Chapter

# The Second Life of Hybrid Electric Vehicles Batteries Methodology of Implementation in Ecuador

*Efrén Fernández Palomeque, Diego Rojas Hiedra, Daniel Cordero and Martín Espinoza*

## Abstract

Hybrid car sales in Ecuador in the last 10 years are very promising. The presence of hybrid electric vehicles (HEV) in the country generates an increase in nickel metal hydride batteries used (NiHm), these batteries do not follow an adequate recycling and disposal process. Several studies show that these batteries have energy levels and that they can be reused in other applications outside of the car as a power supply. This option of using recovered batteries is known as the second life of the battery (SLB). The reuse of batteries generates options to supply power on a large scale and with this reduce the pollution that these batteries can generate, especially in our country that does not have an optimal recycling process. This chapter presents the design of a methodology for the implementation of second life in Ecuador considering the use of NiHm batteries in HEV. For the design of the methodology, two possible scenarios for its implementation are analyzed. Scenario 1 is the use of NiHm batteries to supply energy to laboratories of a University in the city of Cuenca and scenario 2 shows the use of NiHm batteries as an additional energy source at the Airport of Santa Cruz present in the Galapagos Islands.

**Keywords:** Second Life Battery (SLB), NiHm, Hybrid cars, Energy, Battery Pack

## 1. Introduction

In Ecuador, the presence of hybrid vehicles in recent years has had a growth in sales. These vehicles have a traction system based on an electric motor coupled to a combustion engine and a high voltage battery as an energy source. The presence of more than 20,000 vehicles sold from 2009 to 2020 (**Figure 1**) [1], raises concern especially about the high-voltage battery, which in some cases has already reached its useful life. In the country there are no recycling procedures and regulations for the treatment of the different chemical compounds of this type of batteries, this may generate a large environmental impact in the future.

These batteries are generally made of Nickel Hydride metal (NiHm), according to studies presented in [2–4] indicate that their reuse is possible to store energy in a SLB process. Its application in second-life energy storage systems would help in our country to generate NiHm battery reuse projects that in the future would reduce the environmental impact and pollution that these batteries could cause.

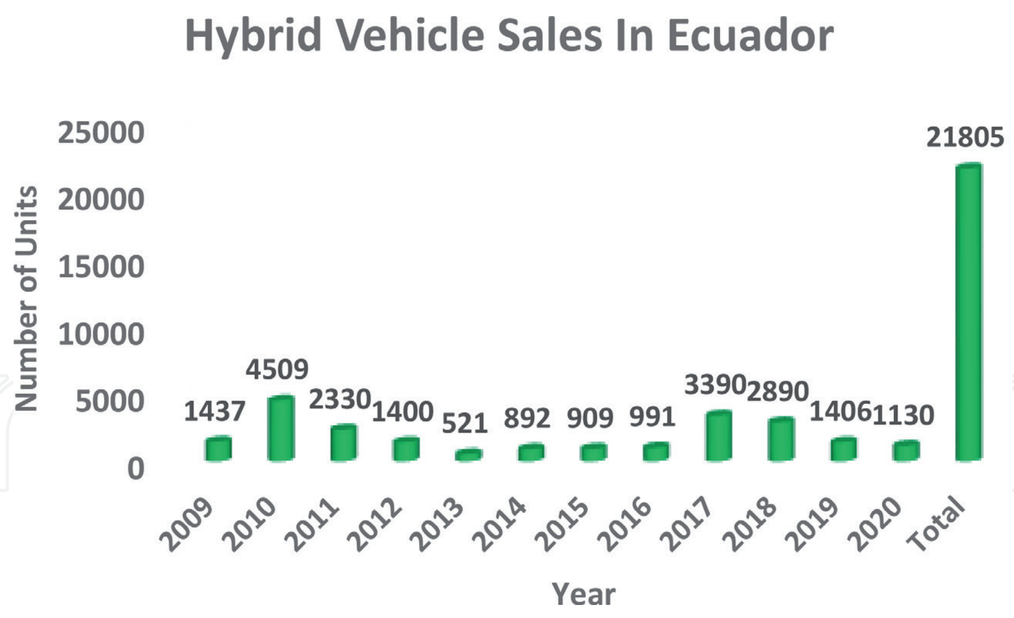


**Figure 1.**
*Sells of hybrids car in Ecuador.*

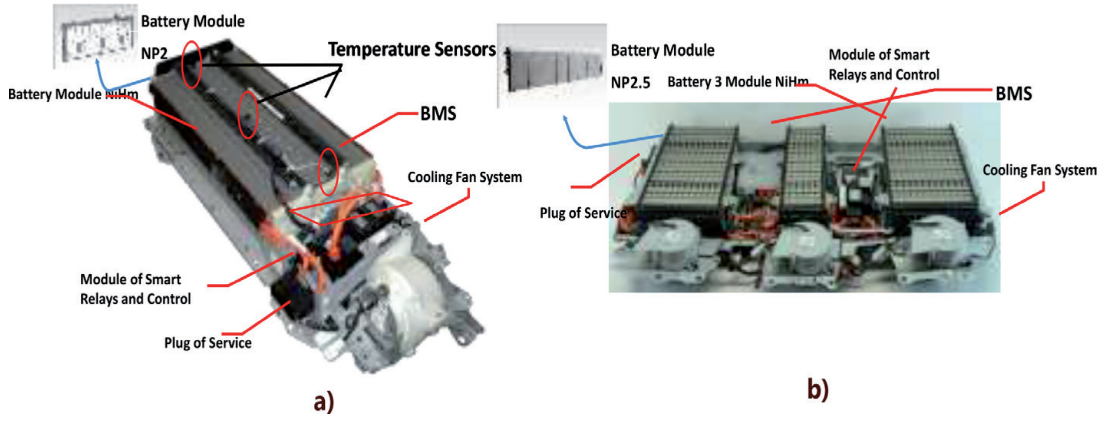


**Figure 2.**
*Types of NiHm batteries in HEV presents in Ecuador. a) Prius C battery, b) Toyota Highlander battery.*

The high-voltage batteries for hybrid vehicles with the most presence in Ecuador are of the NiHm type (**Figure 2**). The battery set is made up of several modules connected in series, these modules are of type NP2 and NP2.5. In addition, it has a control system based on high voltage relays, a cooling system that is activated based on the temperature sensors and a battery management module that is responsible for the supervision of each of the modules.

The NiHm batteries are robust systems that has higher capacity and low maintenance compared to nickel cadmium battery (NiCd). Several laboratories have developed feasibility studies on the use of NiHm batteries in their second life. The studies focus on analyzing the behavior of reused batteries vs new batteries of different chemical compounds, the results show that the use of these batteries in stationary systems is possible with good results [5]. If we consider that SBL systems with lithium-ion batteries are currently being implemented in different countries and show high efficiency and are less expensive, it is due to a high presence of Electric vehicles in these countries [6–15]. But if we compare them with our country, the greatest presence of batteries in the recycling process is that of hybrid vehicles based on NiHm, which allows us to generate an alternative for reuse in energy storage systems.

In continental Ecuador, the battery energy storage system is limited, there are no projects that are developed in this line. In the Galapagos Islands there are projects that consider energy storage based on lead-acid batteries and lithium ion batteries. These projects represent a little less than 5% of all generation capacity on the islands [16]. For all this and the presence of hybrid vehicles, it is proposed to use NiHm batteries as energy storage as an additional supply and with this contribute to caring for the environment and reduce the use of fossil fuels for electricity generation.

This chapter contributes to the search for new sources of energy power based on the use of batteries present in hybrid vehicles and that due to their operating condition can be adapted to a second life process, in the same way it is provided with a methodology for its implementation. Through its implementation, it seeks to improve the recycling processes of this type of batteries and contribute to the care of the environment.The structure of this chapter is as follows: in Section 2 a description of methodology proposed for the implementation of SLB based in NiHm battery of HEV is presented. The Section 3 presents two possible scenarios for the implementation of SBL with NiHm batteries where a comprehensive analysis is presented on the energy demand of each scenario and how much energy storage system with NiHm batteries can contribute if it were to be implemented in each case, considering the proposed methodology; while the conclusion is presented in Section 4.

## 2. Methodology proposed

Recycling processes in Ecuador are still in an early process. According to 2017 demographic statistics only four percent of the total garbage generated in Ecuador was recycled. This was the last year statistics about waste disposal were published. It's not clear how much of this four percent of recycled material has a second life process but most of it it's just simply classified, turned into pallets and sent recycling facilities. In the case of steel, paper and glass, these raw materials are processed in local companies and for most other material such as plastic, aluminum and electronics are sent to recycling facilities in countries overseas.

Such is the case of hybrid modules extracted from hybrid vehicles. Now a days a battery is not a whole individual pack as we seen before with Lead acid batteries but rather a composition or various cells. These cells can actually be replaced in case they are damaged prematurely and will give the whole battery pack a new life. This change will allow the rest of the cells to complete their life span as they may not have been affected. This practice is not sponsored by the manufacturer for safety and commercial purposes, but in this section, we will discuss a methodology proposed in Ecuador to properly and safely do a restoration for the battery de NiHm presents in HEV in order to prolong its life and generate a second life system for using as additional power supply.

The proposed methodology consists of 5 stages (**Figure 3**). The first stage involves the removal of the defective NiHm battery pack from the vehicles, this involves searching for cars with these problems and battery packs that are in recycling shops or automotive dealers. The second stage consists in disarming the batteries to check their shape and discard internal failure or explosion of the cell. In the third stage, the batteries are tested to check their health and charge state, this allows establishing a battery classification and verifying whether or not it is useful in a second life process. Stage four, generates processes for the assembly of battery packs with reestablished cells and the reconfiguration of different elements such as the BMS and the recharging system. Finally, stage 5 shows the implementation of battery packs that can be used as an additional power source in different applications.

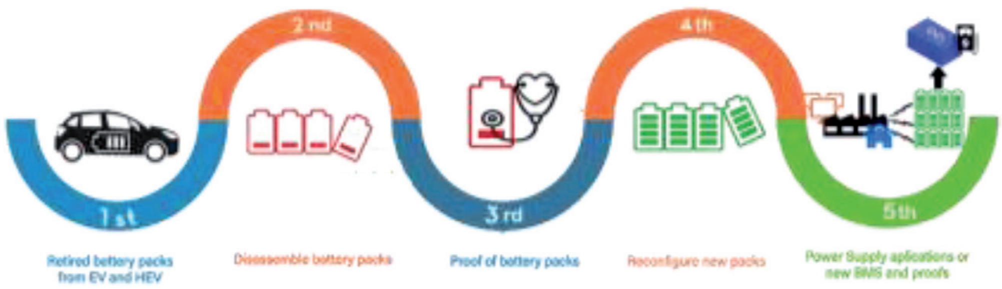


**Figure 3.**
*Methodology proposed for implementation of SLB in Ecuador.*


**Figure 4.**
*Methods for obtain and retired battery packs NiHm.*

### 2.1 Retired battery packs

In this stage we must consider several aspects; the consumer is the first link to building a methodology towards car batteries second life in Ecuador. As the number of HEV grow, costumers of such goods have to be aware of the life span of the battery an of how they should be disposed of after they have completed their life cycle in the vehicle. Costumer should understand that under any circumstance they are not allowed to take their battery home unless they have a special permission to do it. To reinforce this practice, among costumers, applied should be applied policies of change of battery generated by the brand with a presence in the country and laws by part of government that allow good process of recycling for these components. In order to obtain batteries, it is necessary to link with local companies that offer battery replacement and with the dealers of the different brands, in addition to the recycling warehouses, which have these batteries but do not know their origin. All these actions are presented in the **Figure 4**.

### 2.2 Disassemble battery packs

The stage involves the battery disassembly process (**Figure 5**), considering different safety standards, procedures and steps are generated to follow for disassembling the different types of batteries and recycling of parts.

### 2.3 Proof of battery packs

This stage consists of carrying out different charging and discharging processes to select the batteries that are in good condition and carry out a process of cell

**Figure 5.**
*Battery disassembly process.*

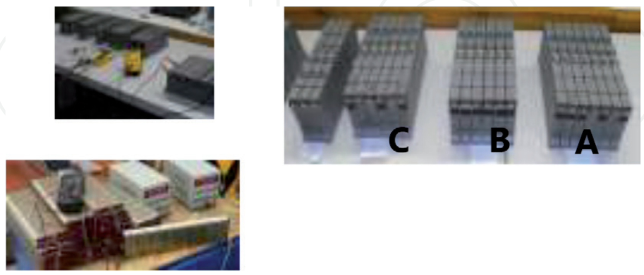


**Figure 6.**
*Process of selection and battery test.*

classification (**Figure 6**). These processes will allow the cells to be classified into three categories, A good condition, B intermediate condition, C damaged cells.

### 2.4 Reconfigure new packs

In this stage, new battery packs are built with the recovered cells and the BMS system is reconfigured in the same way, the battery charging method is selected and power ranges to work are analyzed (**Figure 7**).

### 2.5 Power supply application

This stage implies the use in places and scenarios where they can be installed. Each battery pack is important because it contributes a percentage amount of power at different times of the day such as maximum consumption peaks at certain hours. By restoring the damaged battery cells the conventional network power consumption can be reduced (**Figure 8**).

**Figure 7.**
*Reconfigured new battery packs.*


**Figure 8.**
*Laboratory power configuration with battery packs.*

## 3. Implementation of SLB based in NiHm battery analysis of two scenarios

In Ecuador the electricity sector is considered strategic due to its direct relationship with productive development. In recent years there have been changes in the generation of electricity according to the indicators shown in [17], the sources of renewable energy generation have increased, which is currently well seen by various productive sectors of the country.

The energy requirements at the country level are supplied by hydraulic energy followed by thermal energy and with some generation stations by turbo steam and gas, with solar and wind energy being the ones with the lowest contribution in power generation (**Figure 9**).

The Electricity Regulation and Control Agency -ARCONEL-, according to article 15, of the Organic Law of the Public Electricity Service, has the competence to carry out technical studies and analysis for the elaboration of electricity rates in the public service. The prices and values that to date that are charged in Ecuador

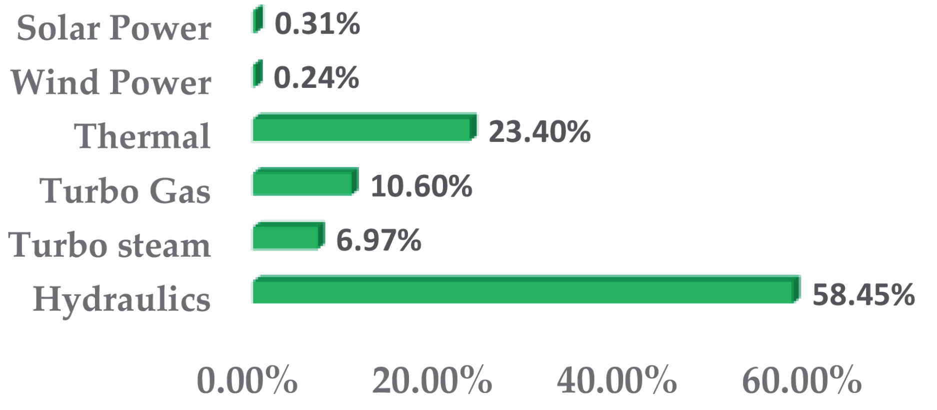


**Figure 9.**
*Forms of power generation in Ecuador.*

are categorized: the first category is the residential sector with energy consumption that exceeds 500 kilowatt hours (kWh) per month, which will pay a flat rate (fixed) of 10 cents per kWh. The second group is the dignity rate for consumptions that do not exceed 500 kWh will pay 4 cents per kWh and the third group is the industrial sector with a rate of 60 cents per kWh this if we speak on a continental level.

The importance of generating alternative options for energy storage systems based SLB recycled batteries can be beneficial to the sustainable development of the country and generate interest to circular economy of systems of batteries for large scale implementation.

This section presents a study of an implementation of SLB in two scenarios using NiHm batteries as energy storage. For the reconditioning and use of the batteries, the methodology presented in the previous section was used. The goal is to be able to analyze its field of application and its energy contribution to reduce the consumption of the conventional network, this would generate a reduction in the payment of electricity value and less energy would be spent from the main power network. The first scenario presents the study of implementation of a system SLB in Galapagos Island. The Galapagos Islands, is a province of Ecuador, they are located 972 kilometers west of the Ecuadorian coast. The capital is Puerto Baquerizo Moreno and it depends directly on the National Government. It is made up of 13 large volcanic islands, 6 smaller islands and 107 rocks and islets (**Figure 10**).

In the Islands since 2007, the governments and the United Nations Development Program (UNDP have promoted the project called "zero fossil fuels", in previous years the main source of generation was thermal, which generated excessive spending on diesel fuel and pollution in the area Currently, different projects based on renewable energy have been built with very promising results [18]. The main sources of generation in the islands are thermal, wind, solar and hybrid.

Energy demand is too high at certain hours, generating peaks that the current energy supplies are not able to handle, therefore the use of additional energy supply systems can be a help to be able to solve these inconveniences.

In the Galapagos Island there are different public and private institutions the **Figure 11** presents differents publics institutions and your monthly electricity consumption before the pandemic and the amount to pay.

The Isla San Cristóbal Airport in Galapagos is the second main passenger terminal in the Archipelago and has an electrical energy consumption of 14,000 kWh approximately per month and represents an expense of $ 1,200 per month


**Figure 10.**
*Galapagos Island geographic map.*

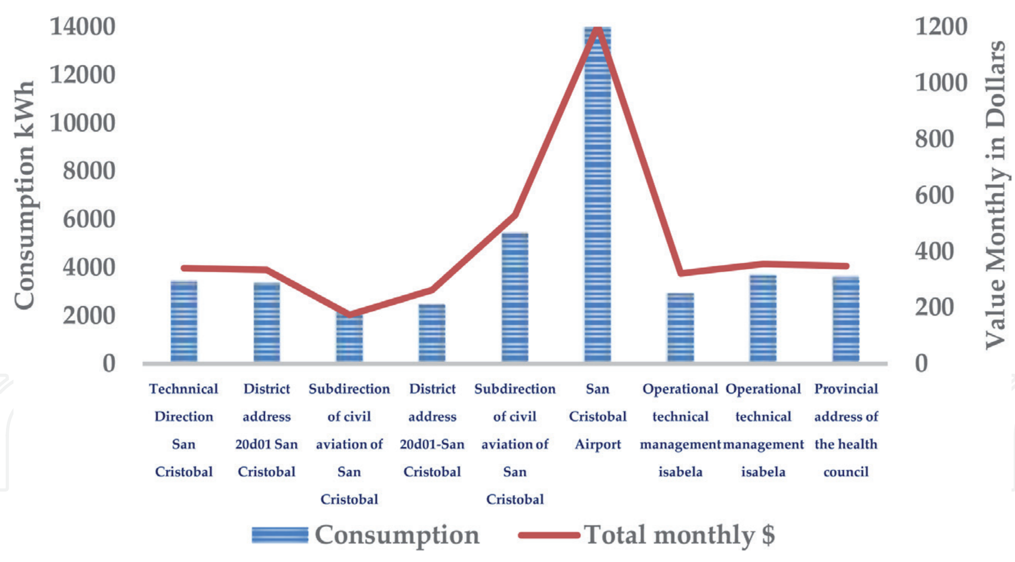


**Figure 11.**
*Energy consumption of public entities in the Galapagos Islands by approximate monthly.*

this data is before the pandemic. Considering the methodology proposed in the previous section, 5 battery racks are implemented and each one with 120 volts dc and with a current of 30 amperes, the design conditions for the system would be as presented below.

Each rack provides a power of 3.6 kW, the SLB system would have a power of 18 kW. To be able to generate a power in this range, the design of a photovoltaic system is needed that will serve to generate the amount of power necessary to charge the battery racks. The photovoltaic system is made up of 50 solar panels of 370 watts a BSP370M system is used, which is a model available in our country. The system is shown in **Figure 12**.

The photovoltaic system proposed generates 18500 Watts. In the Galapagos Islands there is sun throughout the year with a duration of more than 10 hours a

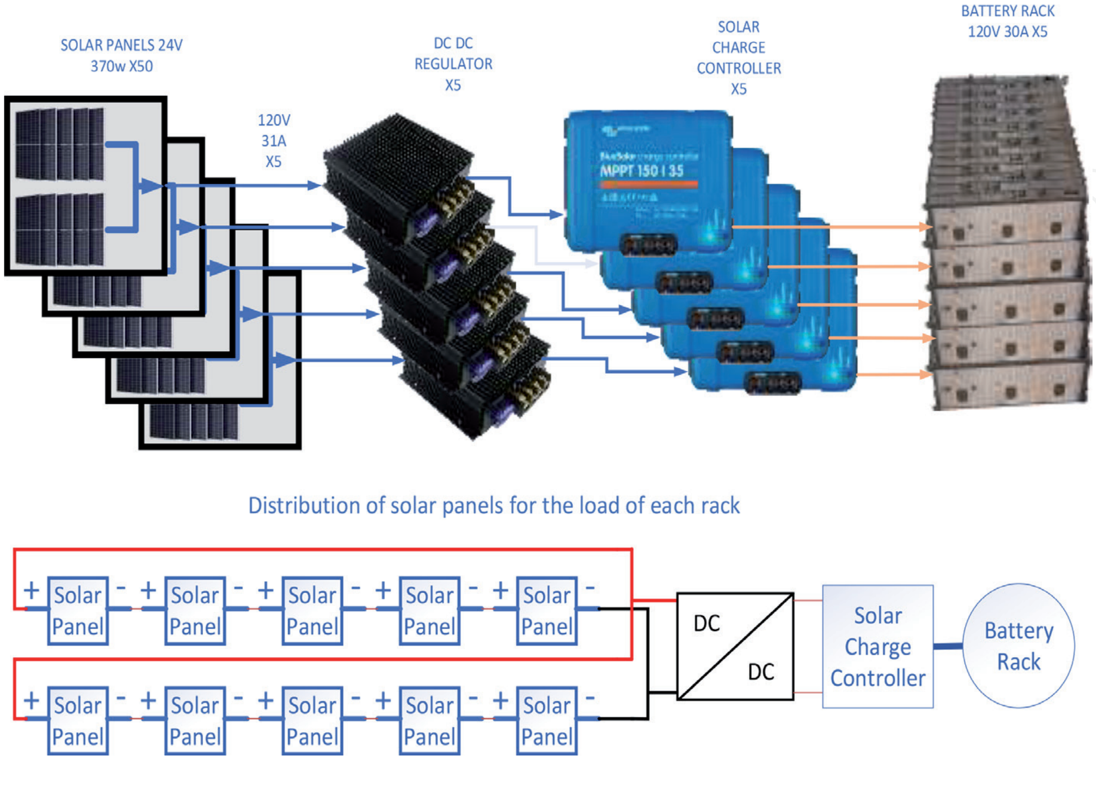


**Figure 12.**
*Photovoltaic system.*

| Battery Racks | Voltage and Current | Power of Panels (w) | N. of Panels | Hours per month | Amount kWh |
|---|---|---|---|---|---|
| 5 | 120 V -30 A | 370 | 50 | 240 | 4440 |

**Table 1.**
*Values and contribution of SBL.*

day of exposure, which allows an optimal generation by the system. With all these data, **Table 1** presents an analysis of this scenario and the contribution that the SLB system has with respect to its possible implementation.

If we compare the results obtained with the system SLB and the actual consumption of the airport, we can analyze that the contribution of system represents the 31.71% of the total of kWh by month. This would allow us to free up a demand of almost 4440 kWh that can be used by other users within the islands (**Figure 13**).

The cost for implementation is presented in **Table 2**. This section does not consider the cost and design of the DC-AC inverters to generate alternating current.

This proposal would cover its implementation expenses in 36 months, considering that the proposed BSL system contributes 4440 kWh at a differentiated rate of 0.086 US cents per kWh (according to the payment rate within the islands) and would generate a saving of US $ 4582.08 per 12 months. Undoubtedly it generates interest for its future implementation within this analyzed scenario.

The selection of the panels for this project was carried out with load and unload tests to verify the state of charge (SOC) of each module. With the panels in better

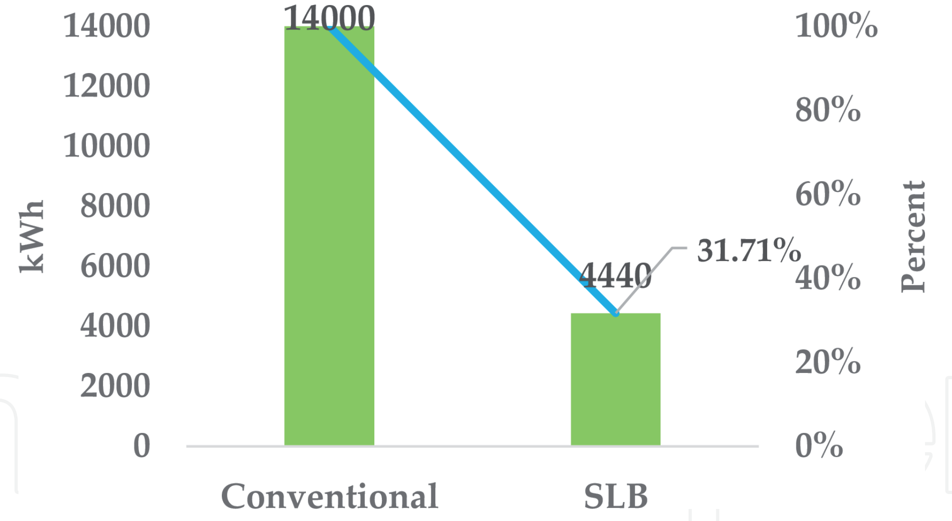


**Figure 13.**
*Analysis of contribution of SLB system first scenario.*

| Devices | Cost Unit | Total |
|---|---|---|
| 50 solar panels BSP370M | $ 204.50 | $ 10200 |
| 80 Battery Cells NiHm | $3 by recycling | $ 240 |
| 5 Solar charger controllers | $ 61 | $ 305 |
| 5 DC-DC regulators | $35 | $175 |
| Total | | $ 10920 |

**Table 2.**
*Cost of implementation.*

condition, we make up the racks used for the supply of energy, but in the future where it will be carried out with a higher number of modules in the new racks, the selection will be made by means of an electrochemical model.

For this model, certain values are considered that establish the aging of the batteries: Temperature (T), Depth of discharge (DOD), state of charge (SOC) and current rate (I). In Eq. (1) the dependence of the factors on the loss capacity is described [19].

$$C_{loss} = f\left(I, V, DOD, T, t\right) \tag{1}$$

The fading of the storage capacity of each cell is a function of current (C) and DOD factors. To obtain these factors, charge and discharge tests should be performed in percentages of a full discharge of C, 50% SOC, and 100% DOD. In Eqs. (2)–(5) the degradation is adjusted in relation to the aging factors [19].

$$I_{ef} = \theta_1 \cdot I^2 + \theta_2 \cdot I + \theta_3 \tag{2}$$

$$V_{ef} = \theta_4 \cdot V + \theta_5 \tag{3}$$

$$DOD_{ef} = \frac{\log_{10}\left(DOD\right)}{2} \tag{4}$$

$$T_{ef} = \frac{e^{\frac{\theta_6}{T}}}{e^{\frac{\theta_6}{298}}} \tag{5}$$

The parameters $\theta_1, \theta_2, \theta_3, \theta_4, \theta_5$ and $\theta_6$ should be determined according to the type of battery.

Once you have the loss of capacity due to aging, the state of health (SOH) is expressed in Eq. (6), it is calculated between the initial capacity of the battery and the capacity obtained in the tests.

$$SOH = \frac{Cap}{Cap_{ini}} \tag{6}$$

The second scenario analyzes the implementation of a SLB system in the automotive mechanics laboratories of the Universidad del Azuay located in the city of Cuenca, in the south of the country. The laboratory has a monthly consumption of 3600kWh each kWh has a value of 0.095 cents of a dollar that per year means an expense of $ 4104 dollars for the University. It is considered to place a 120 V battery rack at 35 amps. The system supplies a power of 4.2 kW. For charging the battery pack using solar panels can be used panels from 24 V to 455 Watts for our system used models JAM72S20–455 MR and consider the structure of the **Figure 14**.

It takes 10 solar panels, two groups in parallel with five panels in series this supplies the voltage and current requirement for battery charging. The arrangement of the panels in series with their reference values and regulators is shown in

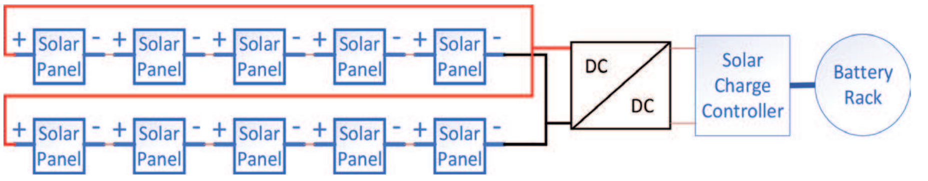


**Figure 14.**
*Charging structure with solar panels.*


**Figure 15.**
*Components of the solar powered charging unit.*

**Figure 15**. The voltage of solar panels varies depending on factors such as ambient temperature, which is why regulators are used that take care of the useful life of the batteries at the time of charging.

Cuenca is a city that is located in the Ecuadorian highlands, it usually has 12 hours of sun but the climatic situations are different, so we consider 8 hours a day in which the solar panel system can generate. The photovoltaic system proposed generates 4500 Watts. The contribution in kWh of this system SLB in second scenario represent 1092 kWh and is shown in the **Table 3**.

The implementation of this system contributes 30% of the consumption in kWh, which represents a good contribution to reduce consumption costs and that the 1092 kWh that this represents can be used by other clients of the electricity company (**Figure 16**).

In this case, the implementation costs would be covered after 26 months. Considering that the proposed BSL system contributes 1092 kWh at a differentiated rate of 0.095 US cents per kWh (according to the payment in the country) and would generate a saving in 1244.88 by 12 months.

| Devices | Cost Unit | Total |
|---|---|---|
| 10 solar panels JAM72S20–455 MR | $ 250 | $ 2500 |
| 16 Battery Cells NiHm | $3 by recycling | $ 48 |
| 1 Solar charger controllers | $ 61 | $ 61 |
| 1 DC-DC regulators | $35 | $35 |
| Total | | $ 2644 |

The following analysis describes the effects caused by the use of this type of batteries in second life considering the two scenarios studied. A comparison of the two scenarios with and without SBL system is made. For this analysis, the need for energy consumption of the scenario is considered, which is 14kWh of this amount, the contribution of the SLB system designed for this scenario is 4.4kWh at the energy cost level, which means a money saving of almost 20% with just 80 cells of NiHm batteries that generate a power of 18 kW (**Figure 17**).

| Battery Racks | Voltage and Current | Power of Panels (w) | N. of Panels | Hours per month | Amount kWh |
|---|---|---|---|---|---|
| 1 | 120 V -35 A | 455 | 10 | 240 | 1092 |

**Table 3.**
*Value of contribution of SLB system in second scenario.*

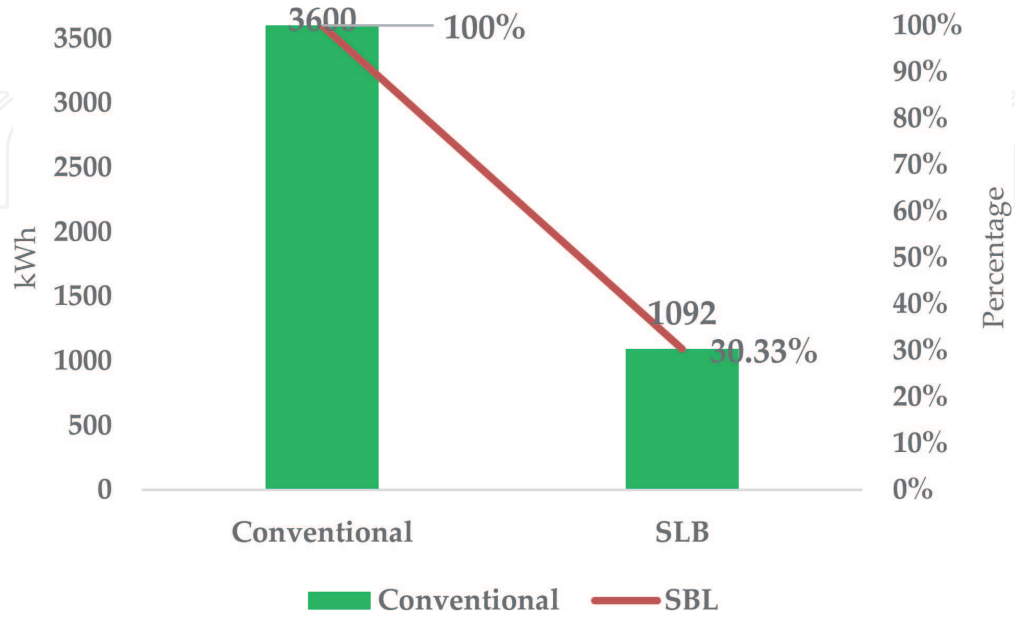


**Figure 16.**
*Analysis of contribution of SLB system second scenario.*

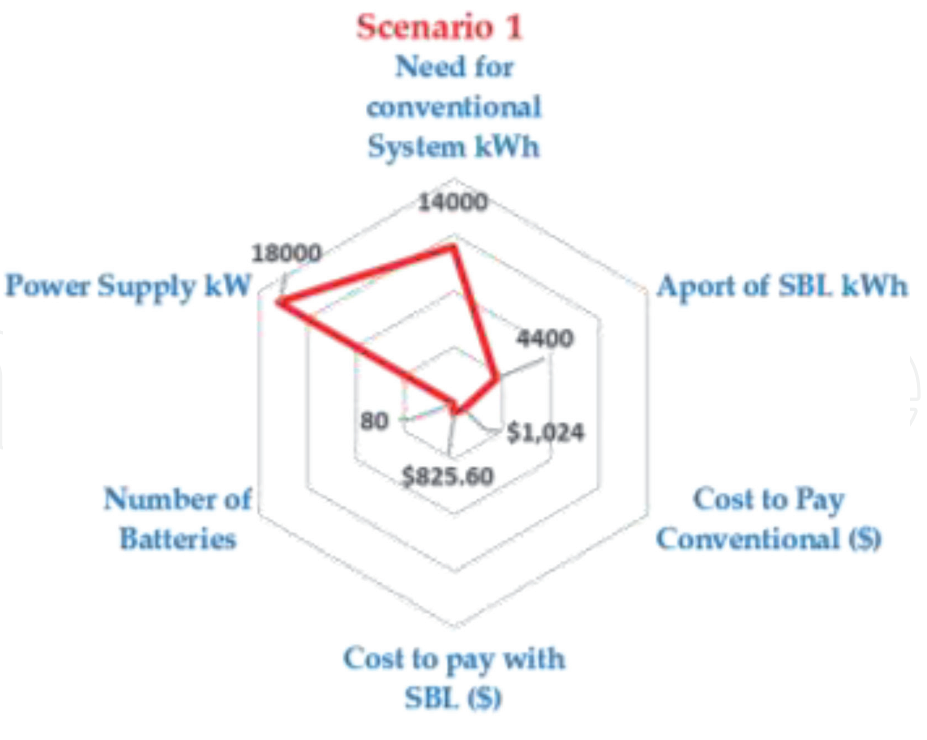


**Figure 17.**
*Analysis and comparison of first scenario with and without SBL system.*

For the second scenario, the need for energy consumption is 3.6 kWh and the contribution of the SLB system designed for this scenario is 2.5 kWh at the energy cost level, which means a money saving of almost 58% with just 16 battery cells. NiHm that generate a power of 4.2 kW (**Figure 18**).

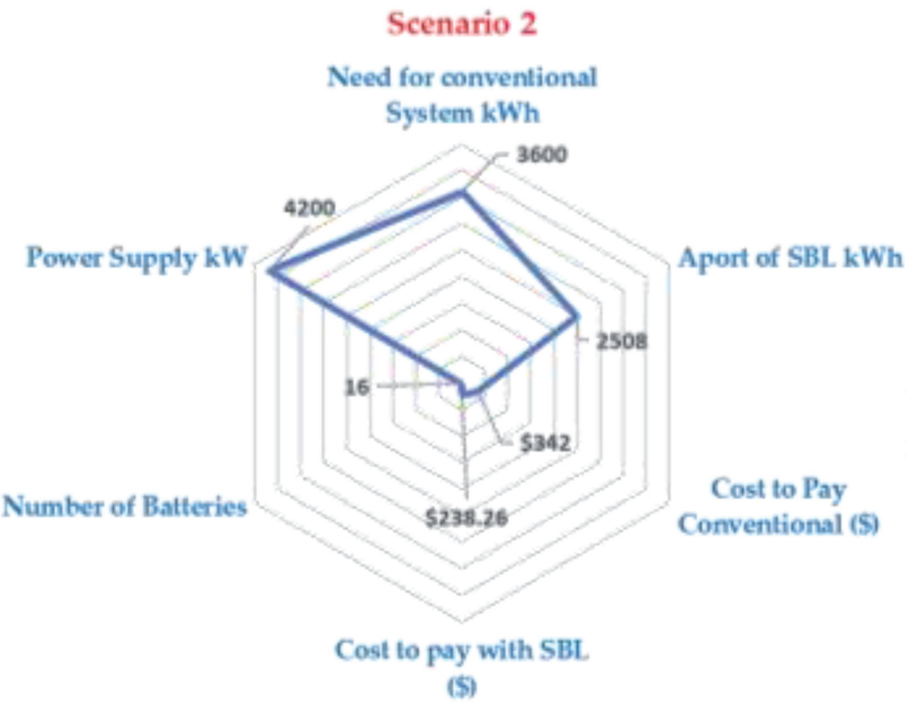


**Figure 18.**
*Analysis and comparison of the second scenario with and without SBL system.*

## 4. Conclusions

The introduction of hybrid vehicles in the country and especially the treatment of battery packs mean that this type of study allows the generation of new lines of research that allow the development of projects based on the second life of batteries. In our country very little is said about the advantages in the use of NiHm batteries present in these vehicles to be used as energy accumulators or as second life systems and the environmental impacts that this can generate.

This study focuses on generating methodologies that allow us to improve the quality of recycling these elements and generate a special treatment for their recovery. In addition, in contributing to society and being able to arouse the interest and attention of local and national government agencies and in conjunction with the academy to be able to generate circular economy projects and recycling regulations for this type of batteries and seek financing mechanisms for their implementation in strategic areas of the country.

The country is not a producer of this type of technology, but if we use correct recycling methods and develop optimal systems with second-life materials in the future, we can become a model to follow for the rest of Latin American countries, considering that hybrid vehicles continue to enter and increase. Sales and the transition to electric vehicles is getting closer.

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## Conflict of interest

The authors declare no conflict of interest.

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