Article

Design and Simulation of Romanian Solar Energy Charging Station for Electric Vehicles

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Abstract: Since mid 2010, petrol consumption in the transport sector has increased at a higher rate than in other sectors. The transport sector generates 35% of the total CO₂ emissions. In this context, strategies have been adopted to use clean energy, with electromobility being the main directive. This paper examines the possibility of charging electric vehicle batteries with clean energy using solar autochthonous renewable resources. An isolated system was designed, dimensioned, and simulated in operation for a charging station for electric vehicles with photovoltaic panels and batteries as their main components. The optimal configuration of the photovoltaic system was complete with improved Hybrid Optimization by Genetic Algorithms (iHOGA) software version 2.4 and we simulated its operation. The solar energy system has to be designed to ensure that the charging station always has enough electricity to supply several electric vehicles throughout all 24 h of the day. The main results were related to the energy, environmental, and economic performance achieved by the system during one year of operation.

Keywords: charging station; electric vehicle; photovoltaic system; Romania; solar irradiation

1. Introduction

Under the Paris Agreement [1], governments have committed to the transition from fossil fuels to cleaner energy sources. Romania's main obligations under the Paris Agreement are to reduce greenhouse gas emissions by 43% by 2030 compared to 2005, and to participate in the European Union's efforts to reduce greenhouse gas emissions by 30% by 2030. The Paris Agreement's signatory countries agreed upon the long-term goal to limit global temperature increase to below 2 °C compared to pre-industrial times and to continue efforts to limit the growth to 1.5 °C to reduce the risks and impacts of climate change.

The new “Energy Strategy of Romania for the period 2016–2030 with perspectives for 2050” [2] has clean energy as its strategic objective, in line with European Commission (EC) Directives 2016/November 30, 2016 [3] (“Clean Energy for All”), and electromobility as a priority direction [4]. The strategy estimates that although the total distance traveled by cars in Romania will increase by about 35% by 2030, CO₂ emissions will remain constant. Consumption is forecast to increase by 6% by 2030 [5] as a result of the energy efficiency of new generations of engines.

The electric motor is characterized by high efficiency and a lack of emissions, resulting from the lack of combustion fuels. The main problem with the electric vehicle is the difficulty in storing electricity [6,7]. From a sustainability point of view, there is also the issue of emissions related to fossil fuel power generation. In time, electric vehicles are expected to play a central role as battery efficiency increases along with the production of large amounts of clean electricity [8].

One of the problems with electric cars that concerns potential customers is the lack of a charging station infrastructure or, in more developed countries, the limited size of this infrastructure [9]. People may not buy electric cars not only because they are expensive or have limited autonomy, but because “outlets are not everywhere” [10].

A major problem faced by electric vehicle production companies and governments is related to fears regarding the capacity of electric power distribution networks and how to address the imminent revolution in electromobility [11]. The actual electric power transportation network in Romania was established in the 1980s in order to ensure a maximum power of 12,000 MW on the national level on a daily basis, based upon the industrial momentum. However, the national capacity in Romania has been severely reduced, so that the national consumption varies between 6000 and 8000 MW. At least in theory, the national network has a power reserve of 50% from the initial design [2,6], which is enough to handle charging, even in the fast-charging mode, of a few thousand electrical vehicles in the next few years, without the network being a risk in the short term. The production and distribution of electric power will be tested by many consumers in the next few years.

After 2020, the number of cars with large and extra large batteries will increase substantially, and then electric power distribution will be a problem. Special attention is being paid to the decongestive knots in the capacity of network distribution in each zone, and especially big cities, where a large number of electrical vehicles are expected to be concentrated along with charging stations [12]. Concerns have also been expressed about isolated areas where there is no access to the national electric power distribution network.

“Strategy on the National Market Policy Framework for the Development of Alternative Fuels Market in the Transport Sector and for the Installation of Relevant Infrastructure in Romania” [13] provides for a minimum number of electric vehicles (EV) and plug-in hybrid electric vehicles (PHEV) feed and recharge points in urban agglomerations, but also in rural areas, thus ensuring broad access to alternative fuels infrastructure in the most populated and relevant areas of Romania. At the same time, the territorial arrangement of these areas ensures inter-urban and cross-border connectivity in relation to the Trans-European Transport Network (TEN-T), distances between proposed site locations or between these and the border areas not exceeding 150 km [13].

The further expansion of electric vehicles usage is currently prevented by the low availability of necessary public charging stations infrastructure [14,15]. The trend is that electric vehicle owners prefer charging stations to be at home or at work (city infrastructure concept). These charging stations may be slow-charging, in alternating current (AC) mode 2 or 3. In order to alleviate concentration from big cities, public fast charging stations will be located in supermarket parking spaces [16], lamp post, bollards, near highways or roads of European interest [17] and they should be strategically located to cover the long-distance intercity trips (city/country infrastructure concept). These charging stations may be rapid-charging, in AC mode 2 or direct current (DC) mode 4.

In an increasingly globalized context, Romania’s energy policy is taking place within the changes and developments that take place at the European and world level. Romania’s energy policy must be correlated with similar policies at the global level to ensure convergence in the field. From the point of view of the use of alternative fuels in mobile applications, Romania is in the process of aligning with European standards in the field.

In realization of the present work, actual relevant studies have been identified regarding the design, the optimization, the simulation of solar charging stations for electrical vehicles, different approaches being critically analyzed, but also the current state of the global implementation of these energy generating systems, based upon the green charging solar station concept for green electrical

vehicles. At the Romanian level the simultaneous approach of the two green concepts, green charging station powered by renewable energy sources and green electric vehicle, has not been developed and approached. The current paper aims to demonstrate the Green-to-Green concept (EC Directive 2016/30.11.2016—Clean Energy for All [3]) that means to combine electrical vehicle and renewable energy resources usage to reduce greenhouse gases emissions. In this respect, this paper proposes a solution with practical applicability, adapted to geographic characteristics and availability of Romanian solar irradiance, but can be developed anywhere in the world, taking into account the particular availability of local renewable resources. The present study represents an intermediate phase that is part of a complex research project [18], whose main objective is the implementation of advanced theoretical and technological solutions in order to provide some green fixed charging stations for electric vehicles (EV) and plug-in hybrid electric vehicles (PHEV). The desired final result is a pilot charging station which is 100% sustained by renewable energy resources. In this context, this paper represents a starting point for developing some comprehensive studies to demonstrate the utility of the presented technology in the energy sustainability of an EV and PHEV consumer. This study also represents a preliminary step in creating a database in order to establish useful premises for procedure elaboration, design standards, execution and implementation of safe conditions for energy generating systems with photovoltaic panels that can be integrated with mobile applications, electromobility, and includes elements of production, storage, transport and distribution—the necessary infrastructure for the development of a green renewable energy-based economy.

The availability of the location spaces together with urban conditions in Romania allows positioning of charging stations based on the Green-to-Green concept proposed by this paper, both in areas with urban agglomerations, as well as in rural areas [19]. In addition, the solar charging station for electric vehicles proposed in the study, through its presence in congested areas with a high power demand, can help stabilize the operation of the electricity distribution network, both by supplying EV and PHEV consumers, as well as through excess energy that can be used in other applications. Also, this type of charging station can be implemented both in areas that can and cannot connect to the public electrical network.

2. Materials and Methods

In order for this case study to be successful, it was necessary to define the input data [19–21] regarding the energy demand of the charging station for electric vehicles, the autochthon availability of solar resources, the characteristics of the energy conversion system, and the photovoltaic system's configuration, technical, environmental, and financial characteristics of the main components. It was also necessary to describe the mathematical and computational elements regarding the design and simulation [22,23] of Romanian solar energy charging stations for electric vehicles.

2.1. Electrical Load

The energy demand of the charging station for electric vehicles that were considered in this study had an average daily load value of 8.63 kWh/day, a direct current (DC) maximum hourly active power load of 360 W, and a DC maximum in half hour intervals of 415 W.

A constant load profile was fixed to establish the maximum system capacity, which was equal to the maximum energy demand that the photovoltaic charging station for electric vehicles could cover during the charging time [17,24].

2.2. Solar Energy Resources

Solar energy is the most important renewable energy resource, being virtually an inexhaustible source of energy. The potential for solar energy in Romania is relatively important, as it is the second sunniest area in Europe. Thus, for Romania, it is possible to define five sunny zones from the Coast area, Dobrogea, and in most southern areas, to a minimum of 1100–1200 kWh/m²/year in mountainous

areas and in the north of the country. In most regions of the country, the annual solar energy exceeds 1250–1350 kWh/m²/year.

Due to geographical location and climatic conditions, the potential of solar energy was characterized by daily average irradiation, which is presented in Figure 1 [25].

Figure 1. Daily solar irradiation [25].

Figure 1 highlights the potential of solar resources for a location in one of Romania's five sunny zones, but the worst site with regards to solar irradiation (Vatra Dornei) was selected to study the design and simulation of a solar energy system that supplies energy and charging stations for electric vehicles. For this location, the average monthly sunshine duration, calculated from multiannual statistical data, is shown in Table 1. The constant solar Cs averaged 1.355 kW/m².

Table 1. Average monthly sunshine duration [25].

Month	1	2	3	4	5	6	7	8	9	10	11	12
Average value (hours)	66.23	77.87	131.63	120.07	202.35	183.26	190.77	232.93	136.63	99.50	62.60	42.80

2.3. Solar Energy System Configuration

The system that sustains with energy the charging station for electric vehicles is shown in Figure 2. During the day, the electricity is supplied directly from the solar energy resources to the electrical vehicle by the DC bus. The energy generated by photovoltaic panels is charged into the batteries when the production from solar energy is greater than the load, and is discharged from the batteries when the production is lower than the demand of the EV charging station [26,27]. Additionally, it has been recommended to place a DC/alternating current (AC) inverter in the system, so if excess electricity is generated, it can be used in other types of applications [23,28].

Figure 2. Schematic diagram of the solar energy system. PV: Photovoltaic, EV: Electric vehicle, VSC: Voltage Sourced Converter, PHEV: Plug-in hybrid electric vehicles, DC: Direct current and AC: Alternating current.

The main components of the system were as follows:

1. Photovoltaic panels (PV) were in accordance with the data presented in Table 2. The loss factor was defined as the increase in power required for the PV generator to compensate for any loss from shadows, orientation, dirt in panels, etc. Usually, the value ranges between 1.1 and 1.3. For this study, the loss factor selected was 1.2 and the PV slope was 60° [29–31].
2. The batteries are lead-acid type, and the input data [32] used for the study are presented in Table 3. The data shown in Figure 3 were provided for each battery for the number of life cycles to failure ($Cycles_i$) for each depth of discharge (DOD_i %), which are displayed in red [30,33]. The simulation software used in this study calculated the cycled energy throughout the battery lifetime for each DOD. This value is displayed in gray.
3. The inverter selected for the solar system operation was a 900 VA inverter. Its main characteristics are shown in Table 4 and its efficiency diagram in Figure 4 [30]. The average power was 40% of the rated power of the selected inverter and the average efficiency considered was 88.9%.

Table 2. Characteristics of photovoltaic (PV) panels [29,30].

Item	Value	Unit
Nominal voltage	24	V
Shortcut current	8.39	A
Nominal power	280	Wp
Acquisition cost	126	€
Operation and maintenance cost	52	€/year
Expected lifespan	25	year
CO ₂ emissions in manufacturing	800	kg CO ₂ equiv/kWp
Weight	24.2	kg
Dimensions	1645 × 990 × 40	mm
Area	1.63	m ²
Operating temperature	−40 to 85	°C
Temperature coefficient I_{SC} (α)	0.03	%/°C
Temperature coefficient V_{OC} (β)	−0.34	%/°C
Temperature coefficient P (γ)	−0.43	%/°C
Maximum wind speed	2400 (219.40)	Pa (km/h)

Figure 3. Cycles to failure vs. depth of discharge for a battery.

Table 3. Battery characteristics [32,33].

Item	Value	Unit
Nominal Capacity	189	Ah
Voltage	12	V
Acquisition cost	227.5	€
Operation and maintenance cost	18	€/year
Expected lifespan	12	year
CO ₂ emissions in manufacturing	55	kg CO ₂ equiv/kWh
Weight	57	kg
SOC minimum	20	%
Self discharging	5	%/month
Intensity max.	37.8	A
Global efficiency	80	%

Table 4. Inverter characteristics.

Item	Value	Unit
Continuous power	900	VA
VDC _{min}	42	V
VDC _{max}	64	V
Pmax _{ren}	1015	W
Power 30 min	1100	VA
Acquisition cost	845	€
Operation and maintenance cost	42	€/year
Expected lifespan	10	year
Weight	9	kg

Figure 4. Diagram of inverter efficiency [30].

2.4. Analytical Description

The power generated by the photovoltaic panels was calculated using Equation (1):

$$P_{PV} = G_i \cdot I_{SC} \cdot F_p \cdot U_{DC} \quad (1)$$

where P_{PV} is power generated by the PV (kW_p), G_i is the hourly solar irradiation (kW/m²), I_{SC} is the short-circuit current (A), F_p is the factor of loss compensation by power due to shading, and U_{DC} is the DC voltage generated by the PV (V) [33,34].

The surface size of the photovoltaic panels was calculated according to the manufacturer's standard dimensions, specified in Table 1 with Equation (2):

$$A_{PV_total} = N_{PV} \cdot A_{PV} \quad (2)$$

where A_{PV_total} is the size of the PV generator (m²), N_{PV} is the number of PV modules needed to obtain the energy ensuring full load coverage during the worst month, and A_{PV} is the standard size of the PV unit (m²) [33,34].

The capacity of the solar energy system storage battery pack was determined based on the maximum load demand, calculated with Equation (3) as follows:

$$C_B = \frac{1000 \cdot T \cdot L_{max}}{N_{days} \cdot V_s} \quad (3)$$

where C_B is the capacity of the storage battery pack (Ah), T is the time of autonomy needed (days), L_{max} is the maximum load demand (kWh), N_{days} is the number of days in the worst month, and V_s is the bus nominal voltage (V) [35].

The cycled energy throughout the battery's lifetime is expressed as:

$$E_{cycled_i} = \frac{DOD_i}{100} \cdot \frac{Cycles_i}{1000} \cdot C_n \cdot V_n \quad (4)$$

where DOD_i is the depth of discharge (%), $Cycles_i$ is the number of life cycles to failure, C_n is the nominal capacity (Ah), and V_n is the nominal voltage (V) [33].

The number of equivalent cycles is calculated as:

$$N_{eq_cycles} = \frac{1000 \cdot E_{cycled_average}}{V_n \cdot C_n} \quad (5)$$

where:

$$E_{cycled_average} = \frac{\sum E_{cycled_i}}{9} \quad (6)$$

The terms in Equations (5) and (6) have similar meanings as in previous reports [33,34].

2.5. Virtual Simulation Condition

The optimization process had mainly two major components: Choosing the optimal components of the energy system (which was done using the multicriteria analysis methods [19,20,31] and constituted input data for the iHOGA software tool [30]) and optimization with simulation in operation of the energy system (which was done using the software tool).

Computational simulations were conducted with iHOGA software version 2.4 [30], which used the input data presented in the previous sections and supplied information regarding the energy, environmental, and economic performance of the solar energy system during one year of operation and financial performance for a 25-year lifetime.

iHOGA version 2.4 [30] is a computer tool for the optimum dimensioning of hybrid installations, including solar, wind, and hydraulic renewable energies, together with support systems, based on

storage (batteries), back-up generators (AC generators), and fuel cells (combined with electrolyser and hydrogen tanks). To achieve this, the software uses genetic algorithms that obtain the optimal combination of components and control strategies [30,33,34].

The optimization type was multi-objective [30,36,37] and conditions were chosen to minimize the following criteria [38]: Uncovered load/operation in stand-alone mode, CO₂ emissions, total system cost, excess energy, and power nominal/equipment components reported for ensuring energy demand.

The solar energy system has to be the appropriate size to ensure the charging station always has enough electricity to supply several electric vehicles throughout all 24 h of a day [39].

In this study, load following control strategy was adopted [30,33,34]. In this case, the operation principle of the solar energy system is based on two conditions. (1) If the power generated from renewable sources with photovoltaic panels is greater than the energy demand of the EV charging station, then the excess energy is stored in the battery. (2) If the power generated from the solar resources is less than the energy demand, energy from the battery will be used.

3. Results and Discussion

The performance of the solar energy system of the EV charging station was evaluated through the following indicators [40]: (1) Technical indicators included energy balance over one year of operation, monthly and annual average power, monthly energy for the charging station, hourly simulation results for a day with poor availability of solar radiation, and for a day with very good availability of solar radiation; (2) the environmental indicator was CO₂ emissions; and (3) the financial indicators included the cost of the initial investment, total system cost over an operating period of 25 years, and the levelized cost of energy production for the solar system.

3.1. Optimally Configured System Components

Based on input data, mathematical equations, and the computational simulations presented in the previous sections, the optimum configuration of the solar energy system was established.

Photovoltaic panels, which are the primary equipment required for renewable energy conversion with a nominal power of 280 W_p, were wired with two in series x 14 in parallel, resulting in a total installed power of 7.84 kW_p. The total installation surface of the photovoltaic panels was 45.65 m².

Lead-acid batteries—the primary solar energy storage component, with a nominal capacity of 189 Ah—were installed with four in series x eight in parallel, resulting in a total battery bank energy of 72.5 kWh. The total weight of the batteries was 1824 kg; the number of full equivalent cycles was 614.4 with a six-day autonomy.

A 900 VA inverter was used in the solar energy system of the EV charging, which was useful for using excess electricity in other types of applications (electric outlet, lighting, etc.).

3.2. Energy Performance

The energy balance of the photovoltaic system is illustrated in Figure 5. For continuous use of the charging station for 24 h per day, for one year of operation, the photovoltaic panels generated a total energy of 5789 kWh/year. From the energy obtained by the solar system, 37.12% was charged into the batteries, 18.35% was used directly via the DC bus by the charging station for electric vehicles, and 12.87% was lost due to the performance of the system components.

Figure 5. Energy balance for one year of operation of an EV charging station.

During the operation of the system, the excess of energy was 1833 kWh/year, which represented 31.66% of the total PV production. The excess energy could be harnessed either in the charging station by adding storage batteries for EV charging, in the maintenance of the charging station, or for other types of applications [41], such as lighting, charging electronic devices, agricultural activities, electricity supply for irrigation, and greenhouses [42], which generate additional costs, either by injecting electricity into the grid network if possible.

The photovoltaic system of the EV charging station analyzed in this paper can operate in standalone mode, being 100% powered by solar energy resources.

Figure 6 shows the monthly and annual average output power of the solar system. Although solar irradiation on the horizontal surface was at its maximum in June and July, the most advantageous month for output power was August due to the average monthly sunshine duration shown in Table 1, with a monthly average power value of 843 W. The worst month for output power was December, with a monthly average power value of 416 W. The rest of the months had intermediate average power values, and the annual average power, which was created by the system, was 657 W.

Figure 6. Monthly and annual average power.

The results of the solar charging simulations for one of the sunny days in August (considered the most favorable month of the year based on system operation analysis) are presented in Figure 7.

Figure 7. Hourly results for the most favorable day of system operating.

For the sunniest day in August, sun irradiation was available between 6:00 a.m. and 9:00 p.m., with maximum values between 12:00 p.m. and 3:00 p.m.—the period during which photovoltaic panels generate power for the direct supply of the EV consumer, as well as for storage in batteries in order to meet the energy demands of the charging station for times with low availability of solar irradiation, such as cloudy days and at night. Additionally, the energy excess on this day could be harnessed by injection into the public electricity distribution network if there is a connection to it, used in other types of applications [41–43]; or be used in isolated areas that do not have access to the grid.

According to the established input data, the maximum hourly DC active power load of 360 W had a constant load profile throughout the day. This charge station power requirement was 100% directly supplied by the DC bus between 8:00 a.m. and 7:00 p.m., was supplied in mixed mode from the DC bus and energy stored in battery between 6:00 and 8:00 a.m. and 7:00 and 9:00 p.m. due to low solar irradiation, and between 9:00 p.m. and 6:00 a.m. due to being in night mode. The energy demands on the EV charging station was 100% assured by the energy stored in the batteries. The storage of solar energy in the batteries for use in the night mode is made in the interval from 8:00 ÷ 14:00, and between 12:00 ÷ 19:00 the excess energy was generated.

The results of the simulations obtained for one of the most unfavorable days in December are presented in Figure 8.

Figure 8. Hourly results for the worst day of system operating.

For this period, solar irradiation was available between 8:00 a.m. and 5:00 p.m., with maximum power output between 12:00 and 1:00 p.m.—the period during which photovoltaic panels generate power for the direct supply of the EV consumer, as well as for storage in batteries in order to meet the energy demand of the charging station during low solar availability periods and nocturnal mode, without producing excess energy.

The power station load required was 100% directly supplied by the DC bus between 9:00 a.m. and 4:00 p.m. Solar energy was stored in the batteries for use at night. Between 8:00 and 9:00 a.m. and 3:00 and 4:00 p.m., due to low solar irradiation, the power to the EV charging station was supplied in

mixed mode—DC bus and energy stored in batteries—and from 17:00 to 8:00, the energy demand was 100% supplied by the energy stored in the batteries.

Figure 9 presents the monthly energy used by the EV charging station.

Figure 9. Monthly energy used by the EV charging station.

In December, considered the worst month in terms of solar irradiation, 82.51% of the energy demand was provided by the solar energy batter and only 17.49% came directly from the PV generator via the DC bus.

In June, the best month in terms of solar irradiation, 51.70% of the energy demand was provided by discharged energy from the batteries and 48.30% was supplied directly from the PV generator via the DC bus.

3.3. Environmental Performance

During the one-year operation, the proposed PV system produced 5789 kWh/year, generating a total CO₂ emission embedded into 583 kgCO₂/year. The amount of pollutants refers only to the CO₂ emissions of the system, as no further emissions were produced from the PV generator operation.

In 2017 in Romania, the classic system produced 1 kWh of energy with 0.3055 kgCO₂/kWh [44]. To produce the same amount of electricity as in the PV system, the classic system would generate 1768.54 kgCO₂. The values are graphically illustrated in Figure 10.

Figure 10. Carbon dioxide emissions.

We found that CO₂ emissions from the PV system were 67.04% lower than the electricity produced from classical methods.

This concept of energy supply with photovoltaic panels on a charging station, alongside electric vehicles, enriches the quality of life and human health and corresponds to the well-being standard

concept. This system can also be implemented in green cities and protected natural areas where there are regulated instruments that provide important opportunities for sustainable economic development [39], both through attracting funds and efficient economic management for the benefit of both people and nature.

3.4. Financial Performance

The initial investment was calculated as €13,767, and this represents the initial cost of all the system components (photovoltaic panels, batteries, and ancillary components), as well as the initial costs of execution, installation, and commissioning.

The levelized cost of energy, defined as the ratio between the total annual cost of the electricity generation system and the total annual electricity generated by the system, was 0.17 €/kWh. The final price for 1 kWh of electricity provided by the national distribution network in Romania was 0.11 €/kWh, being one of the lowest prices in the European Union, where a maximum of 0.30 €/kWh has been recorded in Denmark, 0.29 €/kWh in Germany, and an average in France of 0.15 €/kWh [45].

Notably, the unit price of energy in the photovoltaic energy system was 35.30% higher than the Romanian national energy system, respectively by 43.33% lower than the maximum value perceived by Denmark and 11.76% higher than the average final price for 1 kWh paid at EU level.

Power-generating technologies based on alternative energies are constantly being researched and developed. A number of pilot projects are currently underway in this field, so these systems will be validated and then implemented on a large scale, including energy storage solutions, so these costs are expected to decline in the near future. In addition, the government supports clean energy through a generous system of subsidies, with a number of rules being implemented at the national level that encourages the installation of small green energy production capacities [46] with renewable energy producers receiving these subsidies through the mandatory green certificates quota system.

Total cost (Net Present Cost; NPC) is a global indicator that includes the initial cost, operating costs, maintenance and replacement of component equipment costs, and other costs that occur for the entire 25-year lifespan of the system. Therefore, a total cost of €24,692 for the photovoltaic system of the EV charging station was calculated.

From Figure 11, the biggest share of the costs was the battery bank, which accounted for 60.79% of the total cost; followed by the solar energy conversion technology (PV generator), which represented 19.55% of the total cost; the inverter represented 11.10%; and the installation costs accounted for 8.56% of the NPC.

Figure 11. Total system cost breakdown.

4. Conclusions

We examined the possibility of using solar energy resources to provide energy support for an EV charging station, as a starting point to demonstrate the usefulness of the technology presented in

mobile applications (electromobility), both for areas with a connection to the public electricity supply network, as well as for isolated areas without a connection to the electricity distribution network.

The simulations were conducted using iHOGA 2.4. [30] software (improved hybrid optimization by using genetic algorithms) for the simulation and optimization of standalone electric power generation systems based on renewable energies.

The solar system of the EV charging station presented in this paper can operate in an isolated mode using 100% renewable energy. The total surface occupied by the installed solar panels was 45.65 m². A simulation was performed, considering that several vehicles are charged consecutively using the photovoltaic station at its full capacity for the whole day. The photovoltaic panels generated a total of 5789 kWh/year, and 55.47% of the energy was used for charging the station and 44.53% was the excess energy and the loss of the energy system.

The most advantageous month for output power was August, with a monthly average power value of 843 W and the worst month for output power was December, with a monthly average power value of 416 W. The rest of the months had an intermediate average power value of 657 W.

The environmental performance evaluation, in this situation, refers to the CO₂ emissions due to the process of obtaining electricity. The emissions from the photovoltaic system were 67.04% lower than the electricity produced by classical methods.

Financial performances refer to the following parameters: An initial cost of 13,767 Euros, a net present cost of 24,692 Euros and the levelized cost of 0.17 Euro/kWh.

The results obtained from this study may be useful on a large scale, highlighting the premises and tools for sizing and designing the EV charging station infrastructure powered by solar resources in Romania or other parts of the world, given that solar renewable energy is virtually an inexhaustible source of energy.

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Nomenclature

Abbreviation	Definition
AC	Alternating current
A_{PV}	Standard size of photovoltaic panel unit
A_{PV_total}	Size of the photovoltaic panels generator
C_B	Capacity of storage battery pack
C_n	Nominal capacity
CO ₂	Carbon dioxide
C_s	Average solar constant
DC	Direct current
DOD _i	Battery depth of discharge
EC	European Commission
$E_{cycled_average}$	Average cycled energy for batteries
E_{cycled_i}	Cycled energy throughout battery lifetime
EU	European Union
EV	Electric vehicle
F_p	Factor of losses compensation by power due to shading
G_i	Hourly solar irradiation
iHOGA	improved Hybrid Optimization by Genetic Algorithms
I_{SC}	Short-circuit current

L_{max}	Maximum load demand
N_{days}	Number of days in the worst month
N_{eq_cycles}	Number of equivalent cycles for batteries
NPC	Net Present Cost
N_{PV}	Number of photovoltaic panels modules needed to obtain the energy ensuring full load coverage during the worst month
PHEV	Plug-in hybrid electric vehicle
P_{max_ren}	Maximum input power from the photovoltaic generator
P_{PV}	Power generated by photovoltaic panels
PV	Photovoltaic panel
SOC	Battery state of charge
T	Time of autonomy needed
U_{DC}	Voltage DC generated by photovoltaic panels
VDC	Voltage Sourced Converter
VSC	Voltage Sourced Converter
V_n	Nominal voltage
V_s	Bus nominal voltage

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