Electric Vehicle Integration in an Argentine Educational Institution: The Case of the National University of Rafaela

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***Abstract*—This paper proposes the integration of Electric Vehicle-to-Grid (V2G) at the campus of the National University of Rafaela in Argentina. The analysis aims to optimize the use of parked electric vehicles based on the energy demand of the campus. Additionally, the integration of a photovoltaic system and V2G technology to the building's electrical grid is considered to enhance energy efficiency. This approach also focuses on analyzing the carbon footprint associated with the use of these vehicles, with the ultimate goal of reducing the emission of polluting gases. The simulation results, grounded in real consumption measurements recorded throughout the year 2024, underscore the importance of integrating V2G technology into the campus building under study.**

***Index Terms*—Electrical Energy, Grid, PV-System, Electric Vehicle, V2G.**

I. Introduction

Electric vehicles (EV) have significant potential to improve air quality by reducing greenhouse gas (GHG) emissions. The main emissions produced by vehicles consist of 30% nitrogen oxides ($NO_x = NO + NO_2$), 10% particulate matter (PM), 54% carbon monoxide (CO), 14% carbon dioxide (CO_2), and 47% non-methane hydrocarbons (NMHC). These atmospheric emissions are associated with direct and indirect effects on human health. Among the direct effects were reported conditions such as asthma, hypertension, pulmonary cancer, diabetes, Alzheimer's, dementia and premature deaths. On the other hand, indirect effects on human health arise from increased GHG and associated climate changes (storms, floods, and droughts) leading to a higher incidence of wildfires and variations in air pollutant levels. These implications of vehicular emissions on the environment and human health suggest that current transportation systems are unsustainable, from a health and environmental (air pollution and GHG) point of view [1].

According to the report "National Inventory of GHG of the Argentine Republic - Year 2022" [2], the transport sector is responsible for 9.9% of total national emissions, which are mainly due to the use of fossil fuels, such as gasoline and diesel. At the local level, in the city of Rafaela, the transport sector is also one of the main responsible for these emissions. In 2018, the transport sector represented 29.13% of the city's total emissions [3], as the result of the large number of internal combustion vehicles that circulate on the city's streets and the population growth. To reverse this situation, it is necessary to reduce GHG emissions from the transport sector through to promote the use of EV [4].

Since vehicles are commonly parked approximately 90-95% of the time, their batteries represent a significant idle energy storage resource. For this reason, in V2G (vehicle connected to the grid) systems, EV not only consume energy from the grid to charge, but can also return energy to the grid when needed, acting as flexible sources of energy storage [5]. Moreover, grid-connected EV can also provide ancillary services that are critical to the stability and efficiency of the power grid [6], among them we can mention:

- EV can react quickly to adjust their charge or discharge in response to regulation signals issued by the grid operator, stabilizing reactive power supply and demand. This ensures that the voltage on the grid remains within the appropriate levels.
- V2G can help correct deviations in grid frequency, balancing load and power generation.
- EV can serve as emergency backup power sources for homes and buildings during power outages, providing resilience to the power supply.

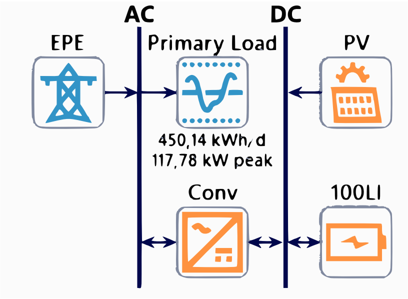

Fig. 1. System under study.

These advantages facilitate the transition to a more efficient and sustainable energy system. V2G system allows EV to store surplus renewable energy when generation exceeds demand, which is especially beneficial during periods of high generation, such as solar daylight hours. When energy demand exceeds renewable energy supply, these vehicles can return the stored energy to the grid, helping to balance supply and demand. Then with a significant participation of vehicles in the V2G system, it is possible to cover a large percentage of the energy demand with renewable sources [7]. These benefits not only contribute to a more stable and sustainable energy system but also represent an economic opportunity for EV owners. This is because they can alleviate peak-hour demand on the grid, not only by reducing their energy consumption, but also by feeding energy back into the grid during periods of peak demand. In this way EV owners can earn additional revenue by selling the energy stored in their batteries during periods of high demand, when electricity prices are higher. This can help offset vehicle acquisition and maintenance costs [8].

Although Argentina has historically used a flat rate system to calculate the cost of electricity. Since the elimination of tariff subsidies in this sector, it is intended to implement a system that considers the costs according to the time slot. For this reason, the present work addresses a study in which EV are a key factor for the purchase and sale of energy and simultaneously, represents a research advance for the country and in particular for the Litoral region. Furthermore, this analysis will be carried out on the campus of the National University of Rafaela located in the province of Santa Fe, a standard public establishment, which has solar panels that inject energy to the grid as well as charging stations for EV.

Fig. 2. Photo of the UNRaf Building.

II. System under study

The system under analysis is connected to the public power grid (PPG), which is supplied by the Empresa Proveedora de Energía (EPE) of the province of Santa Fe. The PPG is connected to the AC bus in parallel with a bidirectional converter rated at 46.1 kW. The load considered corresponds to the UNRaf University Campus building and has a daily consumption of 450.14 kWh, with peak demand reaching 117.78 kW. Additionally, the bidirectional converter is connected to a DC bus powered by photovoltaic (PV) system and coupled to a 100 kWh lithium-ion battery bank, which emulates the aggregated storage capacity of a fleet of 13 identical electric vehicles (TITO-CORRADIR). These vehicles can inject energy into the grid when the PV system are not generating energy, mitigating PPG dependency.

A. *University Campus*

The UNRaf campus is located in the city of Rafaela and as shown in Fig. 2. Rafaela is located in the province of Santa Fe, Argentina, at 31º 15’ south latitude and 61º 21’ west longitude, 90 m above sea level. It has an area of 156 km^2, and if the distance of the city from point to point is analyzed, it is approximately 15 km long and 12 km wide. Given its range, an electric vehicle is suitable for traveling within the city without worrying about running out of charge. Furthermore, the climate is temperate, with historical average minimum temperatures of 5.75º C in July and historical average maximum temperatures of 31.6º C in January. Also, it has a good level of solar radiation (around 4.5-5 kWh/m^2/day), which allows for efficient solar generation.

B. *PV system*

The UNRaf campus has a PV system (on-grid type) designed to cover 20% of the building’s electrical energy demand.

The power generated by the PV system is shown in Fig. 3, using a thermal color palette that represents the entire year along the horizontal axis and

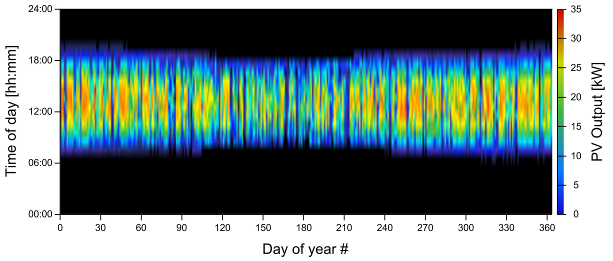

Fig. 3. PV Output.

each day along the vertical axis. The color scale ranges from 0 kW (black) to 35 kW (red). The generation exhibits a typical daily bell-shaped curve, concentrated between 6:00 hs and 18:00 hs, with no production during night time hours. During spring and summer, the daily generation period is extended, and power levels reach higher values, with a predominance of yellow and red tones, indicating effective solar resource utilization. In autumn and winter, the solar window shortens and power output decreases, with cooler colors (blue and green) becoming more prominent. In addition, the intra-day color variability suggests fluctuating weather conditions, particularly intermittent cloud cover. The average power output during active hours is estimated to range between 18 kW and 22 kW.

C. *Electric Vehicles*

The participation of electric vehicles in the Argentine market has shown growth, although relatively low compared to other types, such as hybrids. In 2024, electric vehicles accounted for 4% of the total number of vehicle registrations [9].

Due to the fact that the EV commercialized in Argentina are unidirectional (they only support charging), for the purposes of analysis in this work, it is considered that they have been modified to support V2G technology. Particularly, the first pure electric car built and marketed in Argentina is considered, which is not only one of the best-selling EV but also one of the most economical. A picture of the TITO vehicle is shown in Fig. 4 and some of its technical specifications are listed in the Table I.

TABLE I
TECHNICAL PARAMETERS OF TITO [10]

Battery type	Lithium LFP 8 kWh 2000 cycles
Charge	220V 50hz - Plug 2073
Autonomy	100 km
Maximum charging time	8 hours / Partial recharging allowed

Fig. 4. Electric vehicle used in the analysis.

III. Simulation results

HOMER Grid software was used for the simulation and evaluation of the hybrid network, to model the system's operation. The proposal integrates grid power procurement management, photovoltaic generation (subject to irradiance variability), and V2G technology, which allows electric vehicles to supply energy to the building. In this context, the V2G system provides energy to the building when solar generation is unavailable.

A. *Grid Energy Transactions*

To evaluate the electricity consumption profile of the system under study, data on the electrical energy purchased from and sold to the power grid are analyzed. Fig. 5 shows a heat map representing the energy purchased from the grid over the course of a year during each day. From this data it is revealed that the building exhibits a definite hourly behavior in energy demand from the grid:

- Between 00:00 hs and 11:00 hs, dark shades of blue and green predominate, representing power values between 16 kW and 32 kW.
- From 18:00 hs to 24:00 hs, areas with light blue, green, yellow, and even orange tones are prominent, indicating that the power purchased from the grid can reach up to 64 kW.
- On many days of the year, black bands appear between 11:00 hs and 15:00 hs, indicating zero or near-zero demand from the grid. This reduction coincides with the hours of highest solar irradiance, suggesting that photovoltaic generation covers a significant portion of the demand.

It is worth noting that nighttime consumption (between 00:00 hs and 06:00 hs) is primarily due to reduced demand resulting from low building occupancy and the disconnection of non-essential loads (such as corridor lighting, lighting in unoccupied common areas, office equipment in standby mode, heating, ventilation and air conditioning systems). This reduction may also be influenced by automated control strategies, including scheduled shutdowns, nighttime

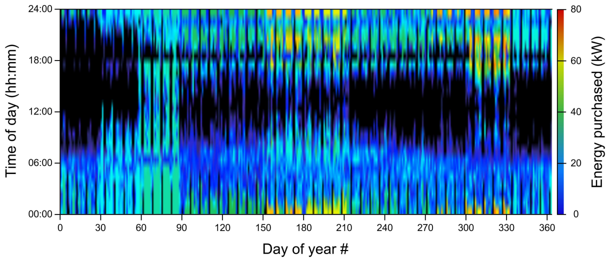

Fig. 5. Energy Purchased From the Grid.

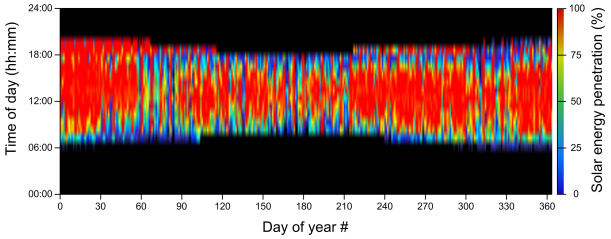

Fig. 6. Solar output as percentage of total generation.

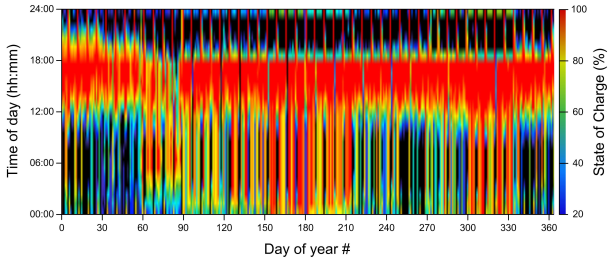

Fig. 7. Generic 100kWh Li-Ion State of Charge.

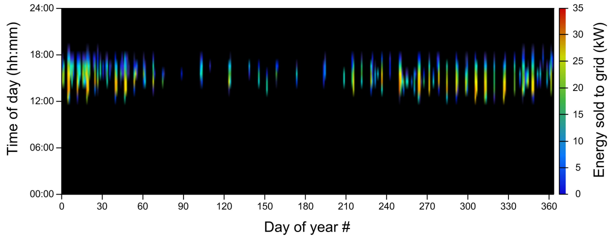

Fig. 8. Energy sold to the grid.

consumption minimization via timers or presence sensors, and time-based activation/deactivation of electrical systems. It is also because the battery bank are discharged at night to supply the building. Finally, there is some variability throughout the year, with more frequent consumption peaks in the second half of the year, where yellow and orange areas are identified due to an increase in the building's electricity demand.

To complement this analysis, Fig. 6 presents a heat map showing the instantaneous solar output as percentage of total generation. Although the annual contribution of energy generated by the panels is 31.6% of the total demand, during peak irradiance hours (between 10:00 hs and 16:00 hs), the photovoltaic contribution often reaches values close to 100%, as indicated by the predominant red band. This indicates that, during these periods, solar energy covers practically all demand and can even generate excess energy. Coverage decreases outside this time range and on days with low radiation, showing a marked seasonality in the intensity and duration of solar participation.

Part of the surplus energy generated by the PV system is stored in a 100 kWh lithium-ion battery. Fig. 7 presents a heat map showing the battery's state of charge (SoC) throughout the year on a daily basis. The color scale ranges from 20% (purple/black) to 100% (red) SoC. Darker colors (black to blue) represent low charge levels (SoC $< 40\%$), typically occurring when the battery discharges to meet the building's demand, mainly at night or on cloudy days when PV generation is insufficient. In contrast, red and yellow shades indicate high charge levels (SoC $> 80\%$), typically occurring on days when the battery frequently reaches full charge between 10:00 hs and 20:00 hs. Days when the battery does not reach 100% are identified by the absence of red during the solar generation period. In many of these cases, the maximum SoC ranges between 60% and 84%, as indicated by the transition to green and yellow shades. This may be attributed to low solar irradiance or increased energy demand on those days.

Regarding energy injection into the grid, it is attributable to surplus solar generation (see Fig. 8). During periods of peak PV generation, the hybrid grid dynamically manages power flow. The energy produced by the solar panels is first used to meet the building's instantaneous demand. Any surplus is then directed to the lithium-ion battery bank until it reaches its full capacity. Once both the internal load and battery charging are satisfied, any remaining excess energy is exported to the grid.

In summary, the results provided in this Section allows us to visualize the criteria adopted by the algorithm. Since midnight to the beginning of the solar activity the loads are provided using energy from the grid. Once the solar activity begins this energy is used to charge the batteries and to feed the loads of the buildings. At the end of the day the solar activity vanishes but the demand from the load increases. Part of this mismatch is covered using the energy stored in the batteries in order to produce energy peak shaving.

B. *Utility Monthly Summary*

This section analyzes the monthly energy exchange between the building and the utility grid, focusing on energy consumption, energy export, peak demand, and contracted demand limits. The objective is to identify operational patterns, assess the efficiency of the current energy management system, and explore opportunities for optimization, particularly through the integration of V2G.

Table II provides a comprehensive overview of the monthly energy transactions. Along a year, the building imported a total of 122651 kWh from the grid and exported only 5013 kWh, resulting in a net import of 117638 kWh. The highest energy import occurred in July, with 14269 kWh, coinciding with the lowest energy export of 59.2 kWh. This pattern suggests increased energy consumption during winter months due to heating demands, coupled with reduced solar generation. Conversely, December and January recorded the highest energy export of 675 kWh and 1183 kWh, respectively, likely attributable to favorable solar conditions and lower energy consumption.

Maximum peak load was observed in June, reaching 99.5 kW, which significantly exceeds the contracted demand limit of 62.5 kW for that month. Similar exceedance were noted in October (75.0 kW VS 36.9 kW) and November (96.1 kW VS 72.7 kW). These overages may result in financial penalties and indicate a need for improved demand-side management or reevaluation of contracted demand limits.

The analysis reveals a strong dependence on grid energy, especially during winter, limited energy export capabilities, and frequent exceedance of contracted demand limits (see Fig.9). To address these challenges and mitigate associated penalties, the implementation of advanced demand-side management strategies is recommended. V2G can provide peak shaving services, thus reducing peak loads and associated penalties.

TABLE II

UTILITY MONTHLY SUMMARY

Month	**Energy Purchased** (kWh)	**Energy Sold** (kWh)	**Net Purchased** (kWh)	**Peak Load** (kW)	**Demand Limit** (kW)
January	5280	1183	4096	33.0	33.1
February	7712	575	7137	48.0	24.8
March	14387	157	14231	60.9	31.2
April	9396	65.4	9330	76.2	36.0
May	10052	138	9914	72.0	37.9
June	13550	85.1	13465	99.5	62.5
July	14269	59.2	14210	95.0	50.4
August	9888	385	9503	69.3	35.4
September	8871	623	8248	73.8	35.9
October	9054	435	8619	75.0	36.9
November	13073	631	12441	96.1	72.7
December	7119	675	6444	65.4	28.2
Annual	122651	5013	117638	117.0	—

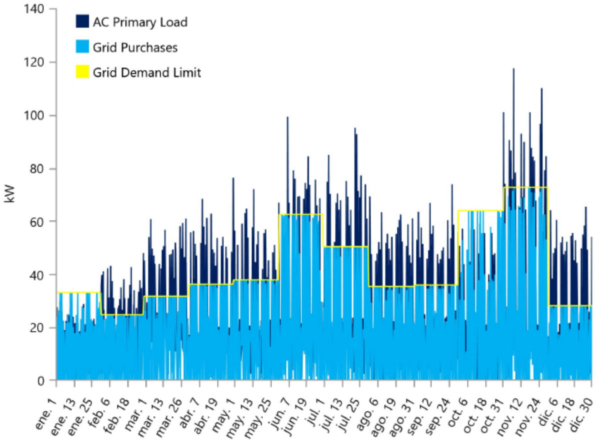

Fig. 9. Electricity Demand and Purchase Trends.

C. *Carbon footprint analysis using V2G*

The energy source used to charge the batteries plays a crucial role in determining the overall carbon footprint of EV, beyond their direct emissions. Consequently, it is essential to assess how the energy mix at the National University of Rafaela influences the carbon footprint associated with EV operation.

To obtain data on emissions produced by electric and gasoline vehicles for the UNRaf energy mix, the online tool AFLEET (Alternative Fuel Life-Cycle Environmental and Economic Transportation) [11] was used. The analysis takes into account the entire fuel life cycle, from extraction to its use in the vehicle, divided into three stages:

1) Well-to-Pump (WTP): includes fuel extraction, refinement, and distribution. For EV, it covers electricity generation and transmission.
2) Pump-to-Wheels (PTW): refers to emissions and energy consumption while the vehicle is in operation.
3) Vehicle Production (or Vehicle Cycle): encompasses several stages, including raw material extraction/processing, manufacturing, final assembly, end-of-life management, and recycling.

Then, the emissions and energy consumption associated with the manufacturing of the vehicle and its battery were included in this analysis. While an EV may have higher manufacturing emissions than a combustion vehicle due to the production of lithium batteries, the EV compensates for these emissions over its lifetime due to its lower energy consumption and lack of direct emissions [12].

Initially, data were collected from ”TITO” EV model 2025 [10], whose estimated consumption is 8 kWh/100km (12.87 kWh/100mi or 261.75 MPGGE). Calculations were made for

TABLE III
COMPOSITION OF THE UNRAF ENERGY MIX

Source	**Percentage**
Natural gas	42.6 %
Residual Oil	2.84 %
Coal	0.29%
Nuclear power	6.17 %
Biomass	2.7 %
Others (wind, solar, hydro, etc)	45.4 %

TABLE IV
PETROLEUM USE AND ITS REPRESENTATION IN GHG EMISSIONS AND POLLUTANT GASES EXPRESSED AS CO_2 EQUIVALENTS (ANNUAL)

Type	**Petroleum** (L)	**GHG** (tons)	**CO** (kg)	**NO_x** (kg)	**PM_{10}** (kg)	**$PM_{2,5}$** (kg)	**VOC** (kg)	**SO_x** (kg)
Gasoline vehicle	1160.6	4.1	19.9	1.8	0.5	0.2	6.3	1.4
EV	47.7	1.0	1.9	1.1	0.4	0.2	2.4	2.8

12400 miles per year (approximately 20000 km per year), which is equivalent to 1600 kWh over a lifetime of 15 years. For comparison, a gasoline vehicle with similar range, performance and cost was analyzed, such as the Renault Kwid model 2025, with a consumption of around 6.5 L/100 km (36.2 MPGGE) [13]. The energy mix considered in this study is composed of the electricity generation data reported by CAMMESA (Compañía Administradora del Mercado Mayorista Eléctrico Sociedad Anónima) [14]. In addition to the national baseline, a 20% increase in renewable energy (specifically photovoltaic) is assumed to reflect the local generation conditions at the National University of Rafaela. This adjusted energy mix, as detailed in Table III, is used to evaluate the carbon footprint associated with the charging of electric vehicles. Table IV shows the results of the EV emissions over one year using the UNRaf energy mix, together with a comparison to the emissions of a gasoline vehicle. EV offers clear advantages in terms of oil consumption and emissions of most pollutants, particularly CO and VOC. However, the increase in SO_x emissions emphasizes that the environmental impact of electric vehicles also depends on the energy mix used for charging [12]. This highlights the importance of integrating renewable sources and implementing strategies such as V2G, which can allow a more effective use of clean energy and further reduce emissions related to transportation [15].

IV. CONCLUSIONS

This study demonstrates that the integration of V2G technology on the campus of the National University of Rafaela can significantly improve energy management by reducing the carbon footprint, optimizing the use of renewable energy, and improving the security of the electricity supply. Enabling electric vehicles to act as flexible energy storage systems supports not only self-consumption but also energy injection into the grid. More efficient battery management could help smooth electricity demand peaks, thereby avoiding penalties and improving both grid stability and economic performance.

In future work, our aim is to design battery energy management algorithms that maximize energy injection into the grid and assess their economic impact.

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