (USD)	%	Invest run		Total (kg CO_2eq.)		%		Total (kWh)	Number of units
				Macrogrid	Site[9]	Macrogrid	Site[9]	Macrogrid	Site[9]		
LODG	313707	31054	9	574877	33873	-240777	+26455	-30%	+257%	673	42
EDUC	377904	45354	11	379625	181039	-223824	-5369	-37%	-3%	822	51
OFF	400960	72184	15	693513	100600	-269314	+61488	-28%	+57%	1693	106
HLTH	352659	61483	15	552891	58575	-369037	+38730	-40%	+95%	958	60
TOTAL	1445230	210075	13	2200906	374087	-1102952	121304	-33%	+48%	4146	259

Notes: LODG - Lodging building complex, EDUC - Educational building complex, OFF - Office building complex, HLTH - Health building complex, TEC - Total energy cost, BC - Base case run, Invest - Invest in microgrid adoption (and PEVs) run. Costs and emissions values are rounded for presentation.

Table 5 shows that, considering the whole building set, the total reduction in energy costs is of 13%, approximately 210k$. Personal PEV investments are not included in the energy costs of the system. An assumption of an energy exchange tariff of 0.06$/kWh is put into use. This tariff determines the level of adoption of PEVS and the energy transfer from residential to commercial complexes. The results presented here do not apply to circumstances under different energy exchange tariffs. It is also seen that, due to PEVs adoption, the site's GHG emissions increase in about 48% to around 374 tCO_2eq. However, these values are negligible when compared to the macrogrid emissions, which drop down 33% to about 2,200 tCO_2eq.. These results are in accordance with prior research findings from Stadler et al. 2012 and confirm that PEVs play a role in economic optimization of building energy management. This switch for electric transportation by conventional vehicles owners incurs in the other hand in reductions of GHG emissions due to fossil fuels offset. In total, 259 PEVs are adopted by building employees, corresponding to an amount of 4146kWh of battery energy. Considering a 259 vehicles former fleet, composed of 56% gasoline and 44% diesel and further data from TIS, 2005, the authors estimate that for the São Miguel region, such substitution could lead to additional GHG emissions savings of approximately 934t of CO_2eq. per year. The net total GHG emissions savings for this community would reach the 1,916t of CO_2eq., annually. From the technology point of view, the current Portuguese/Azorean market and climate conditions favor investments on PV and battery storage rather than on CHP gas-driven DG. The authors believe that such a trend relates to a set of factors, which includes not only the climate and decreasing market price of PV technology but also the high LPG prices in practice in the São Miguel Island context.

[9] These emissions correspond to the sum of emissions from all LPG uses at the site.

Conclusions

This paper proposed an integrated analysis of PEV interactions with microgrid facilities in a case-study setting of an Azorean island, São Miguel. The optimization results deliver that PEV owners charge their vehicles at home at low charge tariffs and allow, while parked at work, that the buildings EMS uses PEVs for energy management purposes. Based on the results and the particular cases approached, it is suggested that PEV adoption can lead to significant total annual costs reductions in the operation of services (commercial) building complexes. The cost minimization optimization results show that PEVs are typically used to transfer low cost electricity from the residential building to the services buildings to avoid high demand and volumetric energy charging during expensive day hours. Office complexes are attractive for PEVs usage, being attained the biggest reductions in TEC. In that situation, PEVs have been used in combination with other DG to reduce demand charges. The analyzed Health facility did likewise attain big reductions in the annual TEC but this happens mostly to relaxed space constraints, which the authors believe approximately reflect the real situation of multi-building Portuguese health facilities. Overall, win-win situations involving energy management of PEVs battery energy can be possibly established between any of the services facilities managers and its employees. Together, PV, PEV, and stationary storage generate substantial GHG emissions reduction due to less macrogrid utility purchases, which can increase if the offset from conventional fossil fuel vehicles substitution is considered. For the studied case, the estimated effect of microgrids with PEVs adoption would result in total economic savings of 210k$ and emissions savings of 1,916t of CO_2eq. per year. The remaining drawback for definitive PEV introduction still is the capital investment that customers have to support. In this context, government actions such as funding and subsidies, which are not taken into account in this paper, are advocated as valuable for an electrical transportation future in Portugal.

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