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Techno-Economic Evaluation of Ultra-Fast EV Charging at Chilean Multifamily Households with Hydrogen and Solar Integration

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ABSTRACT

Decarbonisation has led to a strong electrification in the transport sector; and multifamily households constitute a challenging setting to accelerate electromobility. This work studies the feasibility of installing ultra-fast chargers with the support of hydrogen (H_2) and rooftop solar power in residential contexts for Santiago, Chile: an apartment building with 120 units, and a condominium with 10 houses. A communal use of the chargers is evaluated in three cases: (1) charging directly from the grid, (2) adding supplied H_2 and a fuel cell, and (3) adding rooftop solar, for H_2 production, storage and conversion. Results indicate that H_2 integration into EV charging is technically possible but economically constrained. Case 1 is viable under selling price adjustments, Case 2 can achieve the highest Net Present Value (NPV), and Case 3 has the highest costs, low conversion efficiency (~35%), and potential system underutilisation, deeming it unfeasible with a mean levelised cost of energy of 0.68 USD/kWh and of H_2 of 9.55 USD/kg. Sensitivity analysis highlights the grid electricity price as the most influential factor on NPV, which must be assessed carefully under periods of uncertainty.

KEYWORDS

Electromobility, Techno-economic evaluation, Solar energy, Hydrogen, Residential energy.

INTRODUCTION

Electromobility has been steadily increasing across the globe, driven by a combination of decarbonisation efforts and the rapid expansion of the electric vehicle (EV) market [1]. Greater availability of models, declining costs, and government plans have accelerated EV adoption, positioning electromobility as a central pillar in the transition towards sustainable transport [2]. Within this context, ultra-fast charging technologies are gaining prominence as they promise to reduce charging times and improve user convenience [3]. However, their widespread deployment presents significant challenges to the electricity grid [4], potentially leading to instability and increased demand peaks [5]. Studying the integration of ultra-fast charging under different conditions is therefore essential.

Multiple case studies exist in the literature, ranging from converting gas stations [6], charging electric buses [7], integrating chargers to existing tramway infrastructure [8], and managing fast EV charging in buildings [9], each with distinct requirements and impacts. With a diverse range of applications and EV users' options to charge at home, office, or public spaces, there is a broad agreement in that the additional charging load will stress the local

electric grid. To diminish grid stress, several support strategies have been proposed, mainly comprising electricity pricing, managing EV charging, and integrating renewables and hydrogen to EV charging. Controlling electricity tariffs has proven to be an effective way to reduce peak consumption [10], and optimal algorithms to deliver day-ahead dynamic pricing schemes to modify EV charging behaviour exist [11]. Peak-shaving strategies can also be deterministic, allowing to manage and schedule EV charging, and in particular, buildings with EV chargers and renewable integration can greatly benefit economically from EV charging management [12]. An example of advanced EV charging is multi-objective optimisation to coordinate charging and storage through dynamic pricing [13] another is using model predictive control to reach real-time optimization [14]. Finally, many studies have assessed the benefits of including renewable energy and storage systems to EV charging, highlighting the benefits of integrating solar photovoltaic (PV) and storage, which are not only techno-economic but also possible social benefits [15]. Other studies have raised the potential benefits of storage in mitigating grid effects for EV charging on highways [16], as well as the potential of electrolysers to provide grid balancing and congestion management, and at the same time to deliver different services such as becoming fuel-cell electric vehicle operators [17]. Integrating hydrogen-based solutions to EV charging has been mostly done by either designing a hybrid system for a specific location at a systems level [18], by demonstrating projects such as a pilot experiment in a house [19], or by evaluating their potential technical benefits on a distribution grid level [20].

Charging at multifamily households constitutes a challenging context to promote electromobility. For example, in the United States, while home charging represents 80% of EV charging, less than 5% occurs in multifamily buildings [21]. Some barriers are related to the difficulty of adapting different parking arrangements for EV charging, users' schedules and preferences, infrastructure and even regulatory constraints [22]. Therefore, innovative solutions are required to promote electric mobility in residential settings.

Recent studies have begun to explore integrating renewables and H_2 at a residential scale to support EV charging. The main benefit of integrating such technologies is mitigating the impact on the local distribution grid. Existing works have developed optimization frameworks to size and locate EVs, allowing to minimize grid impacts [20]. Similarly, real-world experiments have demonstrated that managed residential EV charging reduces the grid load peak demand [23]. There are different ways to analyse buildings in the literature. For example, all the combined energy demand was considered in a residential building in Gaithersburg: heating and cooling, lighting, and EV charging, to find the optimal sizing of renewables and EV infrastructure to reduce energy costs and emissions [24]. Similarly, a large complex of 320 buildings in Madurai, India, was studied combining both residential load and EV charging, assuming that all existing conventional vehicles become EVs. The communal use of the EV chargers was studied as an optimization problem with solar forecasting to determine the most cost-effective times for EV charging [25]. These works emphasise the importance of combining energy conversion technologies and the smart management of EV chargers to ensure feasibility in residential contexts, but they treat the demand in an aggregated way, lacking the level of detail to include the specific use that may occur in a communal setting, and therefore they may not consider eventual peaks in power demand. The communal aspect of the residential scale may be one of the most complex factors to ensure both manageability and profitability, and other than proposed systems or optimisation studies, there is a lack of research on realistic case studies to advance these solutions. One reality that is becoming more common and could consolidate in the near future is having a third-party installing and operating the charging infrastructure in a residential complex. In this case, the users would not own such technologies but only allow to install the infrastructure in the parking spaces and use them according to the strategy of the EV charging system, which could be either to follow a price signal or having reserved time slots for charging. This type of solutions, in an ultra-fast charging context, have not received much attention yet, and is what this paper aims to analyse.

This study focuses on analysing the feasibility of ultra-fast charging with the integration of solar photovoltaic and a H_2-based system for use in residential buildings and housing complexes. Two realistic case studies are considered, based on real buildings in Santiago, Chile: a housing complex comprising 10 homes and 10 EVs with a dedicated charging facility, and a residential building with 60 flats, 120 parking spaces, and 12 charging stations. The scenarios examined include direct charging from the electricity grid, the use of externally generated H_2, and local H_2 production through solar PV. This paper makes the following contributions:

- Develops a deterministic approach to the communal use of ultra-fast EV chargers in multifamily households, creating two realistic scenarios for Santiago, Chile
- Performs a techno-economic evaluation of including H_2 into ultra-fast EV charging at the residential level, as a promising alternative to alleviate grid congestion,

This analysis aims to provide insights into the technical and environmental feasibility of integrating hydrogen-based ultra-fast charging systems in residential contexts, contributing to the broader discussion on sustainable and resilient electromobility infrastructure.

METHODS

The following section outlines the case studies analysed and the methodology used to assess the techno-economic feasibility of implementing ultra-fast residential EV charging using H_2 conversion technology. Three case studies and two multifamily household types are considered. **Figure 1** presents a schematic of the methodology employed in this study. First, the EVs to be analysed are selected, and their ultra-fast charging behaviour is modelled. In parallel, the characteristics of the residential buildings under study are defined, and the EV charging demand is modelled based on a scheduling approach, allowing to estimate the resulting energy demand and the equivalent H_2 required to meet it. Additionally, solar PV generation is modelled for the selected locations, along with its H_2 production through an electrolyser. Finally, the main equipment units are selected to perform an economic assessment with key economic indicators for each case. Note that while this paper focuses on certain cases of study for a particular location, the methods can be generalised as desired.

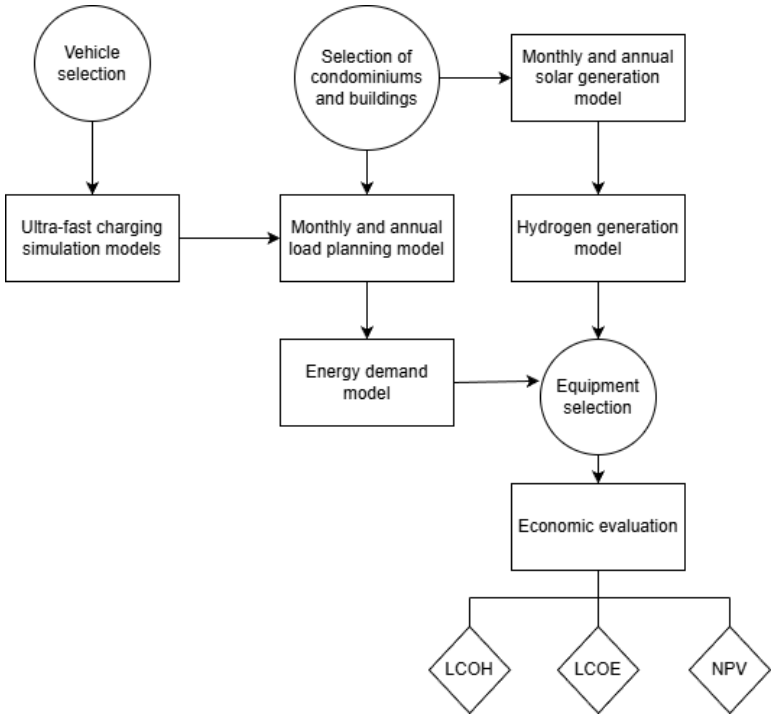


Figure 1. Simulation framework

Cases of Study

Three cases of study are considered; the first as a baseline, and the following represent two possible future scenarios with solar and H_2 integration.

- **Case 1:** EV charging directly from the electric grid. This case considers the incorporation of an ultra-fast charger connected directly to the electricity grid.
- **Case 2:** EV charging using a H_2 fuel cell. In this scenario, the ultra-fast charger obtains its energy from a fuel cell, assuming an ensured supply of H_2.
- **Case 3:** EV charging using a fuel cell with H_2 produced with solar PV. This case is similar to Case 2, with the distinction that both the housing complex and the residential building generate the H_2 required to power the charger using solar energy. If the H_2 produced is insufficient to meet the charging demand, the electricity from the grid will be used as a supplementary source.

EV Selection and Charging Models

To carry out a more representative study, three types of EVs were selected for the current analysis: a city car, an SUV, and a sedan. According to the Zero and Low Emission Vehicle Sales Report in year 2024 in Chile [26], the Tesla Model 3 was the best-selling EV up to June 2024. The Model 3 is the rear-wheel version, with a battery capacity of 57.5 kWh. In the same report, the Kia Niro ranked eighth in sales. Although it was not the best-selling SUV, this model was selected due to technical specifications availability. Finally, the Fiat 500e was chosen as the city car.

Table 1. Characteristics of the selected EVs

Car model	Battery capacity (kWh)	Voltage (V)	Cells in series	Cells in parallel
Kia Niro	64.8	358	98	36
Fiat 500e	42	400	109	21
Tesla Model 3	57.5	355	97	27

After selecting the vehicles to be analysed, their behaviour under ultra-fast charging conditions is simulated. To accomplish this, the behaviour of a single cell is simulated under different charging strategies (CCCV: Constant Current Constant Voltage, or MSCC: Multiple Stage Constant Current), starting from an initial state of charge (SOC) of 10% and reaching a final SOC of 80%. The basis to perform each charging simulation assumes that each battery pack has a specific cell configuration to deliver the nominal capacity and, and each cell is simulated using the PyBamm library [27], employing the Doyle–Fuller–Newman (DFN) model to represent the electrochemical behaviour of lithium-ion cells [28]. Following this logic, four configurations of CCCV and MSCC ultra-fast charging strategies are applied, and their results are then averaged to obtain a representative ultra-fast charging profile for each EV.

Residential Configurations

To select the characteristics of the residential complex to study, qualitative features of EV adoption are considered. Since EV prices are still prohibitive for a part of the population, it is more likely that their adoption will initially increase in areas with higher income levels. In Santiago, Chile, the five communes with the highest income per capita correspond to Vitacura, Las Condes, Alhué, Providencia, and Lo Barnechea. Since this study focuses on houses and apartment complexes, it was necessary to select a location that contains both types of residential arrangements. Among these five communes, Las Condes offers the best proportion of condominiums and apartment buildings, making it the most suitable choice for the study.

The next step involved conducting a survey of the area to select a representative apartment building and condominium, including the number of flats, houses, and parking spaces. A field visit was carried out in Las Condes to collect data, resulting in a sample of four condominiums and four apartment buildings. In addition, Google Earth was used to estimate the roof surface areas of the properties, which is essential to determine the available space for installing solar panels in Case 3. The final selection consists of a condominium with 10 houses, with a total of 1.539,61 m² of roof space, and a residential apartment building comprising 60 flats and 120 parking spaces, with a total roof space of 1.185,92 m².

From this selection, the charging infrastructure was defined in an ad-hoc manner for the scenarios under analysis. In the housing complex, a single charging station will be considered with a scheduled usage, allowing the charging of 10 EVs (one per household). In the residential building, 10% of the parking spaces will be equipped with charging points, equivalent to 12 stations. These will also operate under scheduled usage to ensure that no vehicle remains fully discharged. Furthermore, each flat in the building is assumed to own one EV, resulting in a total of 60 vehicles requiring charging. Currently, there is no local public data on this type of infrastructure; therefore, a more realistic and optimal determination of the number of chargers is left for future work.

Demand Scheduling

Once the residential building characteristics have been defined and the vehicle charging profiles have been simulated, a monthly and subsequently annual charging demand plan is generated. To establish a schedule for the use of the charging infrastructure, three annual driving-distance scenarios for each vehicle are considered based on local statistics [29], as shown in Table 2. The corresponding daily driving distance is then calculated, along with the resulting change in SOC. This makes it possible to determine how many days of use can occur before recharging is required, as well as the amount of energy needed to restore the battery to 80% SOC. Based on these factors, the annual distance travelled and the charging infrastructure available in each residential building, an annual charging plan is developed.

Table 2. Travelling distances for each EV

EV	Autonomy (km)	Annual distance travelled (km)	Daily distance travelled (km)	Daily battery usage (%)
Fiat 500e	330	15,000	41.1	12.45
Kia Niro	460	16,000	43.84	9.53
Tesla Model 3	513	17,000	46.58	9.08

A one-month charging community schedule was then created, including the number of vehicles and type, charging frequency, daily number of vehicles connected, and the duration of charging shifts for both the housing complex and the residential building. The scope was subsequently expanded to a one-year horizon. For Cases 2 and 3, the equivalent amount of hydrogen required to meet this demand was calculated using a cell conversion factor.

Solar Generation

For Case 3, the hydrogen production using solar energy was modelled, based on a simulation on pvlib [27]. The code utilised typical meteorological data, calculated solar position based on the geographic coordinates, given a standard 30º fixed-tilt and north-facing configuration, and determined the PV output power considering technical parameters. PV arrays were defined for both the housing complex and the residential building according to the available roof surface.

The PV energy was calculated monthly, then converted into H_2 production using the electrolyser's conversion factor, and finally into usable charging energy through the charging cell conversion factor. The annual simulation informs the total yearly energy generation and daily averages, as well as additional information for Cases 2 and 3: annual H_2 production, daily H_2 output, and electricity converted from H_2. These results were compared against the previously calculated annual demand to assess whether H_2-based energy production would be sufficient to meet EV charging requirements.

Equipment Selection

A market survey was conducted to select the equipment required for each case study. The chosen equipment had to meet the established technical requirements, with priority given to small units due to space limitations in the infrastructures under analysis. Price quotations were also obtained, necessary for the subsequent economic evaluation.

In Case 1, where EVs are charged directly from the electricity grid, the only equipment required is an ultra-fast charger. Case 2 introduces H_2 as an energy storage and conversion medium, requiring a charger, a storage tank, and a fuel cell. In this configuration, the H_2 stored in the tank is converted into electricity by the fuel cell, which is then delivered to the EVs through the charger. Case 3 incorporates renewable generation, with the necessary equipment consisting of the PV system, an electrolyser, a compressor, a storage tank, a fuel cell, and a charger. Here, solar energy powers the electrolyser to produce H_2, which is compressed, stored, and later converted into electricity by the fuel cell before charging.

The equipment selection process considered the technical specifications required for implementation in both the housing complex and the residential building. Challenges arose due to H_2 being a relatively new technology, with most available equipment designed for industrial applications rather than residential projects. Furthermore, as this was a feasibility study, companies contacted showed little interest in providing detailed quotations, given the absence of real purchase intentions. Consequently, bibliographic references and secondary sources were used to estimate prices and identify equipment suitable for the specific needs of the project. Technical details regarding the specific equipment units selected are available in the Appendix.

Techno-Economic Evaluation

The economic evaluation began with a detailed analysis of the investment costs required for project implementation. These costs were determined from the equipment selection stage, as the investment consists solely of acquiring new equipment. The next step involved establishing the price of electricity (kWh) from the grid and at existing EV charging apps, and an estimation of the annual percentage increase in energy prices. Fixed and variable costs were then considered, with only the fixed cost of annual equipment maintenance included. Note that an approximate conversion of 1 USD equal to 1000 CLP was assumed for simplification purposes.

Cash flow models were developed for each case study in both the housing complex and the residential building. Discount rates and corporate tax values were defined, and the need for reinvestment was assessed based on equipment lifetime and the cash flow period. Six cash flows were calculated and analysed. To better understand their behaviour, sensitivity analyses were performed on the most relevant variables, such as the selling charging price, with results used to evaluate their influence on the Net Present Value (NPV).

The same cash flows were then recalculated under a financing scenario, assuming 60% of the project cost was funded. Two loan repayment methods were compared – constant instalments and constant amortisations – to determine which was more suitable for the study. An additional case was added to consider the effect of including electricity price projections based on tariff data from recent years.

Finally, key economic indicators were calculated. The Levelised Cost of Energy (LCOE) was determined to establish the minimum price per kWh required for profitability, calculated

only for Case 3, as it is the only scenario involving energy generation. In addition, the Levelised Cost of Hydrogen (LCOH) was calculated, representing the minimum price per kilogram of H_2 required for the project to be viable. This indicator was also applied exclusively to Case 3, where H_2 production takes place.

Tools and Software

The EV charging profiles were generated in python using the pyBAMM library with each set of EV parameters, resulting in charging power curves that depend on the SOC. The solar PV power generation profiles were generated in python using the pvlib library with each configuration for the housing and apartment complexes. Finally, the full technical and economic analyses utilised these profiles to perform energy balances and cash flows in spreadsheets.

RESULTS AND DISCUSSION

The following sections portray the main results, focusing first on the technical feasibility and then in the economic evaluation.

Charging Demand and Local Energy Conversion

The modelled charging characteristics for each EV are presented in **Table 3**, which reports the time required to charge the battery from 10% to 80% SOC, the corresponding energy delivered, and the equivalent amount of H_2 needed to supply that energy. These indicators reflect the average characteristics obtained from the simulated charging models.

Table 3. Charging requirements for each EV

EV	Time (min)	Energy (kWh)	Equivalent H_2 (kg)	Min. Power (kW)	Max. Power (kW)
Kia Niro	35.62	49.58	2.98	40.65	118.54
Fiat 500e	35.62	32.35	1.94	26.37	76.91
Tesla 3	35.37	36.93	2.22	30.17	88

Figure 2 illustrates the characteristic charging schedule developed for the condominium of houses, which includes 10 EVs and a single charger. The charging requirement is determined solely by the energy consumed during the days of use, which is assumed as a constant behaviour along the year.

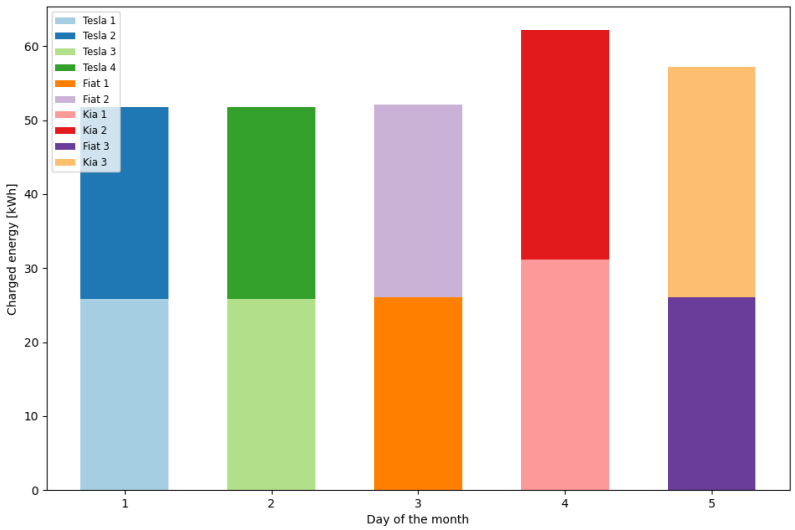


Figure 2. Charging schedule for the housing complex

The analysis determined the charging frequency required to operate within the desired SOC range, preventing full battery depletion. Based on typical average annual travelled distances, an average daily battery consumption was estimated for each model. With a safety margin applied, all vehicles were found to require charging within a five-day cycle.

For the housing complex, which contains ten EVs, the distribution was set at three Fiat, three Kia, and four Tesla. To meet the five-day cycle, two vehicles must charge each day. A single charging station was scheduled to operate in two one-hour shifts at 6:30 pm and 7:30 pm, ensuring vehicles reached a final 80% SOC. These times were selected to align with typical residential working hours.

Naturally, users may deviate from the reserved timeslot for charging. The simulation has a certain margin for error since the charging timeslots are for 1 hour and the needed time to charge is around 35 minutes. If larger deviations were to occur, the daily charging demand may not be constant but have a stochastic behaviour that could be better described through its statistics. The worst case would correspond to a greater charging demand in a specific day, which could result from either charging for longer than the allocated time, arriving with a critically low SOC, or having more users one day than the reservations. These types of variations could result in a larger energy or power demand, which in turn increase the technical requirements of the system.

In the residential building, 60 EVs were evenly distributed among the three models (20 Fiat, 20 Kia, 20 Tesla). To comply with the five-day cycle, 12 vehicles were scheduled to charge daily. A single one-hour charging slot was defined at 7:00 pm, again chosen to suit residential contexts.

Throughout an entire year, subsequent cycles of charging were simulated, with initial SOC values that were estimated from the daily discharge rates and correspond to: 18% for Fiat, 32% for Kia, and 35% for Tesla. Vehicles were then charged from these levels up to 80%.

From these schedules, the daily and monthly energy demand was calculated, enabling estimation of the H_2 required to supply this energy. Extending the model to a full year, with the same charging schedules and EV distributions, allowed to calculate the total annual energy demand, being 21,432.2 kWh for the housing complex and 132,909.4 kWh for the apartments; equivalent to a H_2 provision of 1,286.1 kg and 7,975.4 kg, respectively, as shown in **Table 4**.

Table 4. Summary of energy requirements for each residential complex

Residential complex	Annual demand [kWh]	Equivalent H_2 [kg]
Houses	21,432.2	1,286.06
Apartments	132,909.38	7,975.36

Case 3 analysed EV charging directly from a H2 cell powered by PV panels. Hydrogen production was modelled after the annual solar generation. A standard array with 205 W Kyocera modules **[30]** was considered in a surface limited to 50% of the available roof area in both residential settings. While the building achieved values close to this threshold, the housing complex used slightly less due to inverter capacity constraints, with the resulting PV systems shown in **Table 5**.

The energy generation and conversion model was then extended to a full year, incorporating seasonal variations. Annual results in **Table 6** include total energy generation, daily averages, H2 production, and electricity derived from H_2, allowing a direct comparison with the EV charging demand, to evaluate feasibility.

Table 5. Solar PV system characteristics for each residential complex

Residential complex	Available surface (m^2)	Modules in series	Modules in parallel	Array surface (m^2)
Houses	1,508.9	18	26	696.2
Apartments	1,185.9	16	25	595

Table 6. Solar energy and H2 production for each residential complex

Residential complex	Houses	Apartments
Yearly solar energy yield (kWh/yr)	174.386,60	149.491,35
Mean daily solar energy yield (kWh/day)	477,77	409,57
Yearly H_2 production (kg/yr)	3.603,03	3.088,66
Mean daily H_2 production (kg/day)	9,87	8,46
Yearly energy produced with H_2 (kWh/yr)	60.044,48	51.472,59
Mean daily energy produced with H_2 (kWh/yr)	164,51	141,02

Figure 3 and **Figure 4** present the electric energy generation from H2 and solar sources, together with the charging demand. It can be observed that, in the case shown in **Figure 3**, which corresponds to the housing complex, the demand is met throughout the year, with an overgeneration exceeding 200 kWh during the summer months. In contrast, the opposite behaviour is observed for the apartment complex, as illustrated in **Figure 4**, where at no point during the year does the electricity generation from H2 and solar energy suffice to meet the EV charging demand.

Not meeting the charging demand in the case of the apartment building stems from the assumed constraint of using only the 50% of available roof surface for a solar PV installation. While this constraint could be lifted, it would be unrealistic to achieve a 100%, which would still underserve the demand during winter months. This fact highlights the space limitation inherent in dense urban environments.

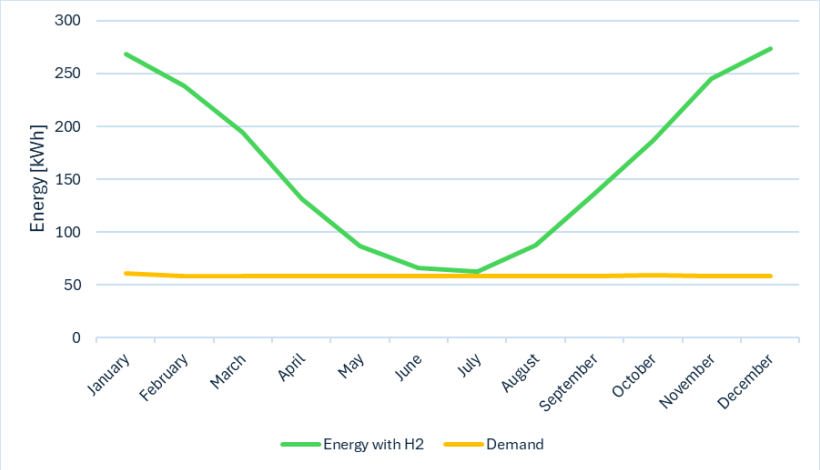


Figure 3. Monthly supply of H2 and EV charging demand for the housing complex

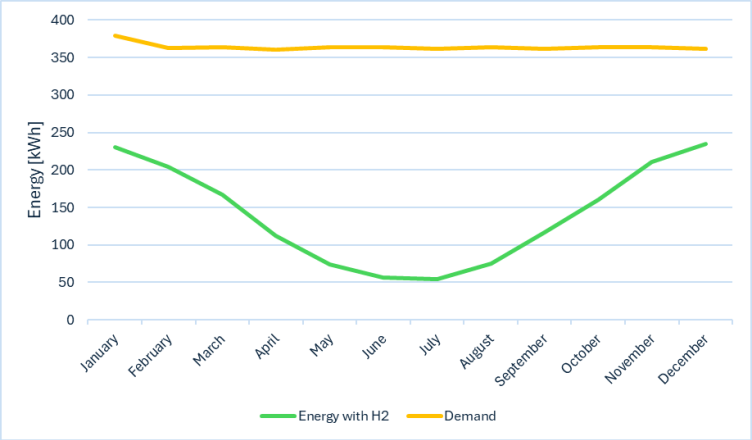


Figure 4. Monthly supply of H2 and EV charging demand for the apartment complex

By calculating the energy generated by the PV system and the energy recovered through the conversion process, the overall process efficiency is obtained, which is approximately 35%. This indicates that when H_2 is used as an energy storage medium, around 65% of the initial energy is lost throughout the process due to the multiple conversion stages before the ultra-fast charger: Case 3 converts solar irradiance to power in PV cells, then that electricity is used to generate H_2 (with an efficiency of approximately 70%), which is stored in a tank, and then reconverted to electricity in a fuel cell (with an efficiency of approximately 50%), which is finally used for charging. In contrast, Case 2 only has one conversion stage: from supplied H_2 to electricity in a fuel cell, and finally, Case 1 does not perform any conversion since electricity is supplied by the electric grid.

This low efficiency is concerning, as it questions whether such technologies are indeed sustainable. However, evaluating sustainability is not simple. Given a future case in which the electric grid may become highly saturated or even experience frequent blackouts due to increased electrification, ultra-fast EV charging could be restricted, and H_2 conversion technologies could offer accessibility and resilience, both dimensions of sustainability. Eventually, multi-criteria evaluations could consider technical and accessibility trade-offs for a comprehensive sustainability assessment.

Economic Evaluation

Table 7 presents the investment costs of the main equipment required to enable residential charging using H2. It is important to note that, among the three cases analysed in this study, the first case requires only an EV ultra-fast charger. In the second case, a H2 tank, a fuel cell, and the EV charger are required, whereas in the third case all the equipment listed in the table is necessary.

Table 7. Summary of capital expenditure costs for each residential complex

CAPEX	Housing complex			Apartment complex		
Equipment	**Qt.**	**Net cost [USD]**	**Cost after taxes [USD]**	**Qt.**	**Net cost [USD]**	**Costs after taxes [USD]**
PV modules	468	37,675	47,524	400	32,199	40,616
Electrolyser	1	51,405	64,842	1	42,059	53,053
H_2 Compressor	1	49,535	62,484	1	49,535	62,484
H_2 Tank	2	4,633	5,390	2	4,633	5,390
Fuel cell stack	1	27,250	34,374	1	27,250	34,374
EV ultra-fast charger	1	53,775	67,832	4	549,529	462,118

Table 7 shows that the costs associated with the apartments are significantly higher compared to the houses. In Case 3, the investment required for the building approximately doubles that of the housing complex. The main difference lies in the number and capacity of the ultra-fast chargers, as the apartment complex requires four 400 kW chargers, whereas the housing complex requires only two 200 kW chargers. The selection of the fuel cell, in this case, was based on the maximum charging power, which ensures effective ultra-fast charging. It is worth noting that if smaller equipment were selected, the feasibility of Case 3 could be improved; and since charging has varying power, there are times when the full capacity is not fully utilised. This could be a matter of future research, to evaluate configurations with lower investment costs, at lower levels of fast charging instead of ultra-fast charging.

Figure 5 and **Figure 6** show the minimum energy charging sale price required for the project to achieve a positive Net Present Value (NPV). These cases assume an initial electricity price of 0.33 USD/kWh and a conservative 5% annual growth. The corresponding NPV at this sale price is also reported. **Figure 5** presents the results for the three case studies in the housing complex, while **Figure 6** shows the results for the apartment building. It is important to highlight that, in both cases, the highest NPV is obtained in Case 2, with sale prices similar to those of Case 1. In contrast, Case 3 requires a significantly higher sale price and results in a lower NPV.

It can be observed that, for Case 1 in the housing complex, the required charging price is relatively close to the current reference values in commercial chargers and could therefore be considered feasible. However, in Cases 2 and 3, the required prices increase significantly, reaching approximately twice and up to five times the current market price, respectively. Given these high costs, H_2-based solutions for ultra-fast charging are unfeasible for the residential scale today, and their eventual deployment in the near future would require important support from subsidies.

For the apartment complex, the prices exhibit less variation across the three cases compared to the condominium. This behaviour is explained by the higher annual energy demand of the apartments, for which a marginal increase in the charging price has a more pronounced impact on the revenue. For Cases 1 and 2, the resulting prices remain close to the assumed market values, whereas for Case 3, the minimum required price rises to more than twice the current market price.

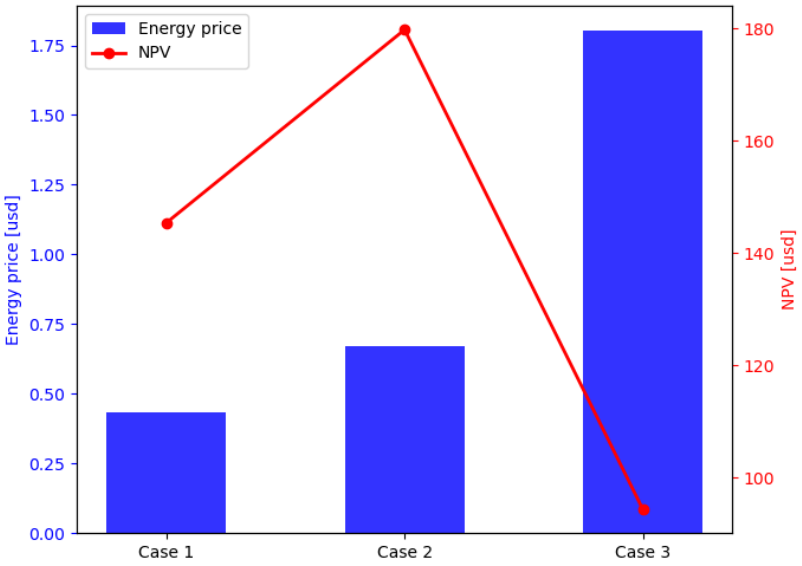


Figure 5. Resulting minimum energy charging price and NPV for each case studied in the housing complex

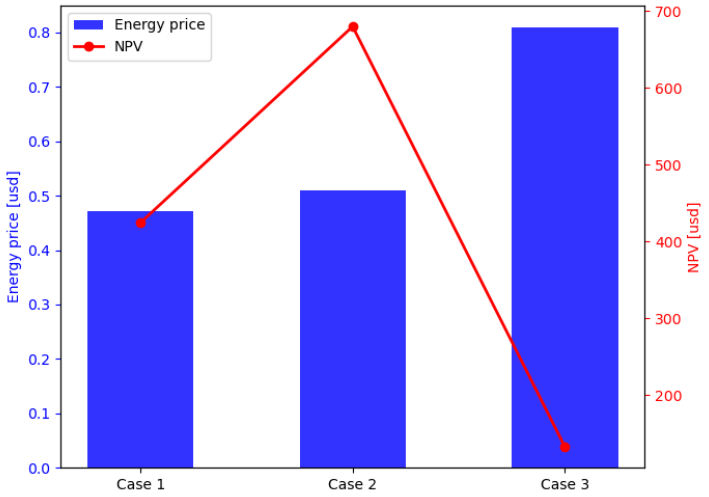


Figure 6. Resulting minimum energy charging price and NPV for each case studied in the apartment complex

Figure 7 and **Figure 8** present a sensitivity analysis conducted for Case 2, in which EVs are charged using a fuel cell and H_2 is stored in tanks. This analysis illustrates how the expected Net Present Value (NPV) of the project changes as four different parameters are varied: discount rate, annual grid electricity price increase, first-category tax, and loan amount. The behaviour of the NPV with respect to these parameters is consistent for both apartment buildings and condominiums. Specifically, the resulting NPV decreases as the discount rate and first-category tax increase, and the NPV increases as the annual grid electricity price increases and loan amount rises.

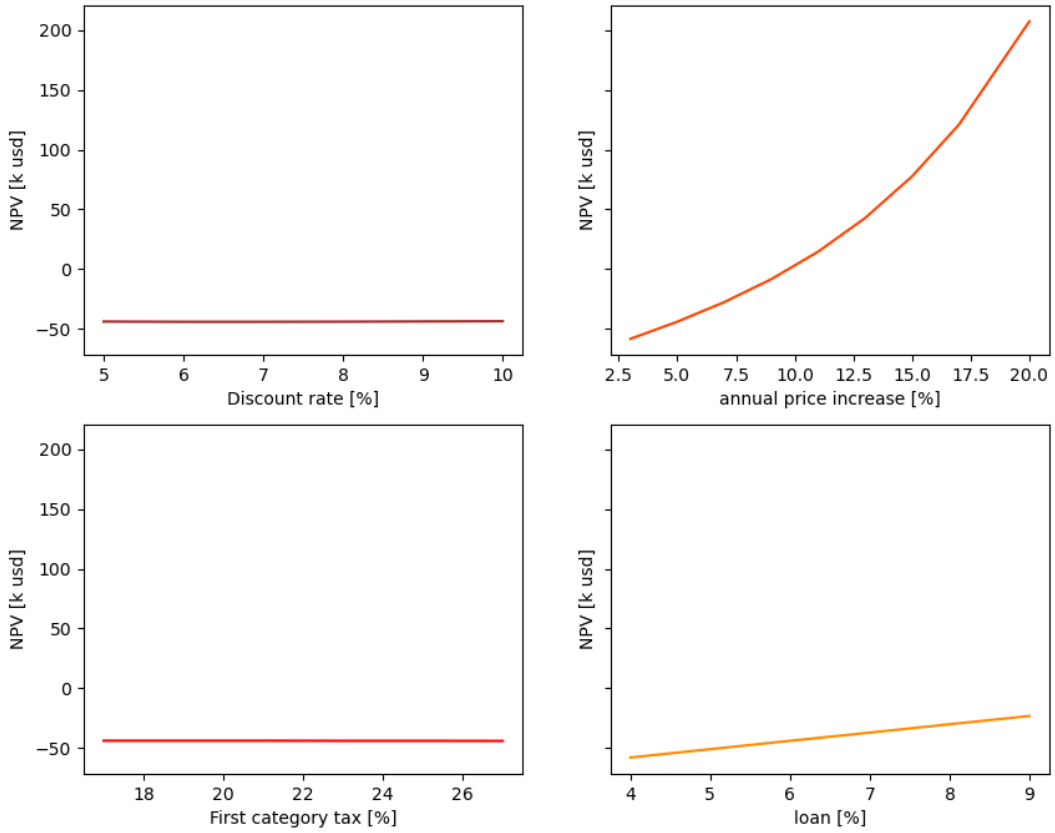


Figure 7. Sensitivity analysis of the economic indicators for case 2 in the housing complex

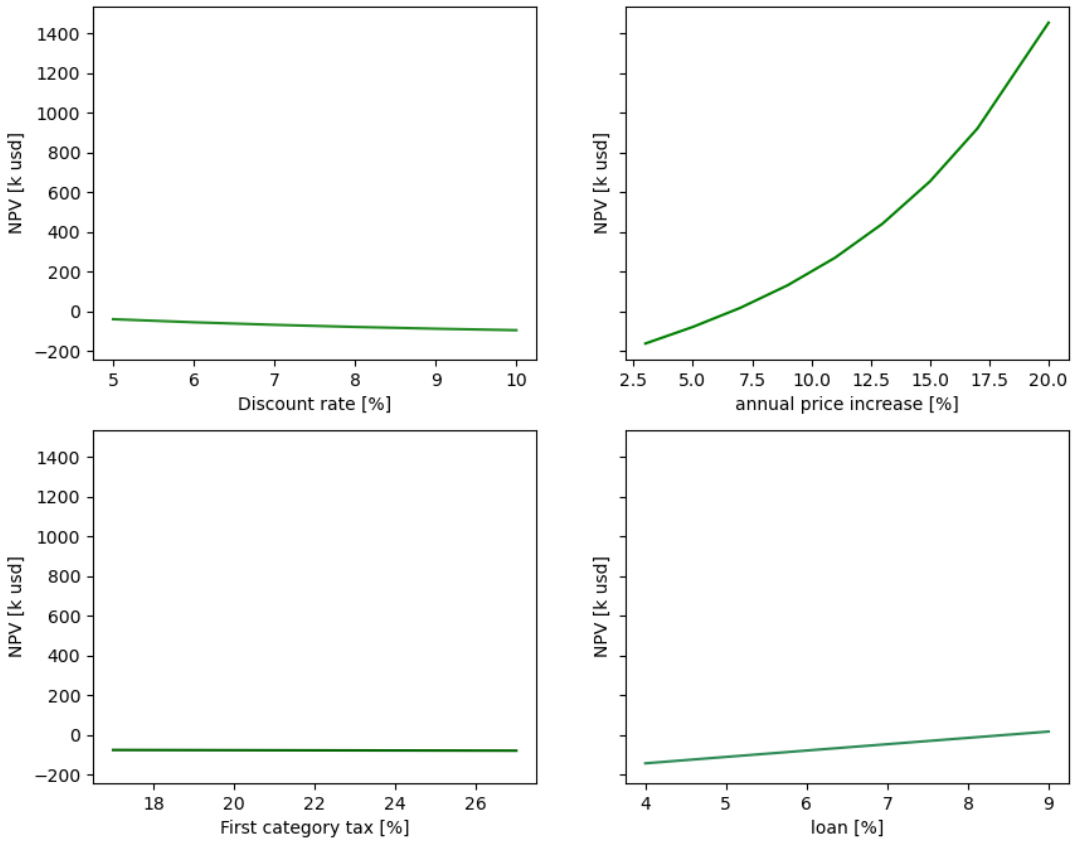


Figure 8. Sensitivity analysis of the economic indicators for case 2 in the apartment complex

From the sensitivity analysis shown in **Figure 7** and **Figure 8**, it can be observed that although the discount rate influences the NPV, its impact is not significant. Regarding the first-category tax, its influence on the NPV is practically negligible. For instance, over a variation range of 10 percent, the NPV for the housing complex changes from −33.7 thousand to −34.1 thousand USD, and for the apartment complex from −74.5 thousand to −77.5 thousand USD. In contrast, the annual increase in the electricity charging price (per kWh) exhibits a strong influence on the NPV. If a 20% annual increase – similar to that observed in 2024 – is assumed, profits of up to 250 thousand USD for the condominium and approximately 1.4 million USD for the building could be achieved.

Finally, **Table 8** presents the results for the two key indicators: the Levelised Cost of Electricity (LCOE) and the Levelised Cost of Hydrogen (LCOH) for both residential settings. These indicators reflect the economic feasibility of electricity and H_2 generation, respectively. They are calculated for Case 3, as it is the only case in which both H_2 and electricity are produced for charging purposes.

Table 8. Summary of resulting levelized costs for each residential complex in Case 3

Residential complex	LCOE [USD/kWh]	LCOH [USD/kg]
Houses	0.67	9.442
Apartments	0.689	9.752

When analysing the LCOE, similar values are obtained for the housing complex and the apartment complex. This is because, although the housing complex incurs in higher costs, its

greater energy production offsets this increase, resulting in comparable LCOE values. According to [31], the solar LCOE for small scale photovoltaic plants in Chile is approximately USD 57.1/MWh. The values obtained in this study are considerably higher than those reported in the reference. This difference is mainly attributed to the high investment costs combined with relatively low energy production for the level of investment required; in other words, due to an underutilisation of the projected charging infrastructure.

In the case of the LCOH, a value of 9.442 USD per kg of H_2 is obtained for the housing complex, while a value of 9.752 USD per kg of H_2 is estimated for the apartment complex. These values are relatively similar, consistent with the results observed for the LCOE. According to [31], the cost of producing, compressing and storing one kilogram of green hydrogen is 6.13 USD. As in the case of the LCOE, the results obtained from the economic analysis shows that the LCOH are higher for the studied case than those reported in the literature. This outcome can be explained by the high costs associated with H_2 production at this scale, combined with a production capacity that is not well matched to the level of investment, and a degree of underutilisation since ultra-fast charging does not demand a constant power.

Since the electricity cost has seen considerable changes in the past years, a final sensitivity study is performed considering the actual electricity price variations observed in the past five years (Nov 2020 to Jan 2026 [32]), as shown in Figure 9. The BT4.3 tariff was selected since it can deliver the power range needed for the considered EV chargers.

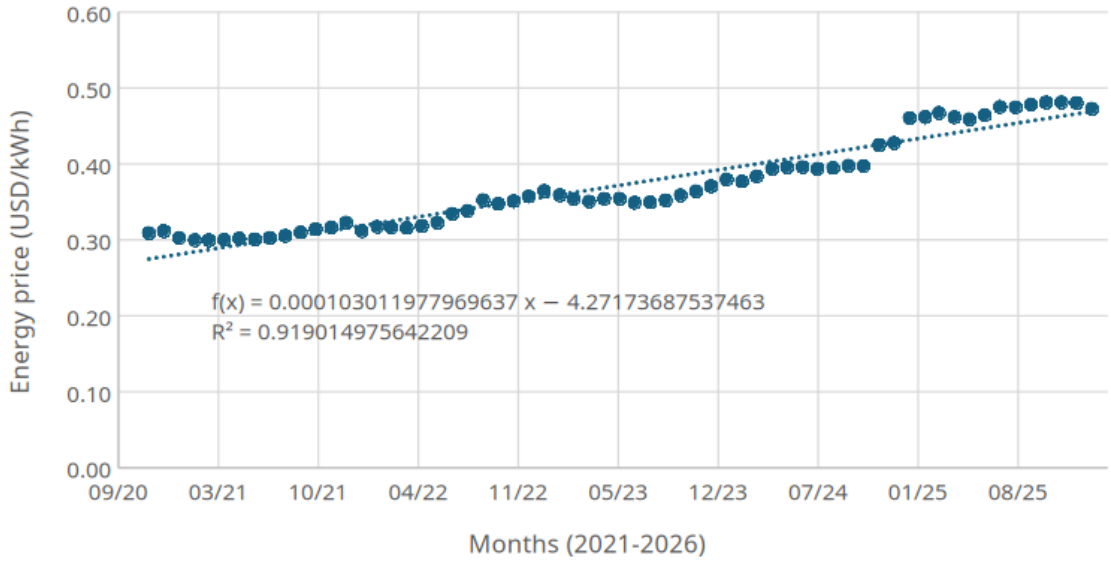


Figure 9. Observed monthly electricity price for the BT4.3 tariff in Santiago

Based on the observed electricity price, a linear regression is used to deliver a price projection for the following 20 years, taking an average case and two variations: a pessimistic and optimistic case, by either adding or subtracting the standard deviation of the observations. The resulting NPV, calculated for each case study considering a loan, is compared to the base case in Table 9. The results with the projections are highly profitable compared to the original cases. The reason behind this difference is the high increase in electricity prices that has been observed in the past years in Chile, which ranges from 8% to 19% annually. While the result sounds promising, we caution that the local context does not assure that prices will continue to increase; since part of the increase was a calculation error that is expected to be partly reverted during 2026 [32]. However, it is still an interesting contrast to actually observe the dramatic effects of such an increase in the estimated profitability of this type of projects.

Table 9. Resulting NPV (USD) considering increasing electricity prices for the cases with a loan

Apartment complex	**Case 1**	**Case 2**	**Case 3**
Original	-32,874	-79,533	-510,313
Projected mean price	232,727	190,806	-224,008
Optimistic projection	248,534	206,979	-206,294
Pessimistic projection	216,715	174,519	-241,722
Housing complex	**Case 1**	**Case 2**	**Case 3**
Projected mean price	2,925	-44,217	-253,480
Optimistic projection	44,720	1,684	-204,490
Pessimistic projection	47,201	4,432	-201,516
Projected mean price	42,221	-1,088	-207,465

Limitations and Future Work

The resulting low competitiveness of H2-based solutions raises an important question. Are there other technologies that could be an alternative? The closest alternative are other storage systems, especially battery energy storage systems (BESS), which were not included in the present study. Even though BESS costs could be high, future work economic evaluation could be performed to evaluate its feasibility at the multifamily household residential scale. A high-power output would be desired for ultra-fast charging, which could lead to high investment costs; however, they have a high roundtrip efficiency (close to 90%) and therefore have lower conversion losses than H_2-based systems.

If, instead, EV charging does not have to comply with the ultra-fast standard, many other options may be more competitive, and even single household charging could be more convenient for housing complexes where parking spaces are close to electric outlets, especially by freeing users of charging time restrictions. However, the communal analysis would continue being a matter of innovation and research for apartment complexes due to the lack of space and lack of access to electricity in all parking spaces.

Another limitation of the present study is the overly deterministic demand model, which could greatly benefit from real-world data if available, or by including statistical deviations of the users' expected behaviour. Still, this is an interesting area of innovation for EV charging startups and developers that are considering solutions for multifamily households. Representing and evaluating their proposals with a techno-economical basis could be a good way to accelerate the transition to sustainable transportation.

CONCLUSIONS

This study demonstrates the technical feasibility of integrating H_2 conversion into ultra-fast charging infrastructure for apartment buildings and housing complexes. The required equipment to enable charging powered by H_2 can be procured and installed, confirming the potential for sector coupling between renewable generation, H_2 storage, and mobility. However, for most of the cases analysed, the proposed solutions are not economically feasible.

Results indicate that the economic feasibility of Cases 1 and 2 can be achieved when loans are considered and when the electricity sale prices are slightly higher than current market prices. In contrast, Case 3, which integrates on-site solar-to-H_2 conversion, is not economically feasible, and would require large subsidies for its deployment. Therefore, from an economic perspective, and with minor adjustments to the assumed prices, Cases 1 and 2 could become viable, indicating the potential feasibility of integrating H_2 into EV charging infrastructure

when hydrogen is supplied externally, offering an option to reduce investment costs and provide grid flexibility.

Multiple parameters influence the economic feasibility of the proposed ultra-fast charging projects, with the electricity price and the financing proportion through loans standing out as particularly significant. In addition, several external factors affect feasibility, such as the current state of H_2, which, as an emerging Power-to-X technology, is characterized by a limited market penetration and restricted supply chains. Moreover, the equipment currently available for green H_2 production and conversion is typically designed for large-scale applications, which substantially increases costs when deployed in smaller projects.

Nevertheless, as H_2 production and demand is projected to increase, technology maturity and diversification are expected to deliver cost reductions and improved features. These developments could significantly improve the economic viability of projects that integrate H_2 production and storage into EV charging infrastructure, increasing the resiliency of energy networks.

Future work should focus on evaluating different EV charging configurations and flexibility solutions, including the optimal number of chargers and scheduling in different multihousehold settings, the effect of users not charging as scheduled, as well as considering fast charging instead of ultra-fast charging for better system utilisation. New research efforts should also include the input of actual residents to assess user preferences and social feasibility. Another research direction is evaluating synergies that could increase the utilisation of residential EV charging systems, such as providing daytime charging for a commercial EV fleet, or evaluating the potential of working as a daytime public charging station.

Overall, this study contributes to the ongoing discussion on resilient and robust energy networks powered by renewables, highlighting the role of hydrogen-based Power-to-X pathways in enhancing grid balance and system flexibility.

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NOMENCLATURE

Abbreviations

CCCV	Constant Current Constant Voltage
CLP	Chilean Pesos
DFN	Doyle-Fuller-Newman
EV	Electric Vehicle
H2	Hydrogen
LCOE	Levelised Cost of Energy
LCOH	Levelised Cost of Hydrogen
MSCC	Multiple Stage Constant Current
NPV	Net Present Value
PV	Photovoltaic
SOC	State of Charge
SUV	Sport Utility Vehicle

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APPENDIX – Equipment Selection

For the three cases considered, different equipment units were selected to adequately build a cost structure and perform an economic evaluation. This Appendix contains the details of the equipment selection and main equipment features.

Several electrolyser options were initially evaluated, including models from Plug Power, Accelera, Hygreen Energy, Cummins, and LONGi. These units were designed for industrial-scale projects and deemed unsuitable for the residential scope of this study. For example, the Plug Power EX-2125D has a production capacity of up to 2,125 kg of H_2 per day, while the housing complex and building require only around 10 kg per day.

The final choice was the AEM electrolyser from Hygreen Energy [33], which uses an anion exchange membrane for H2 production. Although the company offers models up to 500 kW, smaller capacity units were selected to match project requirements. Based on average solar generation hours and daily hydrogen demand, the building was estimated to require 8 Nm^3/h and the housing complex 10 Nm^3/h. Using the technical specification of 4.4 kW per Nm^3, the required electrolyser sizes were calculated as approximately 36 kW for the apartments and 44 kW for the housing complex.

Cost analysis was carried out using reference values from H2 production studies. While no specific price range was available for AEM electrolysers, PEM and alkaline units were reported at approximately 1,000 USD/kW and 1,400 USD/kW, respectively [34]. A mean value of 1,200 USD/kW was adopted for estimation. Under this assumption, the cost of the electrolyser was calculated at 52,800 USD for the housing complex and 43,200 USD for the building. Although the AEM technical datasheet did not specify lifetime, bibliographic references suggest an expected service life of around 15 years [35].

Hydrogen storage presents several alternatives, each with specific advantages and challenges. Storage at atmospheric pressure is the simplest option, requiring no additional equipment, but the low density of H_2 under these conditions results in very large volumes and significant space requirements. Liquid storage increases density but demands extremely low temperatures (around –253 °C), requiring highly efficient refrigeration systems that raise both investment and operating costs while reducing overall energy efficiency.

To balance feasibility and efficiency, H2 storage was set at 700 bar, a widely used pressure that increases density from 0.09 kg/m^3 to 42 kg/m^3. This approach reduces storage volume without incurring the high costs of liquid storage. Accordingly, a H_2 compressor capable of raising pressure from atmospheric levels to 700 bar was selected. The chosen equipment, supplied by Made-in-China, is priced between USD 37,000 and USD 65,000; the average value of USD 51,000 was adopted for the study [36]. Based on bibliographic references, the expected service life of compressors of this type is approximately 20 years [37].

The selected storage system is a Type IV cylindrical tank, designed to withstand 700 bar and with a capacity of 185 litres, enabling storage of up to 7.4 kg of H2 per unit [38]. Type IV cylindrical tanks are the current standard commercial solution for high-pressure H_2 storage (up to 700 bar), characterized by a non-metallic (polymer) liner encased in a carbon fiber

composite wrap. They are significantly safer than previous tank generations: Type I (all-metal) and Type II (metal liner, hoop-wrapped) are heavy and less structurally advanced, while Type III tanks (metal liner, full composite) still incorporate a metallic liner susceptible to fatigue and potential rapid, explosive failure [39]. Type IV tanks eliminate the metal liner, allowing the design to control failure; in the event of a catastrophic event or impact, the tank is engineered to rupture without fragmentation, ensuring a controlled release of hydrogen instead of creating an explosive projectile hazard [40]. As both the housing complex and the apartments building produce more than 7.4 kg of H_2 per day, two tanks are required. Price references for this equipment proved difficult to obtain; therefore, a benchmark value of USD 2,200 was adopted, based on a similar product listed on Alibaba [41]. The expected service life of the tank was estimated at 10 years, in line with bibliographic references for equipment of comparable characteristics [42].

Several fuel cell options were evaluated. Large-scale systems such as Plug Power's Megawatt-Scale Fuel Cell Power Generation System and Accelera's Fuel Cell Power Systems were excluded due to capacities far exceeding project requirements. Smaller units from Plug Power's GenSure line were also considered but proved insufficient. Ballard's Fuel Cell Power Module for Marine Applications offered a suitable maximum output and compact design, but its minimum operating power of 55 kW was incompatible with the study, as the minimum demand from the three vehicles is 26 kW. Both maximum and minimum output requirements need to be met for ultra-fast charging. The final choice was the Ballard FCgen® – HPS Durable heavy-duty fuel cell stack, which met the production requirements and offered the most compact and practical configuration [43]. This unit provides a maximum output of 160 kW. Based on cost estimates of USD 175 per kW [44], the total price was calculated at USD 28,000. Bibliographic references indicate a service life of 10 – 20 years; an intermediate value of 15 years was adopted for this study [45]. Efficiency was also considered: H_2 has an energy potential of 33.33 kW/kg, and fuel cells typically achieve 50% conversion efficiency, yielding a usable factor of 16.67 kW/kg, which was applied in the analysis [46].

The only technical requirement for selecting ultra-fast chargers was ensuring sufficient maximum power to meet the charging demand of the EVs. Several market options were evaluated, including models from Circontrol, Chargepoint, ABB, and Siemens. For the housing complex, the chosen unit was the Alpitronic Hypercharger HYC200 [47], with a maximum output of 200 kW and dual connectors allowing simultaneous charging. The equipment cost was estimated at USD 53,775 [48]. According to bibliographic references, the expected service life of the charger is approximately 10 years [49].

Finally, the solar PV modules were monofacial Kyocera 205 W [30], and considered an average reseller price of 55 USD per module [50]. The expected lifetime of the modules is 25 years [51].

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