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# PROFITABILITY STUDY OF THE INVESTMENT IN ELECTRIC VEHICLE CHARGING STATIONS, WITHIN A DISTRIBUTED GENERATION NETWORK

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The integration of electric vehicle charging stations into electricity distribution networks is a challenge for both grid managers and investors in this type of installation. This work aims to evaluate, from the point of view of investment profitability and levelized cost of energy, the integration of electric vehicle charging stations within an electrical distribution network with renewable distributed generation and storage, by means of battery banks. For the development of the model, the simulation tool HOMER(c) is used.

*Keywords:* Sustainability; electric vehicles; renewable energy; storage

# ESTUDIO DE RENTABILIDAD DE LA INVERSIÓN EN ESTACIONES DE CARGA DE VEHÍCULOS ELÉCTRICOS, DENTRO DE UNA RED CON GENERACIÓN DISTRIBUIDA

La integración de las estaciones de carga de vehículos eléctricos en las redes de distribución eléctrica supone un reto tanto para los gestores de la red como para los inversores en este tipo de instalaciones. Este trabajo pretende evaluar, desde el punto de vista de la rentabilidad de la inversión y el coste nivelado de la energía, la integración de las estaciones de carga de vehículos eléctricos dentro de una red de distribución eléctrica con generación distribuida renovable y acumulación, mediante bancos de baterías. Para el desarrollo del modelo, se utiliza la herramienta de simulación HOMER(c).

*Palabras clave:* sostenibilidad; vehículos eléctricos; energías renovables; almacenamiento

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## 1. Introduction

The 2030 climate and energy framework targets proposed at the European growth strategy for the present decade, together with other strategies promoted by the European Union, have settled the objectives of reducing Greenhouse gas emissions (European Union Communication, 2014).

Because of the goal of the European Union of reducing the energy usage, electrical vehicles have become more popular among the community, due to their inherent capacity and objective of reducing CO2 emissions. Globally, 24% of total energy consumption is under the responsibility of “transportation” and considerable amount of this requirement met by fossil fuel production in 2018 (IEA et al., 2018). In order to help to reduce greenhouse emissions, an EU regulation (2019/631) set mandatory emission reduction targets for new cars for 2025 and 2030 (Regulation (EU), 2019). This Regulation provides a clear pathway for CO2 emissions reductions from the road transport sector such as 15% and 37.5% reduction of the average emissions of the new passenger car fleet from January 1, 2025 and from January 1, 2030, respectively (Regulation (EU), 2019).

The concept of Electric Vehicle (EV) charging stations arises in this context, with the intention of adjusting EV charging station principles to a highway near an urban district. By settling the mentioned principles and objectives to a highway charging station, the strategy of considering different energy generation and consumption sources brings the possibility of revealing different tolls on the electrical grid.

Accordingly, the Highway Charging Station approach has the objective of addressing the rapid and demanding charges of electrical vehicles and the issues that may arise on the grid which are fundamentally based on energy performance and renewable energy generation near its consumption site. Regarding the performance aspect, the influence of batteries and the context of their surroundings are taken into account to obtain a higher energy performance assessment accuracy (Amaral et al. (2018)).

Hybrid power systems using Renewable Energy Sources (RES) are becoming most popular due to their potential advantages (Rohani et al. (2010)). The concepts of Photovoltaic (PV) and Wind energy are well known, as well as the technologies for these energy resources. However, the variation of solar/wind energy generation does not match with the energy consumption, and a storage system must be used to ensure the energy availability. Research developed worldwide indicates that a hybrid system including PV, wind and batteries is a reliable source of electricity (Borowy and Salameh (1996)), (Jalilzadeh et al. (2009)).

National Renewable Energy Laboratory’s (NREL) Hybrid Optimization Model for Electric Renewable (HOMER) software has been employed to carry out the present study. It performs comparative economic analysis on a distributed generation power system.

Inputs to the model will perform an hourly simulation of every possible combination of the components and rank the resulting systems according to the criteria specified by the user, such as cost of energy (COE, €/kWh) or Internal Rate of Return (IRR). Furthermore, the tool can perform “sensitivity analyses”, where the values of certain parameters (for example, cost of the energy obtained from the grid) are modified, in order to analyze their impact on the system configuration (Homer1).

## 2. Methodology

In this paper, the simulations have been analyzed using the simulation software HOMER® to evaluate and determine the cost of different models.

### 2.1 Modelling Software

The software was developed by the NREL (Homer1) and is generally used for the design and analysis of hybrid power systems. In this paper, the previously explained electrical load, solar radiation and wind speed data are used as input data, together with component details and costs.

### 2.2 Cost analysis procedure

1. Net Present Cost (NPC): NPC indicates the installation and the operating cost of the system throughout its lifetime. The following formula is used to calculate the NPC (Homer2), (Nurunnabi and Roy (2015)):

   $$NPC = \frac{TAC}{CRF(i, Rpr_j)} \tag{1}$$

   Where, *TAC, CRF, i* and *Rprj* are the total annualized cost, capital recovery factor, interest rate in percentage, and project lifetime in year, respectively.

2. Total annualized cost (TAC): It is the sum of the annualized costs of every component of the system, together with operation, maintenance, and replacement costs (Rezzouk and Mellit (2015)), (Nurunnabi and Roy (2015)).
3. Capital Recovery Factor (CRF): It is a ratio used to calculate the present value of a series of equal annual cash flows (Rezzouk and Mellit (2015)), (Nurunnabi and Roy (2015)).

   $$CRF = \frac{i \cdot (1 + i)^n}{(1 + i)^{n - 1}} \tag{2}$$

   where, *n* represents the number of years and *i* the annual real interest rate, respectively.

4. Annual real interest rate: Is a function of the nominal interest rate shown as (Rezzouk and Mellit (2015)), (Nurunnabi and Roy (2015)):

   $$i = \frac{i' - F}{1 + F} \tag{3}$$

   where *i* is the real interest rate, *i’* the nominal interest rate and *F* the annual inflation rate.

5. Cost of the Energy (COE): Is the average cost of each kWh of useful electrical energy produced by the system. The COE is calculated as follows (Rezzouk and Mellit (2015)), (Nurunnabi and Roy (2015)):

   $$COE = \frac{TAC}{L_{prim,AC} + L_{prim,DC}} \tag{4}$$

   where, *Lprim,AC* and *Lprim,DC* are the primary Alternative Current and Direct Current, respectively.

## 3. System Description and Setup

Model simulation software needs some input data to optimize the results of the simulations.

### 3.1 Load profile

Based on the hourly usage and peak usage moments of a normal gas station, the total load profile of the EV charging station has been stablished. Table 1 shows the hourly EV visits to the charging station. As a result, a total energy consumption of 9914 kWh/day has been stablished. Figure 1 shows the profile of the daily average consumption load per hour of the highway EV charging station, in which 17:00 to 21:00 h time lapse is considered the peak of the load, with a peak load of 10 visits/h or an equivalent of 1500kW. Figure 2 shows the monthly average consumption per hour in the proposed EV charging station.

**Figure 1. Profile of the daily average energy consumption**

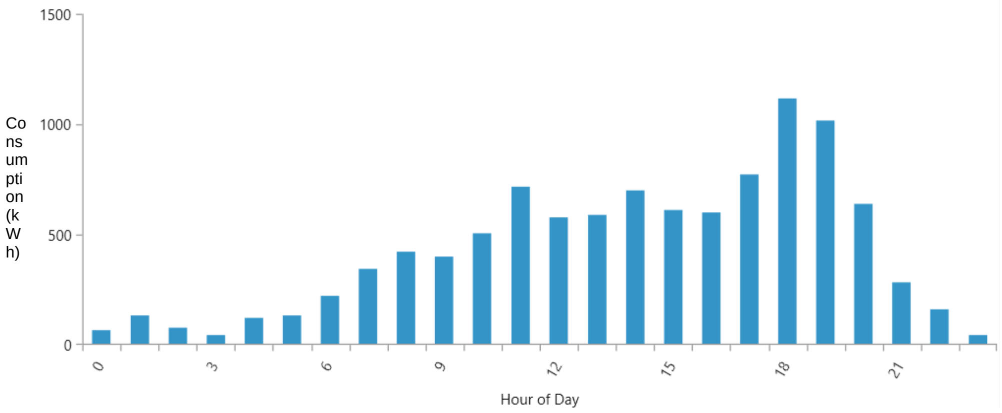
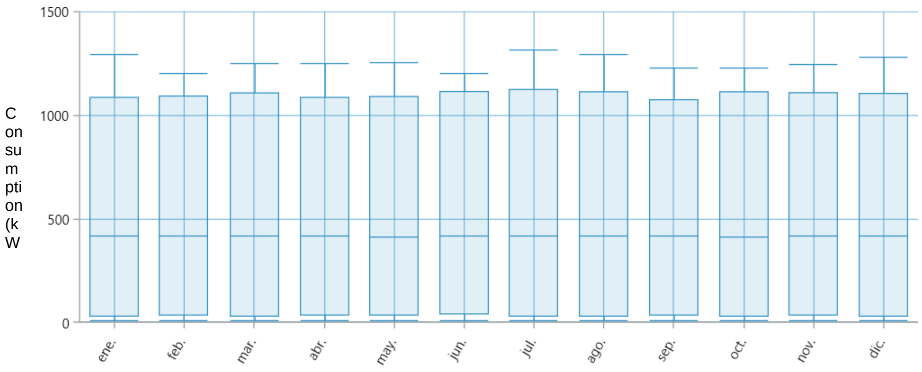


**Figure 2. Profile of the monthly average energy consumption**



### 3.2 Wind speed and Solar Radiation

The model brings the option of downloading the data of the wind speed and the solar radiation of the selected location from NASA surface meteorology and solar energy database.

Figure 3 shows the monthly average radiation data and the clearance index. Monthly average wind speed data of Seville are shown in Figure 4, with a minimum value of 4,21 m/s in August, and a maximum of 5,75 m/s in December.

**Figure 3. Solar Radiation and Clearance Index**

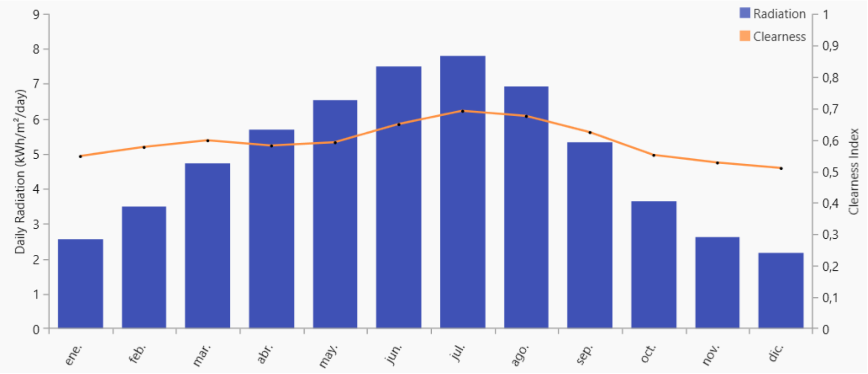
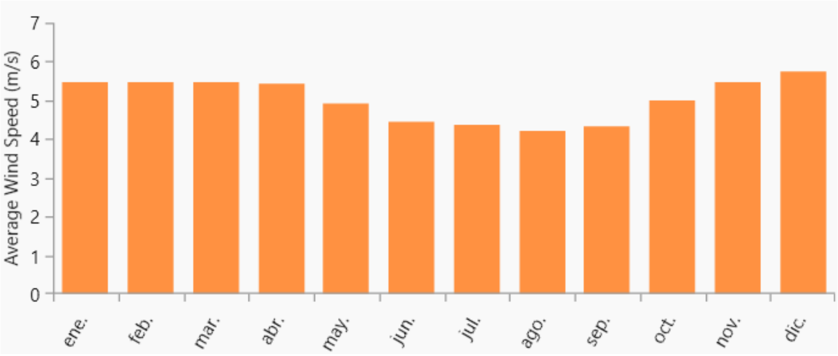


**Figure 4. Monthly average wind speed**



### 3.3 Grid

The grid is used as an energy source for the period in which renewable energy sources are not capable of producing all the energy the load requires. For the estimation of the energy price, the data of the energy price in Spain between August 2021 and July 2022 have been used (OMIE (2023)), and all the prices have been divided in five sections. Table 2 shows the energy price of each section.

**Table 1. Energy Prices of the Grid**

| Section | Price (€/kWh) |
|---|---|
| Section 1 | 0.3140 |
| Section 2 | 0.2607 |
| Section 3 | 0.2073 |
| Section 4 | 0.1539 |
| Section 5 | 0.1006 |

## 4. Simulation Model and Case Studies

The components used for the simulation of the system are selected from the internal library. As illustrated in Figure 5, the fundamental scenario serves as the basis for all simulations. The top left corner of Figure 6 (a) portrays the schematic of the fundamental system accompanied by the requisite batteries and inverter. The top right corner of Figure 6 (b) depicts the configuration of the subsequent system, which includes the same components as the former case along with the integration of PV elements. Similarly, the bottom left corner of Figure 6 (c) demonstrates the equivalent configuration as the previous case, however, the source of energy has been replaced with wind power supply. Lastly, the bottom right corner of Figure 6 (d) showcases the grid-interconnected system that has been subjected to simulations. This system contains PV generation, wind energy generation, power storage batteries, an inverter, the grid, and the load. Table 3 shows the selected elements for the system.

**Figure 5. Schematic of the EV Charging Station and Grid**

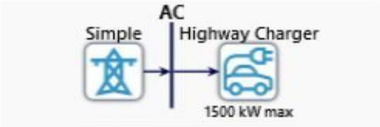
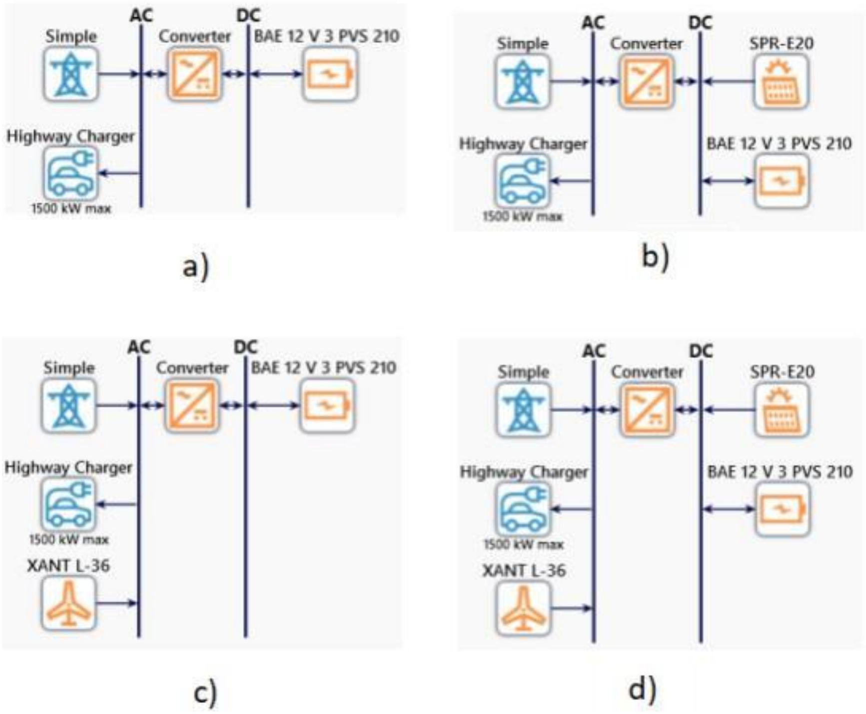


**Figure 6. Schematic of the battery-connected (a), system with solar (b), with wind (c), and with a combination of wind and solar (d).**



a)

b)

c)

d)

Once the system has been defined, it simulates all the different possibilities for the given PV and wind generation powers, with the objective of finding the best possible combination in terms of costs and benefits.

**Table 2: Components of the model**

| Component | Reference | Capacity |
|---|---|---|
| Inverter | ABB PSTORE-PCS | 2880 kW |
| PV Panel | SunPower E20-327 | 0.327 kW |
| Wind Turbine | Enercon E-82 E2 | 2000 kW |
| Battery | BAE SECURA SOLAR 12 V 3 PVS 210 | 2.41 kWh |
| EV Charging Station | Highway Charger | - |
| Grid | - | - |

## 5. Optimization and Results

In order to compare the outcomes of various scenarios, the fundamental system depicted in Figure 5, comprising solely of the grid and EV charging station, will be utilized as the reference. On this framework, the underlying system generates outcomes in which the energy procured from the grid and the electricity consumed by the EV charging station are superimposed upon each other. This outcome is expected due to the absence of additional components within the system.

With the objective of visualizing the efforts from the grid at the given location and load profile, a simulation for each case has been made to find the results, using the previously stated components, for the different cases of Figure 6.

### 5.1 Batteries

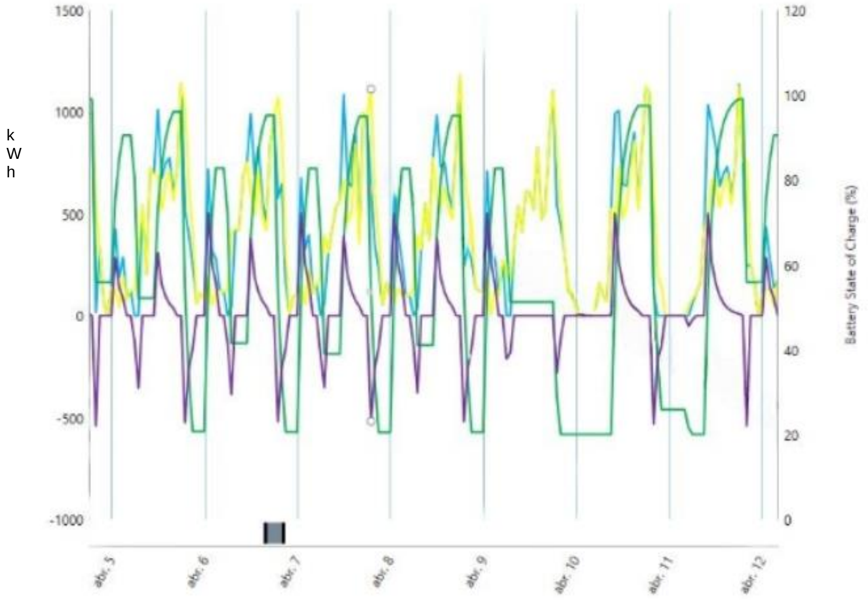
It shows the daily electricity consumption in kWh of EV Charging Station facility from April 5$^{th}$ to April 11th, 2021. The chart shows the performance of an energy system that includes battery storage, grid power purchases, and an EV charging station. The x-axis represents the date and time, and the y-axis is split into two parts: the left side shows power consumption in kilowatts per hour (kWh), while the right side shows the state of charge of the battery in percentage.

From the chart, we can see that the battery storage system plays a key role in balancing the energy supply and demand in the system. The green line shows the amount of energy stored in the batteries at any given time, while the purple line shows the amount of energy being used to recharge the EVs. The blue line shows the amount of energy purchased from the grid when demand exceeds supply, while the yellow line shows the power being supplied to the EV charging station.

Overall, this chart demonstrates how a combination of battery storage, and grid power can be used to balance the energy supply and demand in a system that includes an EV charging station.

The financial details and energy-related parameters of a proposed energy system with a Net Present Cost of 22.8M€. The system's capital expenditure (CAPEX) is estimated at 1.49 M€, with an operating cost of 1.65 M€ per year. The levelized cost of energy (LCOE) is projected to be 0.487 €/kWh, and the energy system's simple payback period is undefined. The net present utility bill savings are estimated at -67,344 €, and the annual energy charge savings are projected to be -5,209 €.

**Figure 7. Energy consumption of a grid-connected EV Charging Station with Batteries**



Note: Blue line represents the power purchased from the grid. Yellow line is the power output to the EV charging station. Purple line is the power input to the batteries. Green line is the state of charge of the batteries.

These details suggest that the proposed energy system has a high initial cost and due to the savings per year resulting negative, it can be deduced that the investment will not be returned. That is the reason why the simple payback time is undefined.

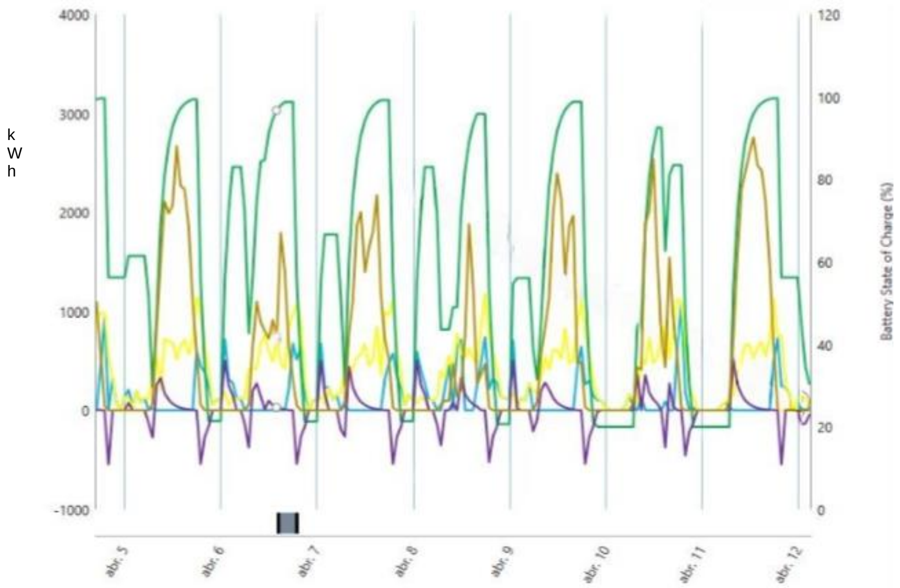
### 5.2 Combination of PV Energy, and Batteries

The peak value of the solar power is held on January 3rd, with 3429.77 kWh, whereas the peak value of the charging station is held on July 7th, with a value of 1317.5 kWh. The reason of this difference is that the same criterion for PV is to be used throughout the different simulation cases and PV value is as high as it is because of the last simulation parameters. It is acknowledged that the supply is higher than needs to be. Furthermore, the excess is sold back to the grid.

In this next simulation, the graphic provides financial and energy-related details of a proposed energy system with a capital expenditure (CAPEX) of 2.96 M€. The levelized cost of energy (LCOE) is estimated at 0.125 kWh, with an operating cost of 587,003 €per year. The net present cost (NPC) of the system is projected to be 10.5 M€. The proposed energy system has an internal rate of return (IRR) of 33%, and a simple payback period of 2.8 years. The energy system is expected to yield annual utility bill savings of 1.26 M€. The annual energy charge savings are also projected to be 1.26 M€.

Based on these details the proposed energy system has a high initial cost but has the potential to yield significant cost savings in the long run, making it an attractive investment opportunity for companies seeking to reduce their energy costs and environmental impact.

**Figure 8. Energy consumption of a grid-connected EV Charging Station with Batteries and PV energy supply.**



Note: Blue line represents the power purchased from the grid. Brown line is the solar power supply connected to the system. Yellow line is the power output to the EV charging station. Purple line is the power input to the batteries. Green line is the state of charge of the batteries.

### 5.3 Combination of Wind Energy, and Batteries

In this third scenario, where wind energy replaces PV energy as the only renewable energy source, the chart appears to show the performance and usage of an electric vehicle (EV) charging station with integrated battery storage and wind power input.

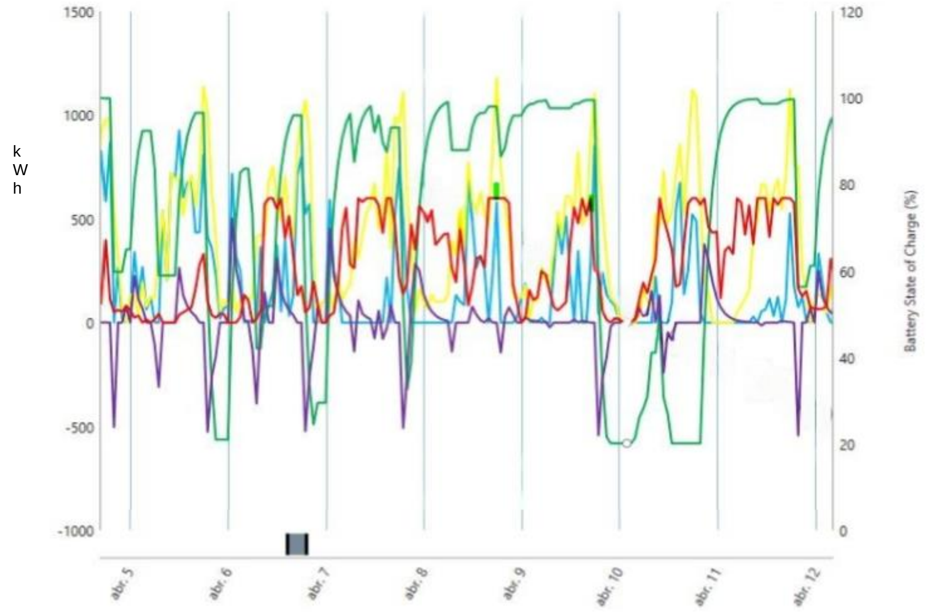
From the chart, we can see that the state of charge of the batteries fluctuates throughout the day, as energy is stored and discharged to meet the demand for charging EVs and other loads. The blue line shows that the station purchases energy from the grid during periods of low wind generation or high demand. The yellow line shows that the charging station serves varying amounts of energy to the EVs throughout the day, depending on the number of EVs charging and their charging rates. The red line shows that wind power contributes to the charging station's energy supply during periods of high wind generation. The purple line shows that the batteries supplement the charging station's energy supply during periods of high demand or low wind generation.

Overall, this chart demonstrates the complex interactions between different energy sources and loads in an EV charging station with integrated battery storage and renewable energy input.

This input represents the economic parameters of a specific energy system. The Net Present Cost (NPC) for this system is at 16.5 M€. The Levelized Cost of Energy (LCOE) is at 0.330 €/kWh. The operating cost per year is 1.03 M€, which is higher than the first two examples. The initial capital expenditure (CAPEX) for this system is 3.1 million euros, which is the lowest of the three examples. The internal rate of return (IRR) is 15%, which is also lower than the previous examples. The simple payback period is 5.5 years, which is the highest of the three examples. The utility bill savings per year are 633,528 €, which is lower than the previous examples, and the net present value of these savings is 8.19 M€. The energy charge savings per year are the same as the utility bill savings, at 633,528 €.

This system has a higher net present cost but a lower LCOE, operating cost, and energy charge savings in comparison to the previous simulation. It also has a longer simple payback period and lower net present utility bill savings. However, the CAPEX and IRR for the current system are lower.

**Figure 9. Energy consumption of a grid-connected EV Charging Station with Batteries and wind energy supply.**



Note: Blue line represents the power purchased from the grid. Red line is the wind power supply connected to the system. Yellow line is the power output to the EV charging station. Purple line is the power input to the batteries. Green line is the state of charge of the batteries.

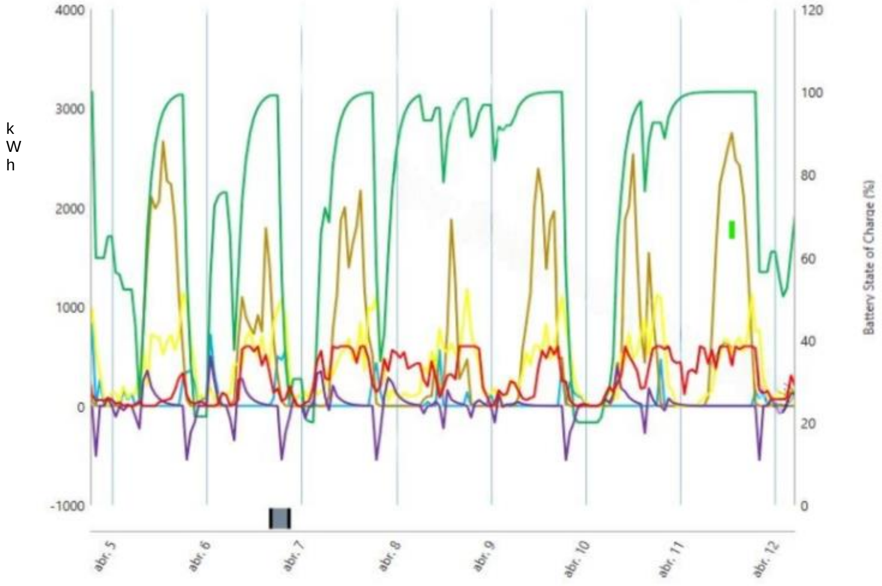
## 5.4 Combination of PV and Wind Energies, and Batteries

This system consists of a conglomeration of all the components previously stated. In this simulation it can be seen that the purple line, the line that represents the battery input to the system is smaller than on previous simulations. It is not as valuable as before because the combination of renewable energy sources is on many occasions enough to fulfill the need of the EV charging station. There are periods of time, however, where the battery is almost totally discharged, up to 20% charge minimum, set as an input in the system. the battery's level of charge is influenced by several variables, such as input from the grid, wind and solar power, and output to the EV charging station. If the cost of purchasing power from the grid is high at specific times, the battery might be discharged instead of using that expensive energy source. This can cause the battery's state of charge to decrease, as seen on the graph with a lower green line.

This simulation provides information with a NPC of 7.19 M€. The LCOE is 0.0727 €/kWh, which is lower than the previous example. The project has an operating cost of 210,897€/year, which is less than the previous example, but the CAPEX is higher at 4.46M€. The IRR is 30%, which is slightly lower than the previous example. The Simple Payback (years) is 3.1, which is also higher than the previous example. The Utility Bill Savings per year is 1.65M€, which is higher than the previous example, and the Net Present Utility Bill Savings is 21.4€. The Energy Charge Savings per year is 1.65M€, which is identical to the previous example. Overall, this project has a lower NPC, higher LCOE, higher operating costs, higher CAPEX, and a lower IRR than the previous example. However, it has a higher Utility Bill Savings per year and Net Present Utility Bill

Savings, indicating a more significant potential for cost savings over time.

**Figure 10. Energy consumption of a grid-connected EV Charging Station with Batteries and PV-and wind-energy supply.**



Note: Blue line represents the power purchased from the grid. Brown line is the solar power supply connected to the system. Red line is the wind power supply connected to the system. Yellow line is the power output to the EV charging station. Purple line is the power input to the batteries. Green line is the state of charge of the batteries.

## 5.5 Economic comparison of the simulations containing batteries

**Table 3: Economic results for the analyzed alternatives**

| Energy System | Base Case (BC) | BC with Batteries | BC with Batteries + PV | BC with Batteries + Wind | BC with Batteries + PV + Wind |
|---|---|---|---|---|---|
| Net Present Cost (M€) | 19.3 | 22.8 | 10.5 | 16.5 | 7.19 |
| Capital Expenditure (M€) | 0 | 1.49 | 2.96 | 3.1 | 4.46 |
| Operating Cost (M€/year) | 1.5 | 1.65 | 0.587 | 1.03 | 0.211 |
| Levelized Cost of Energy (€/kWh) | 0.413 | 0.487 | 0.125 | 0.33 | 0.0727 |
| Simple Payback Period (years) | Undefined | Undefined | 2.8 | 5.5 | 3.1 |
| Internal Rate of Return (%) | Undefined | Undefined | 33 | 15 | 30 |
| Net Present Utility Bill Savings (M€) | 0 | -0.067344 | 0.0163 | 0.0819 | 0.0214 |
| Annual Energy Change Savings (M€/year) | 0 | -0.005209 | -1.26 | -0.633528 | -1.65 |

Table 4 provides an economic comparison of the four different simulations of energy systems that contain batteries, with varying combinations of solar and wind energy, all compared to a Base Case (BC), which is the case shown in the schematic of Figure 5. The examination of the numeric values presented in Table 4 enables a straightforward comparison and thorough analysis of the economic performance of each simulation. The precise evaluation of economic parameters is essential in identifying the most suitable energy systems for a particular application.

## 6. Conclusions

Based on the findings of the simulations, it can be concluded that while batteries offer numerous benefits for various applications, a system with batteries alone may not be a cost- effective solution. Despite the initial investment required to purchase and install batteries, the long-term financial benefits may not be sufficient to justify the expense.

However, the combination of renewable energies and batteries can be highly beneficial. This approach offers the advantages of both technologies, with renewable energies providing a sustainable and environmentally friendly source of power, and batteries offering efficient and reliable energy storage. The time difference between renewable energies and battery power sources, couples with the fact that batteries can be recharged and reused, ultimately leads to substantial cost savings over time.

In addition to the above conclusions, utilizing second-life batteries in energy systems offers potential benefits. These batteries extend lifespan, provide a sustainable and cost-effective solution, and maximize their value through repurposing for stationary energy storage. This approach promotes environmental sustainability, economic viability of renewable energy integration, and enhances overall efficiency, reliability, and cost-effectiveness of energy systems. Future research and practical implementations should consider the potential benefits of second-life batteries for sustainable energy solutions.

In future endeavors, it is advisable to incorporate a multicriteria decision-making tool to evaluate and determine the most suitable option for specific purposes. Such an approach can facilitate a comprehensive assessment of various factors, including economic considerations, environmental impact, and system performance, to make informed decisions regarding the optimal integration of renewable energies and batteries. By employing a multicriteria analysis, stakeholders can weigh the advantages and disadvantages of different options and select the most favorable solution tailored to their unique requirements. This methodology will enhance the decision-making process and ensure the selection of the most appropriate energy system configuration.

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7 AFFORDABLE AND CLEAN ENERGY

11 SUSTAINABLE CITIES AND COMMUNITIES