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Electromobility with Photovoltaic Generation in an Andean City

Bryam Paúl Lojano-Riera [1,2], Carlos Flores-Vázquez [1,*], Juan-Carlos Cobos-Torres [1,3], David Vallejo-Ramírez [1,2] and Daniel Icaza [1,2]

[1] Electrical Engineering Career, Research Group in Visible Radiation and Prototyping (GIRVyP), Universidad Católica de Cuenca, Cuenca 010101, Ecuador; david.vallejor@ucacue.edu.ec (D.V.-R.)
[2] Laboratory of Luminotechnics, Center for Research, Innovation and Technology Transfer (CIITT), Universidad Católica de Cuenca, Ricaurte 010107, Ecuador
[3] Academic Unit of Postgraduate, Embedded Systems and Artificial Vision in Architectural, Agricultural, Environmental and Automatic Sciences Research Group (SEVA4CA), Cuenca 010111, Ecuador
* Correspondence: cfloresv@ucacue.edu.ec

Abstract: This research focuses on the measurement of the solar generation potential on the roads of the Andean city of Cuenca, Ecuador, and its application in electric vehicles. The tests were conducted in real environments, whereby natural and artificial structures obstruct direct radiation to the panel during the trajectory. An initial study is presented with daily operating conditions, using an urban bus route as a case study. The methodology used consists of taking measurements on different days and weather conditions to evaluate the photovoltaic generation and its contribution to the energy autonomy of the electric vehicle. Additionally, the energy autonomy between the electric vehicle with its factory configuration versus the one equipped with the solar panel is compared. For this purpose, a photovoltaic panel is installed on the roof of the vehicle, connected to a control system that monitors the radiation and current data, regulating the charging and discharging of the batteries. The aim is to demonstrate that the installation of solar panels on electric vehicles can significantly increase their energy autonomy. The contribution of this research could serve as an initial guide for governments and private companies to make decisions on the deployment of electric buses, electric vehicles and other vehicles integrated with solar photovoltaic energy, taking into account their routes. The findings of the study reveal that the implementation of the mobile charging system improves the range of the electric vehicle used in this study. In detail, an average increase of 40% in range was achieved in favorable environmental conditions and an increase of 14% in unfavorable environmental conditions. It is important to highlight that Cuenca has favorable conditions for solar systems due to its geographical location: altitude, hours of radiation and angle of incidence.

Keywords: electromobility; solar panels; electric vehicles; solar charger; energy autonomy

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1. Introduction

The energy demand has grown considerably in recent years. The current rate of consumption and the pollution it produces have reached a point where it is necessary to assess the environmental impacts and the adequacy of resources to meet future demands and take measures to avoid a coming crisis [1,2], so interest is currently growing in terms of economic, legal and social renewal, leaving behind the oil systems that have been a highly polluting source and are rapidly depleting [3].

Electric power is the most efficient alternative to fulfill demand and reduce pollution levels due to its various renewable generation forms (solar, wind, among others) [4].

The Sun is the planet's largest source of inexhaustible energy [5,6]; thus, modern technologies have been developed with the main objective of generating electrical power through collected solar energy [7]. The energy produced by the Sun can adequately fulfill the world's total energy demand if the collection and supply technologies are more accessible [8]. The Earth receives approximately 4 YJ of solar energy annually, of which 50 MJ can be easily exploited [9].

Although the planet's exploitable solar potential is high, solar energy's contribution to the global energy supply is still very low [10]. Currently, there is a more significant trend towards using this type of energy since solar systems can supply the energy demand in rural sectors and contribute with a clean energy recharge system in electric mobility [11,12].

On a global scale, 26% of gross energy consumption for transport purposes is established, accounting for 23% of greenhouse gas emissions [13]. It is found that urban traffic (city traffic) accounts for a 74% share of the global transport area [14].

Propulsion technologies must be replaced by more efficient and environmentally friendly alternatives to meet mobility needs, reduce emissions and move away from fuel dependency [15].

The transportation sector has struggled to reduce CO_2 emissions due to its reliance on internal combustion vehicles [16]. Many countries are developing strategic plans to replace conventional vehicles with EVs.

In the transition to a sustainable society, electric mobility technologies with a high degree of efficiency are required worldwide; electric vehicles (EVs) represent this type of technology [17]. These vehicles constitute an efficient transportation system, do not present CO_2 pollution and offer advantages such as noise reduction in urban areas, especially at speeds below 50 km/h, where they show a reduction of 1 to 3 dB [18].

Related works [19,20] establish 100% renewable systems in electric mobility by 2050. Although the solar potential is significant, there are no studies on the behavior of recharging systems in predetermined trajectories of the study city [21], which is necessary because it will help to determine the feasibility and the autonomy increase that an electric vehicle can have, the high radiation points in the city for vehicle recharging and the areas where there is no efficient charging [22].

Therefore, several studies have focused on the design and analysis of an EV charging station using solar energy as a power source. As is the case of [23], where it provides a comprehensive approach to the design and analysis of a solar-powered EV charging station, taking into account the specific challenges of Indian cities. Its content is relevant to the development of a sustainable and efficient charging infrastructure in the context of electric mobility in countries with similar conditions.

It is also important to consider that a complete and detailed review of EVs in energy systems should be carried out, exploring their integration with renewable sources, different charging levels, vehicle types and applicable standards. An example of this would be research [24] that provides a broad overview of EV technology and its role in the transition to more sustainable mobility, considering aspects such as standards and regulations, communication protocols and safety requirements, including the analysis of the different levels of EV charging, from slow charging in homes to fast charging in public stations, and its impact on infrastructure.

Consequently, it is necessary to maintain a comprehensive view on the management and optimization of large-scale EV charging on the grid. Valuable information on energy management strategies and optimization techniques that can help address the challenges associated with bulk EV charging and ensure efficient and sustainable integration into the grid can be found in the paper [25].

Similarly, in article [26], an analysis of the energy balance between a photovoltaic installation and a small electric vehicle under real conditions is presented. Here, data were collected on the energy production of the solar panel and the electrical consumption of the vehicle during one year. A correlation was found between the energy produced by the PV system and the energy consumption of the vehicle. The energy consumption of the electric vehicle was higher in winter than in summer, leading to the conclusion that the energy consumption of an electric vehicle is influenced by the type of route and the distance traveled. These scenarios represent a preliminary stage in the development of the EV energy-consumption simulation model.

In addition to the generation of electrical energy through renewable resources for EV charging stations, the optimization of this process through different methods should be attempted. Therefore, this research studies the functionality of a mobile solar charging system incorporated into an electric vehicle with a low cost system, but especially considering that the established study area is the city of Cuenca, located in the Andes Mountains at 2500 to 2700 m above sea level, with a radiation index of 1517.02 kWh/m^2 [27,28] and the higher the altitude, the lower the thickness of the atmosphere and, therefore, the lower the absorption and reflection of shortwave solar energy [29,30].

Considering that all renewable energy sources have different operational characteristics, it is necessary to perform a standard study and procedure to integrate renewable energy sources into the required system [31]. In this case it is an electric vehicle.

It is important to understand that the energy produced by the Sun begins with direct and diffuse radiation reaching a given surface. Direct radiation refers to rays that reach the surface directly, and diffuse radiation refers to rays that reach the surface indirectly due to interruptions in the medium [32,33].

The amount of electricity generated depends mainly on the efficiency of the solar panels and their technical characteristics, but is also closely related to geographical location, weather conditions and the presence of atmospheric elements, such as clouds, hydrometeors, gas molecules and submicron-sized particles suspended in the air. These elements can scatter and absorb the shortwave solar radiation reaching the panels. [34].

In this research, photovoltaic modules composed of thin-film monocrystalline silicon cells, as indicated by the manufacturer, are considered. These solar cells are highly sensitive to wavelengths in the visible light range (400 to 700 nanometers), but can also have some response to wavelengths in the near infrared and near ultraviolet. Through the photovoltaic effect of semiconductor materials, they convert visible light into electrical energy [35,36], with the ability to store energy in photovoltaic batteries to manage its use and respond to existing demand [37].

Integrating photovoltaic panels into vehicles could increase driving distance and reduce reliance on fossil fuels to charge batteries [38,39]. Some automobile manufacturers have introduced solar panels in some of their vehicles, but the conversion efficiency of solar cells remains a challenge [40]. Improving this efficiency is one of the problems to be solved to maximize power generation [41].

Reinoso and Ortega, in their article [42], implement a solar panel on the roof of the electric vehicle, as a mobile charging system; originally this vehicle had a single static charging system. The main objective is to improve the vehicle's autonomy, providing more kilometers than those from the factory; the solar panel is 350 W and has an energy converter to provide all the necessary load to the five batteries in series. Once the modification was completed, the vehicle worked satisfactorily, safely operating within the city without any inconvenience, reaching a maximum speed of 45 km/h with a range of 12 km. Its most crucial particularity is that it does not pollute or generate noise as an internal combustion engine vehicle does.

These types of tests have been performed on other more robust vehicles, such as the Kia Soul [43]. It deals with the implementation of a charge regenerator system using panels that generate voltage and current, to improve the vehicle autonomy, placing a structure on the roof of the EV. Likewise, it demonstrates aerodynamic simulations and efforts combined with aluminum, which is the best option to maintain the minimum weight, with its deformation almost zero. It shows an advantage for resistance conditions while maintaining an excellent safety factor, thus taking advantage of the solar panel at its best performance conditions. This study concludes as a useful improvement for the Kia Soul's mobile charging.

By implementing photovoltaic panels on EVs while traveling real city routes, it provides an overview of the range extension of driving autonomy [44]. Thus, conducting this study can provide information on the technologies and approaches used, as well as the benefits and challenges associated with solar charging on EVs in Andean cities. This approach has the potential to improve the autonomy of EVs and promote the adoption of renewable energy in the urban transport sector.

Considering the above-mentioned points in this research, a detailed analysis of the performance of an electric vehicle in the city of Cuenca, Ecuador, which has special solar conditions due to its geographical location, is carried out. The vehicle has a system of photovoltaic panels integrated in its upper part, which provides additional energy to the battery. The behavior of the vehicle is evaluated in the usual routes of the city, taking into account the real driving conditions and the amount of energy generated by the photovoltaic system.

In this way, it is expected that accurate data on the operation of the charging system will be obtained, such as the improved percentage of autonomy of the electric vehicle [45,46] and the behavior of the mobile charging system on a pre-established route in which direct and diffuse solar radiation is present.

Based on all the previous studies presented, Section 2 explains the design of the photovoltaic system to be implemented in the electric vehicle and the tests in the different routes selected in the city. The obtained data and their corresponding analysis are presented in Section 3. A brief discussion is also presented based on different guide articles in the Section 4. Finally, the conclusions of this research are presented in Section 5.

2. Materials and Methods

To perform the analysis of autonomy improvement, a mobile charging system has been established; this system consists of a solar panel coupled to an electric vehicle which will convert the captured radiation into electrical energy to power the batteries of the electric vehicle [47]. Although this configuration has been used in related research [48,49] to obtain greater autonomy, a study of the behavior of the system according to the routes traveled in real-time is not presented.

The main objective of the research is to obtain baseline data on the behavior of a mobile charging system concerning road interference to obtain data on the charging and discharging of the vehicle's batteries, as well as the amount of irradiation that can be achieved on a specific route and how it affects the autonomy of the electric vehicle [50]. The obtained results will make it possible to identify whether the zones influence the higher and lower charging of the vehicle and its behavior for interferences (architectural, climatic, decorative, among others).

This section will detail the procedure for implementing and monitoring the mobile solar charging system, presenting the methodology, programming and other implemented tools during the development and measurement process and establishing routes and specific data of the vehicle used for the research. It is expected to provide irradiation data in critical areas and the vehicle batteries' behavior against this irradiation through the methodology used.

2.1. Operating Principle

Currently, electric mobility and photovoltaics are a fundamental part of the transition towards self-sustainable systems and zero dependence on oil by 2050 [51,52]. As a result, there has been a growth in demand for self-sustainable systems such as EVs in recent years. In 2017, the global fleet of EVs reached two million units, and solar energy presented the highest growth of all energy sources [53,54].

The autonomy of EVs has been improving over the years, especially due to battery improvement and the charging speed of charging stations [55–57]. However, new alternatives have been sought to improve autonomy because of its current demand; one of the most feasible is the application of solar charging systems to EVs to generate energy feedback [58]. Another viable alternative for autonomy improvement is through route optimization [59].

The proposed autonomy improvement system comprises a mobile charging and measuring unit designed to monitor the battery state of charge and the incident irradiation absorbed for the panel cells with characteristics indicated in Table 1 in real-time. Monitoring the amount of incident irradiance will help to determine the battery charge, the behavior against different irradiance variations and environmental disturbances. The composition of the system can be seen in Figure 1.

Table 1. Photovoltaic Panel Information.

Data Sheet	
Power output (Pmax)	350 W
Power tolerance	0 + 5%
Panel efficiency	18.04%
Maximum power voltage (Vmp)	39.19 V
Maximum power current (Imp)	9.25 A
Open circuit voltage (Voc)	46.88 V
Short circuit current (Isc)	9.38 A
NOCT	45 °C ± 2 °C
Cell type	Monocrystalline (156 × 156 mm)
Number of cells	72
Dimensions	1956 × 992 × 40 mm
Weight	22.8 kg

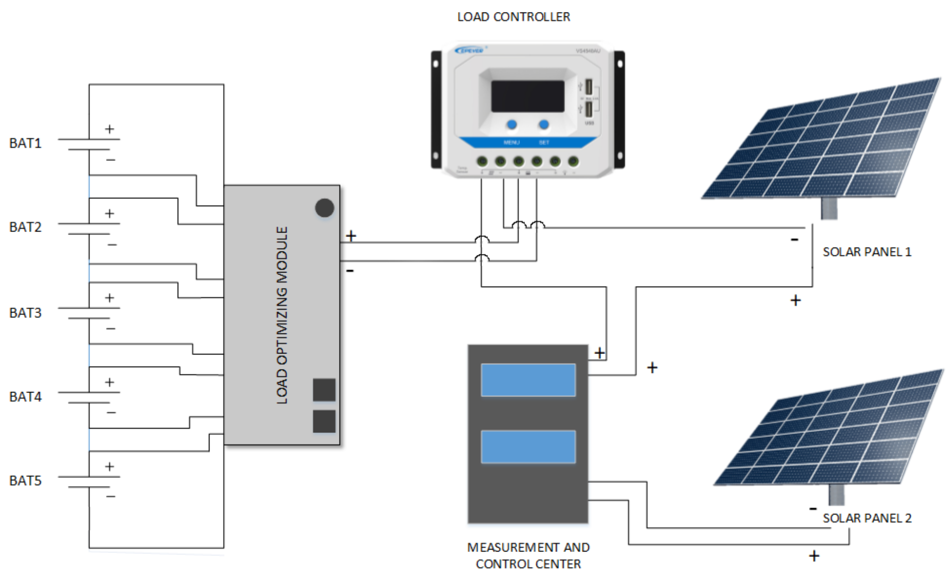


Figure 1. General system structure.

The basic operating principle of the system is to charge the five vehicle batteries individually using a charge optimizer powered by a solar panel. The control and measurement center will store the irradiation and current generation data. Through this system, it is possible to measure the efficiency of a vehicle on a predetermined route and the vehicle's behavior in unfavorable situations on the route. The operation of the controller and control center is detailed in Section 2.2.

2.2. System Composition

The central system (Figure 1) has in its subcomposition two secondary subsystems that perform most of the control and charge optimization: the charge optimization module and the system control and measurement center. The first subsystem performs the battery charging process, and the second monitors the state of charge current, irradiance and location to obtain data on charging behavior and radiation incidence. The composition of these systems is detailed below.

2.2.1. Load Optimizing Module

The charge controller is a system to optimize the solar's electrical energy; the system is responsible for individually redistributing the charge to each battery. This is because the common distribution of the electric vehicle presents a joint charging of the batteries [42,60], limiting the speed and charging efficiency of the batteries. Therefore, higher charging efficiency is obtained by redistributing the energy produced to each battery separately [47,61].

The primary purpose of this system is to census the voltage of the five batteries the vehicle has. The individual voltage of each battery is 12 V [62]. Usually, the batteries are connected in series, which provides a voltage of 60 V as a whole. This way, when connected to the charge optimizer, it can power each battery individually and continue to work with the 60 V to move the electric vehicle. The connection of the batteries can be seen in Figure 2.

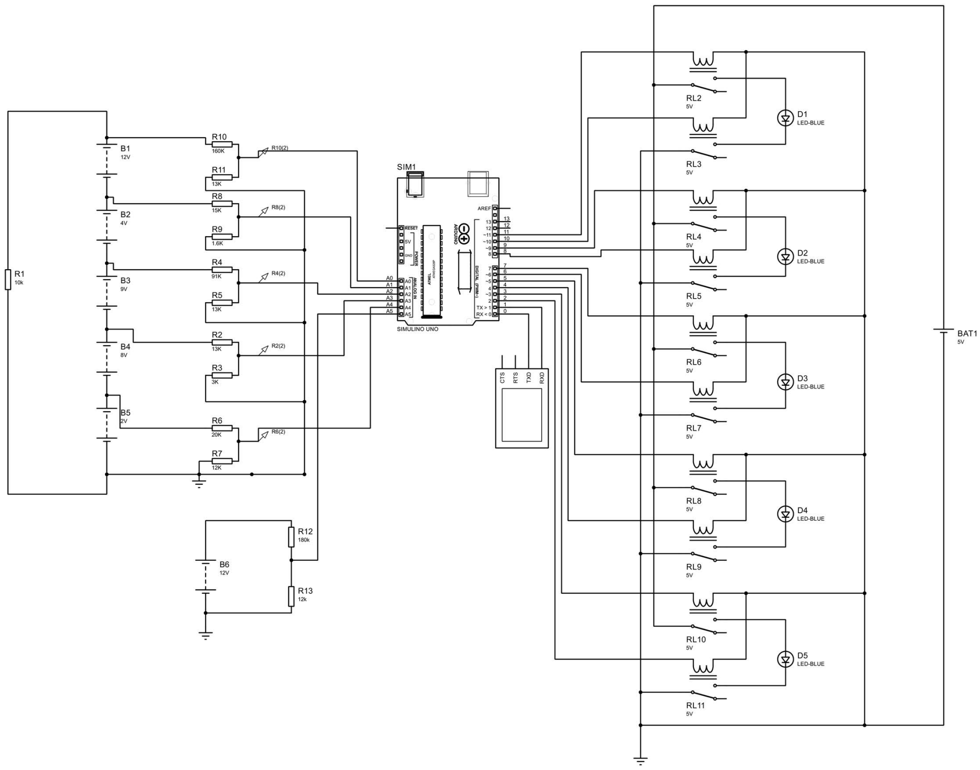


Figure 2. Load optimizing module diagram.

The configuration of the charge optimization system is presented in Figure 2. The cascaded batteries are connected separately in a relay for each battery; the function of the relay is to allow the charging of the batteries individually. A voltage divider is used through configuring resistors to measure the level of each battery and reduce its voltage. The Arduino controller can interpret the voltage values, census each battery's voltage level and activate the charge to the battery with the lowest voltage; the charge and discharge data will be stored for later interpretation.

2.2.2. Measurement and Control Center

This subsystem is responsible for monitoring and controlling the obtained data. The system comprises two ACS712 current sensors designed to measure the irradiance and the solar panel's current generated to charge the batteries. The purpose of the measurements is to determine the current ratio and the batteries state of charge. Through this system, it is possible to study the batteries' behavior against a random level of irradiation. The internal composition of this system is shown in Figure 3.

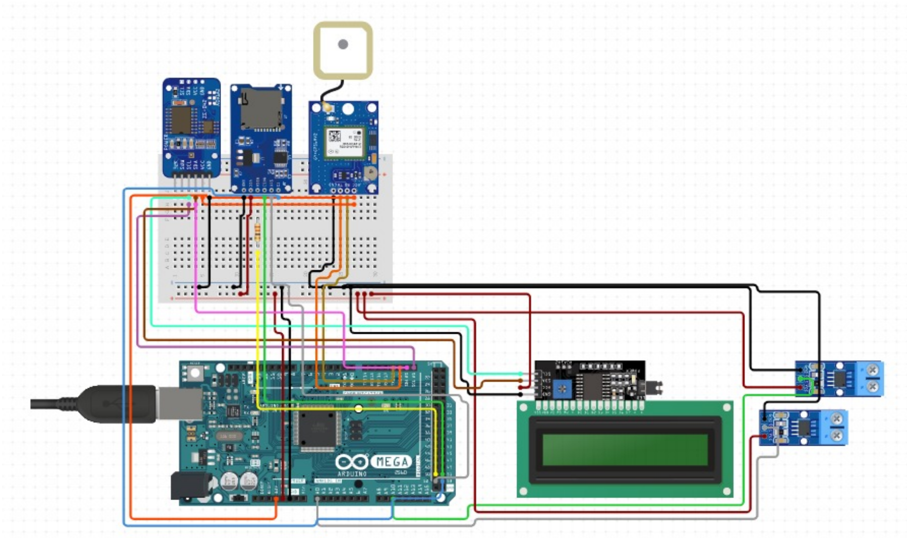


Figure 3. Measurement and control center diagram.

The system shown in Figure 3 comprises a central controller (Arduino mega 2560) that converts the voltage values obtained from the sensors. The ACS712 sensors interpret the current values as voltage [63]. These values are converted by the ADC of the central controller at 10 bits into current values through the programming set for their respective visualization on the LED display. The current and irradiance values are stored on an SD card for further analysis. In addition, the system has a GPS module to establish a relationship between the generated load, the solar collection environment and the position

2.3. Electrical Measurement Unit

According to the Association of Automotive Companies of Ecuador (AEADE by its Spanish acronym), 109 units were acquired in 2016, of which 75.21% are located in the Coast and Sierra areas (Guayas and Pichincha provinces). The leading successful brands in the commercialization of EVs in Ecuador are Kia, Renault and Dayang. These brands were pioneers in promoting clean energy without fuel use [64,65].

The Chinese company called Dayang is engaged in the manufacture of 100% EVs. Among the various models produced by this company is the CHOK-S2 model (cost of USD 8400), which is designed to transport four people. This electric vehicle meets all the requirements to be used in the city (easy handling, a comfortable interior for the occupants, and being able to travel small kilometers with maximum speeds of up to 50 km/h). See the image of the vehicle in Figure 4.

Figure 4. DAYANG brand CHOK-S2 electric vehicle.

This type of vehicle no longer has a combustion engine and moves its wheels utilizing one or more electric motors, so this model has a fuel tank. EVs have approximately 90% fewer parts than internal combustion vehicles. The main component of the electric vehicle is the battery, which includes a series of auxiliary components that allow it to operate, as shown in Figure 5.

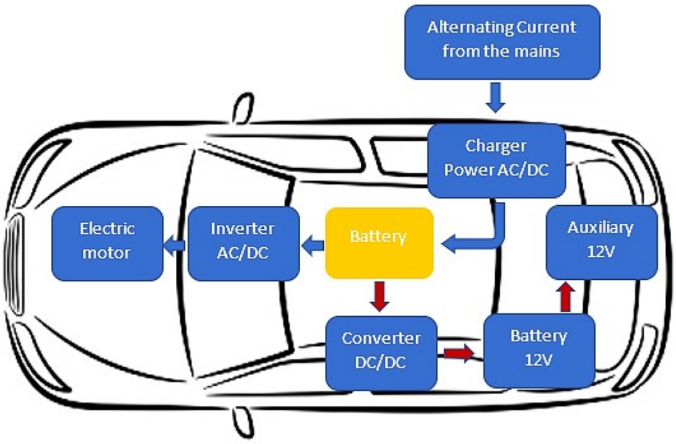
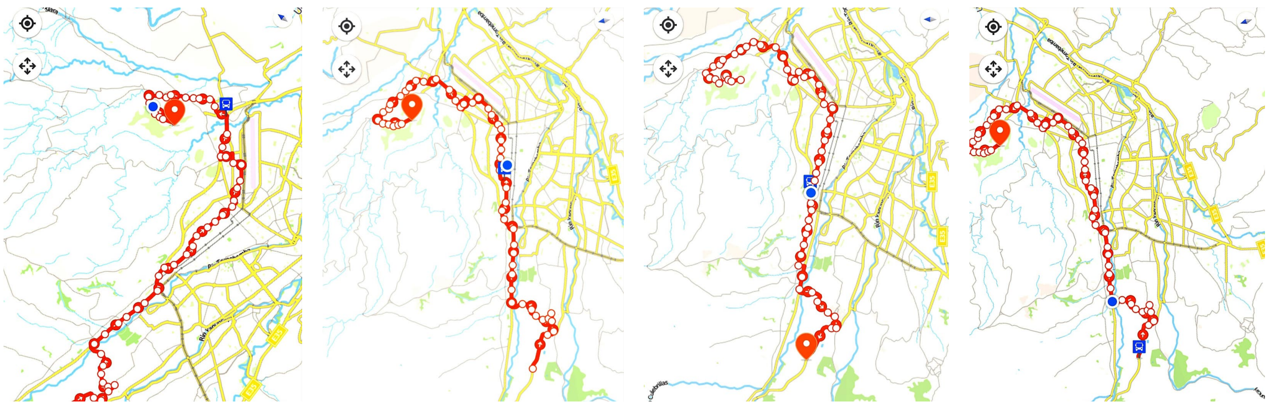


Figure 5. Dayang CHOK-S2 electric vehicle.

This car uses a 4.5 kW electric motor and five batteries model 6-EVF-150, capacity 150 AH (3 h). This type of battery has been on the market for the longest time and has an excellent price–performance ratio. The lead–acid battery is a type of battery (wet battery) that uses a sulfuric acid solution as an electrolyte.

2.4. Data Collection

A specific route is established to determine the different conditions to which the electric vehicle may be exposed. Roads with a low rate of obstacles to roads with a high rate of obstacles prevent the capture of solar energy for the photovoltaic panel [66]. The trajectory used is the eighth line (Trigales–San Joaquín). See Figure 6a.



(**a**) (**b**) (**c**) (**d**)

Figure 6. Study Routes-Andean City: (**a**) First trajectory_(Trigales). (**b**) Second trajectory_(Downtown). (**c**) Third trajectory_(Ave. Americas). (**d**) Fourth trajectory_(Ordoñez Lasso–San Joaquin).

The first trajectory indicates the starting point in the Trigales area, located at the highest point, with efficient solar collection and few impediments for capturing solar irradiance; see Figure 6a.

The second trajectory indicates the downtown area, which has several factors that affect the energy collection of the solar panel. This is the most critical area as several buildings produce shadows in broad daylight, causing the solar panel's performance to drop considerably, with little solar irradiance captured; see Figure 6b.

The third trajectory indicates the area of Americas Avenue, an extensive road, which provides all the facilities to capture solar energy in the photovoltaic panels; the irradiation increases, directly proportional to the current generation of the batteries; see Figure 6c.

The fourth trajectory indicates the Ordoñez Lasso–San Joaquín area. On these roads, efficient irradiance was achieved with few obstacles, such as advertisements and buildings, which do not make pronounced shadows. The circulating vehicle passes the shadow and continues with all the irradiation by the feedback system, obtaining electric charge in motion. In addition, when the vehicle is parked, the electric charge will continue contributing to clean energy through photovoltaic panels; see Figure 6d.

The different conditions detailed above indicate several cases of zoning in the area, constituted by several factors, such as the shadow produced by the existing buildings in the city, though it was more evident in the city center. In all these conditions, the solar panel was exposed and met all expectations as a clear improvement of greater autonomy [67].

3. Results

With electricity generation through the photovoltaic panel, it has been possible to determine the increase in electric vehicle autonomy. With this study, it can be seen how the vehicle improves with the implementation of a solar module on the roof of the vehicle, generating an auxiliary power supply system for electric charge when the vehicle is moving and also when it is static, giving the user a greater electric autonomy and ability to move a few more kilometers.

The results will allow us to analyze the vehicle behavior according to its batteries (current average) in different conditions (favorable, standard and unfavorable) to quantify the autonomy achieved in real conditions. It is important to explain that the current curve profile differs from the irradiance curve profile due to the performance of the load controller and the load optimisation module.

3.1. Favorable Day

Figure 7 shows the results obtained from the respective measurements, in which the relationship between the current generated and the respective incidence of radiation collected during the route established in Section 2.4, obtained on a sunny day, is considered favorable.

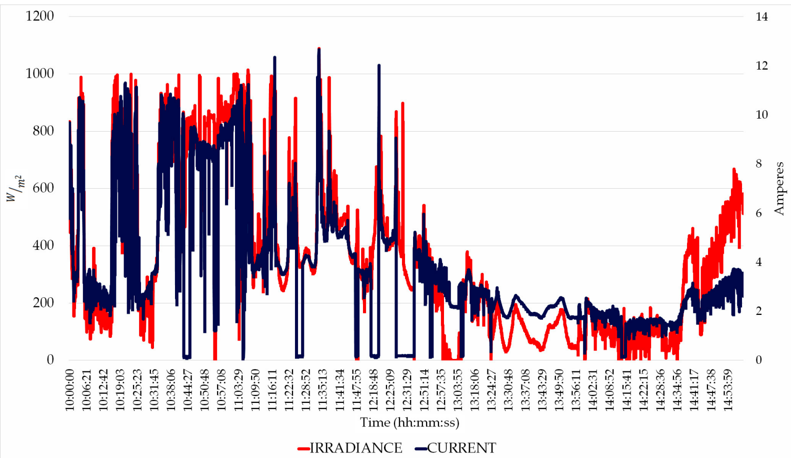


Figure 7. Favorable condition behavior–(Sunny day).

The graph shows similar behavior for the two cases, both in irradiation and current generation. As expected, the current presents a directly proportional relationship with the solar incidence. Through this principle, it is possible to establish critical points of batteries' charge and discharge, which will be reflected in the vehicle autonomy and the graphs of battery behavior. Figure 7 presents the following results from 10:00 a.m. to 15:00 p.m.

- The general average irradiation presented is 353.73 W/m^2 with a current of 3.78 A.
- The peak irradiance is 1088.68 W/m^2 taken at 11:34:01 to 11:34:04, while the peak current is 12.66 A given at 11:33:59 to 11:34:01.

Figure 8 represents the charging behavior of the five batteries of which the Chok-s2 vehicle is composed. The variations shown in the graphs are due to the favorable conditions of this day. It does not present low voltage values due to the energy compensation obtained from the radiation.

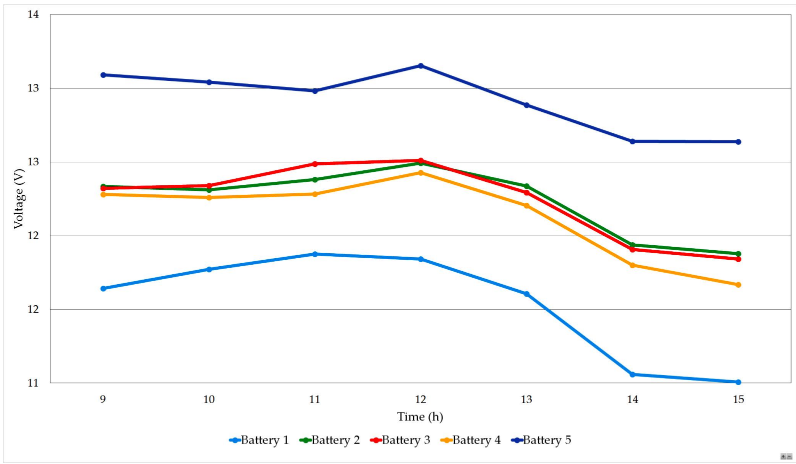


Figure 8. Favorable day: Cascading voltage behavior of the five batteries.

Figure 8 shows the voltage compensation generated in each of the five batteries, reaching high voltage levels to charge the batteries. Likewise, the inflection points where the battery reaches small voltage values can be observed; however, there is a recovery of the battery charge, and the behavior is similar for all batteries. On this day, a range of 70 km was achieved, which exceeds the estimated range of 50 km of the vehicle.

3.2. Standard Conditions

Figure 9 shows the data obtained on a partially sunny day and how the load current evolves with the variation of the solar irradiation of the photovoltaic panel. The graph shows the relationship between irradiation and cumulative current of the day.

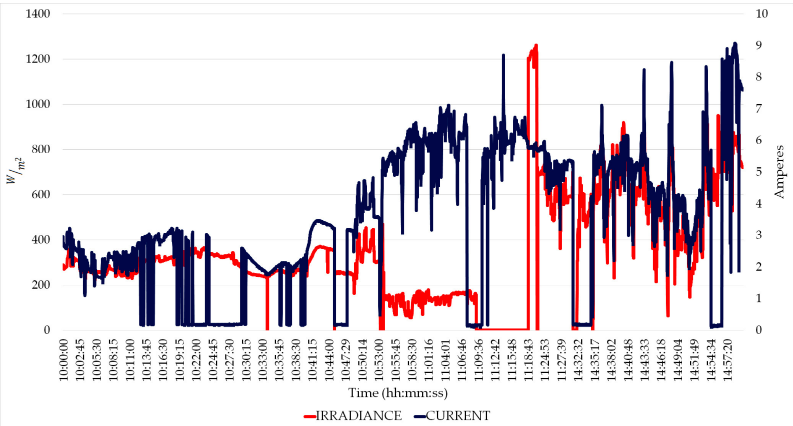


Figure 9. Standard conditions behavior (Partially sunny day).

It is interesting to note how the existing solar radiation in Cuenca is optimal for photovoltaic generation. Of course, when the PV panel is in motion, its solar gain performance decreases due to the various obstacles that produce shade.

- The general average irradiation presented is 348.73 W/m^2 with a current of 3.49 A.
- The peak irradiance is 1261 W/m^2 taken at 11:23:14 to 11:23:16, while the peak current is 9.07 A given at 14:58:37 to 14:58:44.

It can be seen how the autonomy of the electric vehicle improves with the car batteries. Despite apparent obstacles in the city center, batteries receive an additional charge via mobile solar panels. There are also places with few obstacles providing an additional charge to the vehicle, helping to increase the electric vehicle autonomy by up to 40%. In addition, the batteries do not go down in their entirety, avoiding deep discharges.

Figure 10 presents the equivalent averages of each of the batteries involved. The values correspond to the average voltage generated during the established hours. As can be observed, the voltage of the batteries presents a descending behavior from the first hours of the morning. A range of 65 km was achieved on this average day, which is 15 km more than the estimated 50 km range of the vehicle.

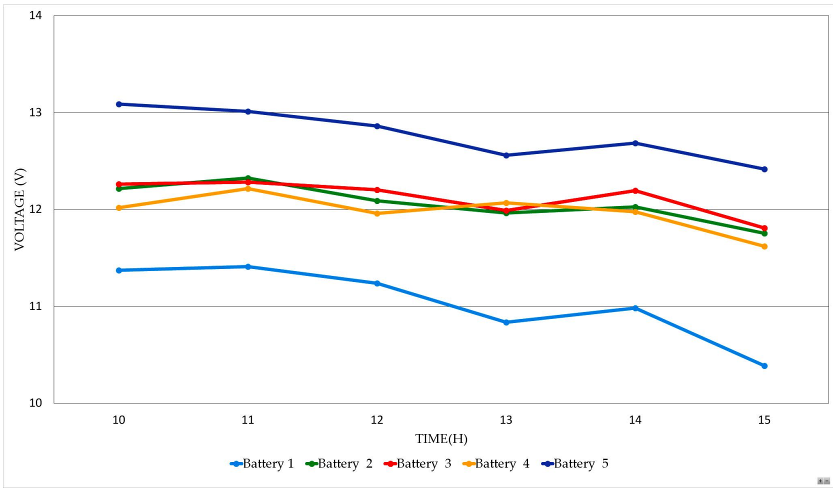


Figure 10. Standard Conditions: Cascading voltage behavior of the five batteries.

3.3. Adverse Conditions

The red line indicates the charging current or generation in amperes [A], while the blue line indicates the irradiance the solar panel captures during the measurement on the road. The average irradiance is 166 W/m^2; these data show how on a day in unfavorable conditions, the solar panel can capture solar irradiance regardless of many obstacles on the road Figure 11.

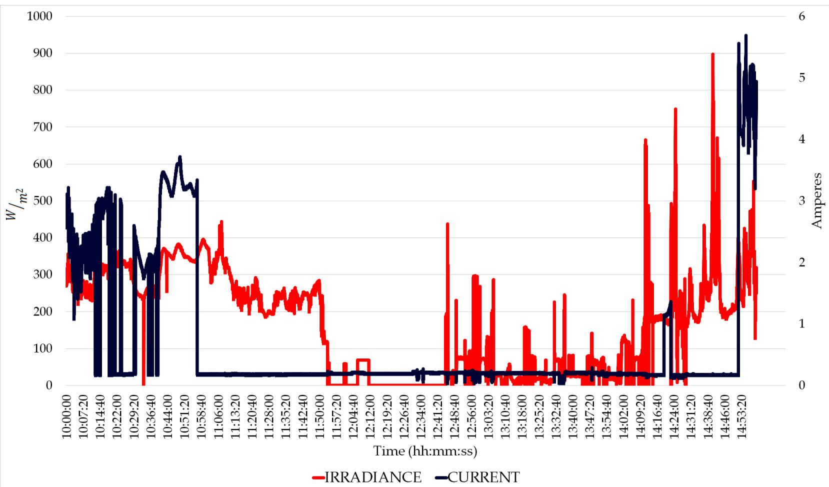


Figure 11. Adverse Conditions behavior (Cloudy day).

Electric vehicle batteries tend to charge 2% in unfavorable conditions when circulating in the city. A useful performance can be noted for users who need to mobilize when there is no considerable solar irradiation.

- The general average irradiation presented is 166.21 W/m^2 with a current of 0.69 A.
- The peak irradiance is 897.7 W/m^2 taken at 14:41:04 to 14:41:06, while the peak current is 5.69 A given at 14:55:31 to 14:55:32.

Figure 12 presents the comparative of the voltage values obtained for each electric vehicle battery. It is possible to notice the low values of voltages due to the adverse conditions of the day.

With these values, it is possible to establish an approximation of the amount of current that can be obtained with a certain amount of irradiation received by a solar panel. The average amount of current that can be achieved in a week in these conditions is approximately 3.46 A.

According to the exposed conditions, the car reached a range exceeding the estimated 7 km, i.e., a total of 57 km was obtained.

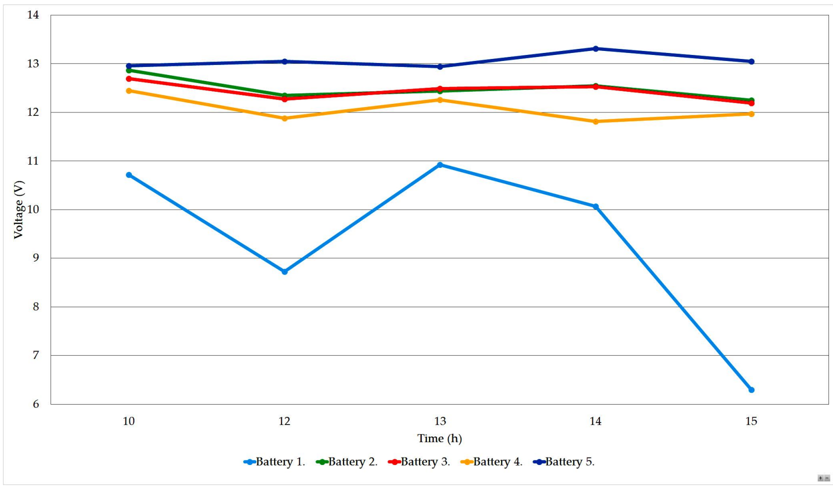


Figure 12. Adverse Conditions: Cascading voltage behavior of the five batteries.

4. Discussion

With respect to the study conducted under similar environmental conditions [43], it was observed that the charging infrastructure of the KIA Soul EV benefits from a more developed and extended charging infrastructure compared to the Dayang Chok-S2. However, it is highlighted that the Dayang Chok-S2 offers a smaller and more accessible investment option for the general public.

It is important to clarify that the tests conducted by the KIA Soul EV vehicle were of short duration and were carried out in a controlled environment, such as a car parking lot. In addition, when outdoor tests were conducted, only 47 km were covered in a single trajectory, which does not simulate real traffic conditions in the city of Cuenca. Therefore, it is necessary to consider that these results may not fully reflect the actual conditions of use in an urban environment. The study presented in Sections 2 and 3 considers the most realistic conditions possible, urban public transport trajectories, with traffic and city obstacles such as signs, trees and buildings.

Several authors highlight the importance of integrating solar PV systems and electric vehicles in residential settings [26], as a solution to increase energy efficiency and reduce carbon emissions. This integration has significant potential to address current environmental and energy challenges.

Existing studies of EVs and solar panels are based on experimental analysis using real data collection, which provides a solid and reliable basis for analysis and conclusions. However, it is important to mention that the results were mainly interpreted from data obtained from generation plants or stationary charging centres [23,26,44], where electric vehicles have to be parked for charging. This differs completely from the study objective of this research. The advantage of this proposal is to charge the vehicle while it is on the move and even parked in uncovered spaces. Therefore the user obtains energy from a free source and without loss of time.

Importantly, because the charging is carried out directly in the vehicle's batteries, the impact on the local power grid is reduced, as indicated in the research [24,25,32,33]. This means that the demand for energy from the grid is reduced, which is beneficial for both the users of electric vehicles and the existing electrical infrastructure. This in turn contributes to maintaining the stability and efficiency of the local power system.

This research demonstrates the feasibility of this proposal due to the high percentages of autonomy that can be achieved (up to 40%).

5. Conclusions

The main novelty of the research proposal is to test solar panels on the move to generate electricity and contribute to increasing the autonomy of EVs. Currently, no studies of this type have been conducted where the system is tested in the middle of city traffic and with actual conditions of solar obstruction by the various elements existing in the Andean city streets.

Another important contribution is to demonstrate the feasibility of increasing the autonomy of electric vehicles with solar panels while they are in motion. This results in three additional positive outcomes: the first is a shorter waiting time for recharging by the users. The second is a lower incidence of increased load on the local electricity grid. The third is lower charging costs for the user.

In this research, a mobile charging system was implemented, composed of photovoltaic cells designed to generate electrical energy to power an electric vehicle throughout its routes. This has managed to increase the limit of autonomy that the vehicle has in its factory configuration, thus facilitating charging in adverse situations for the user. It is worth noting that, in the most favorable conditions, the increase in range was 40% (20 km), and in unfavorable conditions it was 14% (7 km).

It has been possible to redistribute the energy obtained by the photovoltaic module of each of the batteries, obtaining an improvement in energy, performance and lifespan by employing charge equalization made up of electronic control systems designed to measure the state of the batteries.

Through the radiation measurement system, it has been possible to establish a relationship between the current generation of the panel, to carry out the charging, and the amount of direct and diffuse irradiation obtained from the environment. With this, it has been possible to determine the study route's critical points and of higher and lower radiation areas.

Factors that prevent adequate solar gain are climatic factors, such as cloudy, partly cloudy and rainy days. Obstacles on the route, such as buildings, were also found to affect solar gain. The real-time measurement system determined that the points with the worst solar gain along the route are located in the historic downtown of Cuenca. Finally, it is essential to mention that Cuenca is close to the middle of the world, so it has spring conditions all year round; the hours of radiation and the angle of incidence are favorable for solar systems.

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