Conference Paper

Controller Design and Experimental Validation of a Solar Powered E-bike Charging Station

Carlos José Oliveira Inácio, Ivan Joel Ponciano Silva, João Pedro Domingues Faria, Jose Alvaro Nunes Pombo, Maria do Rosário Alves Calado, and Sílvio José Pinto Simoes Mariano

UBI

Abstract

Electric Vehicles (EV) have gained interest over the past decade. Because of this, to support EV technology installation of charging stations are required. Charging EVs from renewable energy provides a sustainable means of transport. E-bikes can help mitigate some mobility problems, particularly in large cities and metropolitan areas. This paper shows the development and implementation of a solar e-bike charging station with photovoltaic production, with energy storage system. The implemented system has a centralized control and allow an efficient management of the various resources and contemplates the possibility of four simultaneous e- bikes where user identification is performed by RFID. Finally, it is provided a user interface through an HMI panel and a web page where it will be possible to access the DataLog to consult the user activity and all charging parameters.

Keywords: Renewable energy, Solar charging station, Programmable logic controller

Corresponding Author:
Carlos José Oliveira Inácio
carlos.inacio@ubi.pt

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1. Introduction

Nowadays, almost every vehicle used for public and private transport use internal combustion engines, dependent on the use of petroleum and their derivatives. Due to the finiteness of this natural resource, atmospheric pollution and global warming, a search for alternative options has begun. Battery research has led to significant improvements in energy storage systems, which provides an advance in electrical mobility. These advances have made the Electric Vehicles (EV) charged from renewable energy a sustainable means of transport [1], [2]. The electrical grid power is still very dependent on the use of fossil fuels. Thus, charging EVs through electrical grid results in indirect emissions. Electric Vehicles (EV) provide a clean and pollution-free mode of transportation. However, they are only considered sustainable if the electricity they use to be charged comes from sustainable energy sources, such as solar and wind [1], [3]. Sustainable mobility has its main objective in reducing the environmental and

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social impact. Prioritizes the use of EVs, whether in public or individual transport and promotes the reordering of urban spaces and activities, in order to reduce travel needs and their costs.

The European Commission (EC), together with partners from the European Green Vehicle Initiative (EGVI), has set a specific goal for the coming years: to improve by 50% the efficiency of the energy transmission system between 2010 and 2030, including: 80 % more energy efficiency for urban vehicles and 40% more energy efficiency in long distance freight transport; 5 million electric and hybrid vehicles in the EU by 2020; Battery life and energy density double and reduce their cost by up to 30% by 2020 compared to 2009 Li-Ion technology [4].

This new paradigm of mobility includes e-bikes. The term e-bike (electric bicycle) refers to a two-wheeled vehicle with the addition of an electric motor powered by a rechargeable battery and a controller that regulates the power applied to the motor. Essentially, e-bikes come in two types of configuration: some that appear as traditional bikes and some with scooter styled bodies. The first configuration can be either a power-only bicycle (via a hand throttle) or an electrically assisted pedal bike, called *Pedelec* or EPAC (Electrically Power Assisted Cycle) [5], [6]. *Pedelecs* have an electric motor to assist the rider's pedal-power, thereby improving their performance and reducing the effort required, especially on steep climbs and thus making traveling easier and faster.

The global e-bike market is divided between those that incorporate Sealed Lead Acid (SLA) and Lithium-ion (Li-ion) batteries. By 2025, projections for the SLA batteries market estimate an average annual decrease of 4.7%, while for the Li-ion batteries, an average annual increase of 11.4% is estimated [7]. Therefore, the e-bike market is making progress towards the use of Li-ion batteries. This dominance is related to the large investment in this technology due to its advantages over SLA batteries, namely lower weight, higher energy density, higher efficiency in the charging and discharging process and lower environmental impact [8], [9].

E-bikes can help mitigate some mobility problems, particularly in large cities and metropolitan areas, making them very effective when compared to other modes of transport and should be increasingly adopted by people, especially the younger population. The use of bicycles brings individual and social advantages, namely [5]:

- It is the most energy efficient and most sustainable means of mobility, integrating physical exercise in the daily routines of users;
- It has the potential to replace short or medium distances by car;

- It is the cheapest means of transport (no registration tax, no insurance, no driving license, no parking costs and no high maintenance costs);
- Significantly reduces traffic, noise, parking problems and air pollution in urban areas.

This project is part of an Iberian project within the Interreg program that studies the future of urban mobility and the charging of electric batteries using solar energy. Named “URBAN AIR - Melhoria do Ambiente Urbano e Redução da Poluição do ar através de Soluções de Mobilidade Sustentável nas cidades de Portugal e Espanha”, the project's main objective is to promote the use of e-bikes charged by renewable energy like solar energy.

The e-bikes used in this project take in account the standards applied to electric bicycles. According to the Portuguese driving laws, e-bikes are human-powered vehicles that are equipped with an electric motor that can be used to assist the rider. The maximum power provided by the motor is 250W, which is reduced linearly with increasing speed or interrupted when reaches a speed of 25 km/h [10], [11].

This paper presents the development and implementation of a solar charging station for e- bikes. This work is divided into the next topics: description of the solar charging station, description of the control system and its software and finally with conclusions of the work performed.

2. Solar E-bike Charging Station

Figure 1 illustrates the four e-bike charging stations that will be installed at the University of Beira Interior. These will be constructed in places that allows to cover the various spaces of the UBI, namely the Residência Universitária de Santo António (Figure 1.d), Faculdade de Ciências da Saúde (Figure 1.b), Faculdade de Engenharia (Figure 1.a) and Residência Universitária do Sineiro (Figure 1.c).

All e-bike charging stations will be equipped with an array of 16 photovoltaic panels with a rated power of 5.5kWp and an electrical energy storage system consisting of 4.8kWh Li-ion batteries.

Figure 2 shows the overall architecture of the system implemented in e-bike charging stations. It is a system with photovoltaic production, interconnected with the grid, with energy storage system. The selected architecture has a centralized control allowing an efficient management of the various resources and can apply a set of predetermined constraints and priorities such as, prioritizing the use of solar energy or the use of Li-ion

Figure 1: Charging stations installed in different spaces of the University of Beira Interior

batteries for charging the e-bikes. The main Control Unit, responsible for monitoring and controlling the charging station, is a Programmable Logic Controller (PLC).

The implemented system only contemplates the possibility of four simultaneous e-bikes where user identification and unlocking of the e-bike charging station is performed by Radio-Frequency Identification (RFID).

3. System Control Design

Figure 4 shows the wiring diagram of the Solar e-bike charging station control and the respective power circuit. The control circuit is based on the Siemens SIMATIC S7-1500. This PLC family offers a wide range of CPU models that vary, depending on the model, memory capacity (Work memory and Load memory) and number of inputs and outputs.

In this project we used the CPU 1512C-1 PN with a working memory of 250 KB and a load memory of 1 MB. The working memory can be extended using a memory card, in this case a 24 MB memory card was used. This PLC has a module of 5 analog inputs and 2 analog outputs (AI5 / AQ2) and 32 digital inputs and 32 digital outputs (2x16 DI / DQ). The CPU has a power supply of 190 W 120/230 V AC [12].

The communication between the PLC and the RFID reader, was made by the communication module SIMATIC RF180C. This communication module allows the connection

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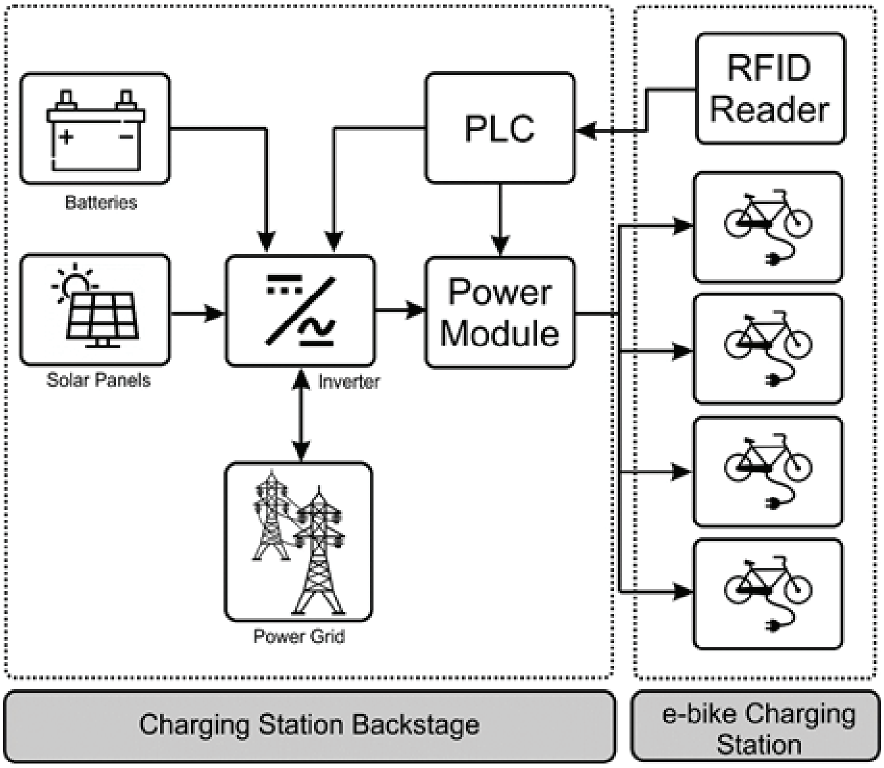

Figure 2: Overview of proposed solar e-bike charging system

of two RFID readers with a data transfer rate of up to 100 Mbits / s. Regarding RFID readers, the RF340R model with reading and writing capacity was used.

For a greater interaction between the user and the system, an HMI touch panel (KTP400 Basic) was used. It allows the user to interact with the control unit, obtaining real-time process information, alerts, analysis and feedback [2].

The power circuit of each Solar e-bike charging station's positions includes a smart meter and a power contactor controlled by the main control unit. In addition, an external AC-DC converter was chosen, allowing a plug and play solution to make the expansion of the Solar e-bike charging station more versatile and flexible.

The TIA Portal software tool provides the necessary tools for programming the PLC. PLCs can be programmed in 6 different languages according to international standard IEC 61131-3 which are: Ladder Diagram (LD), Block Diagram (FBD), Structured Text (ST), Instruction List (IL), Diagram Sequential Function Diagram (SFC) and Continuous Function Diagram (CFC) [13].

The Structured text language is referred to by Siemens as SCL (Structured Control Language) and is a high-level Pascal based language allowing the programmer greater freedom. Considering this advantage, it was decided to program all the software in SCL.

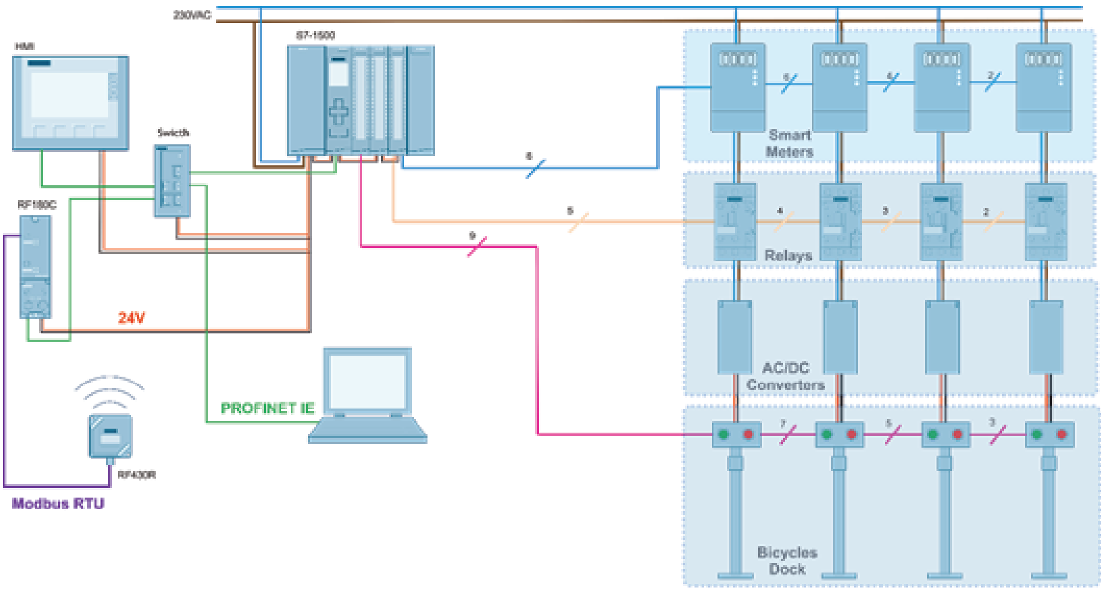

Figure 3: Overview of Urban Air project

4. Software

The operation of the solar e-bike charging station from the user's perspective can be divided into four stages, as shown in figure 4. The user can ride freely and recharge his e-bike on one of the four solar e-bike charging station available on the urban perimeter. To do this, the user must park the e-bike in a free parking position in the solar e-bike charging park frame and connect the charging plug to his e-bike. Lastly, the user must identify himself in the system through an RFID card. The software will detect the connected e-bike to the system and then start the charging process.

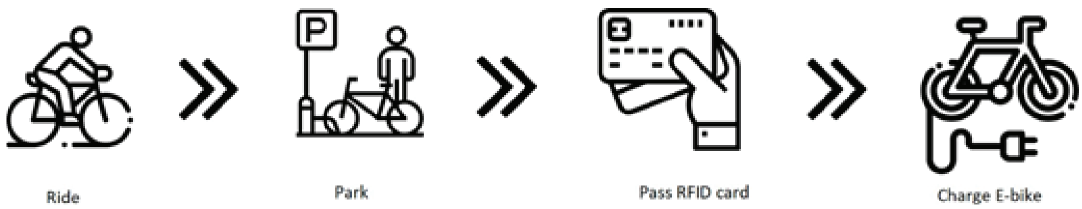

Figure 4: Operating dynamics

The structure adopted for the software consists of 6 states that correspond to 6 subroutines with different functions. This way it is possible to make the program much more modular, allowing states to be called at any time in the program. It should be noted that the flowchart with all these subroutines/states is shown in Figure 5. Below is described the functions performed by each of these subroutines.

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State 0: In this state, the RFID reader is reset to an operational state for future reading or writing of RFID cards. If an error occurs in the reader operation, the program returns to this state.

State 1: In this state the program waits for the presence of a potential user. If any user identifies through RFID card, the program jumps to state 3. Also, in this state a timer is activated and at every 60 seconds force the program jumps to state 2.

State 2: In this state, the program reads the energy consumption and verifies if the value is higher than the previous value. If the charging process has not finished yet (current value is higher than the previous value) the program returns to state 1. On the other hand, if the charge is finished or the e-bike was removed, i.e., the current value of the energy consumption is equal to the previous value, the program transits to state 5.

State 3: This state is activated after the presence of a potential user. The program verifies if the user is in the database of previously authorized users. If the user belongs to database is authorized to carry out the charging and the program goes to state 4. In case the user does not belongs in the database, the program returns to state 1 and waits for the presence of a new user.

State 4: In this state, the program waits 60 seconds for the e-bike connection to the charging station. If the connection is not performed, the program returns to state 1. In other way, if the connection is established, the power contactor is activated, and the charging is initiated.

State 5: In this state the power contactor is turned off and all parameters associated with the charging process are saved in a DataLog such as, charging time, name of the user and charging date and time. This DataLog is saved in.xlsx file format and made available on the website for future consultation.

5. User Interface

The user interface can be performed in two ways: With access to the HMI panel or by consulting the web page, where it will be possible to access the DataLog to consult the user activity and all charging parameters.

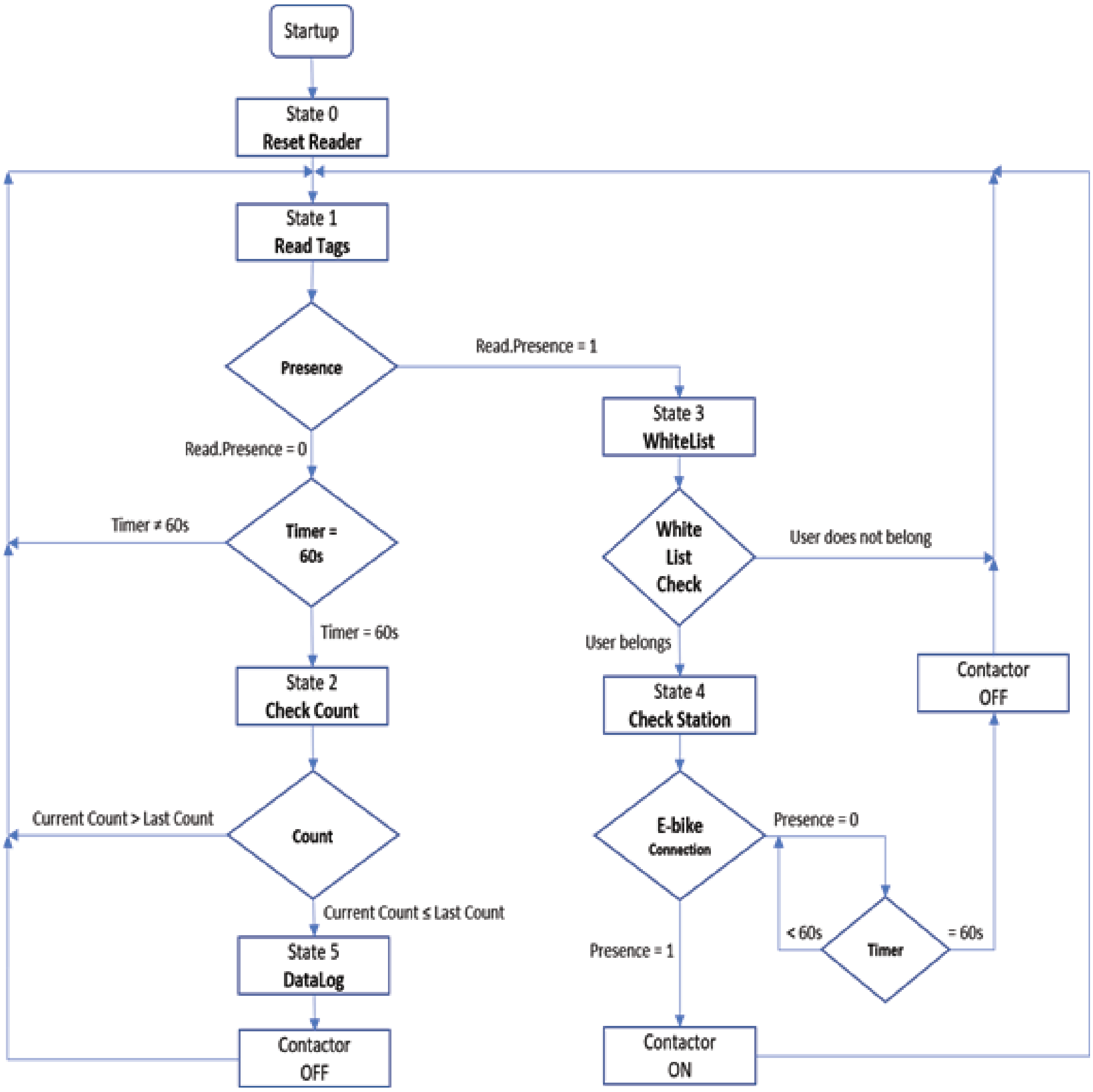
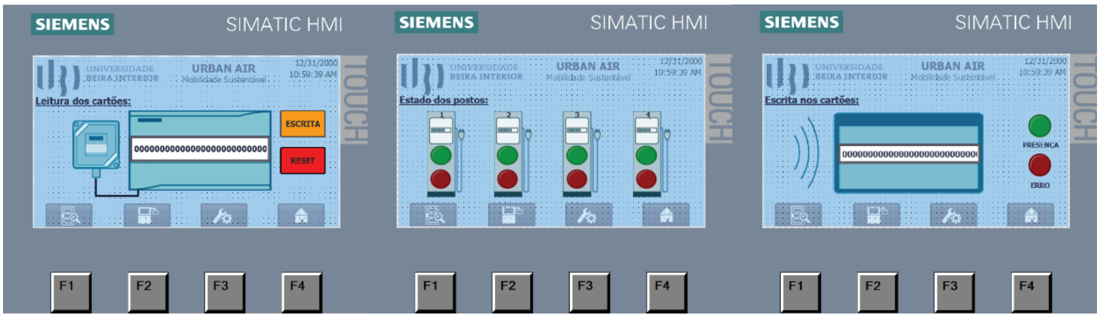


Figure 5: State/Dialogue flowchart explaining the software operation

6. HMI

In addition to what has been said previously about HMI panels, this type of console provides a solution that fits the specific needs of each application, delivers optimal performance, a wide range of screen sizes and a mounting capacity to facilitate updates. For this project we used the SIMATIC KTP400 Basic model which has a 4.3-inch touch screen with a resolution of 480x272 px and four physical keys that can be programmed with any desired function.

The Figure 7 shows some of the screens created for the project. One of the screens shows the information when any user identifies through RFID card (Figure 6.a). Figure 6.b shows the information about the charging stations and Figure 6.c shows a screen that allows writing new information on the cards, so it can only be accessed using a username and password.



a) b) c)

Figure 6: Some ofthe scre ens represented on the HMI panel

7. Web Page

The web page consists on the integration of a PLC in a local area network (LAN) to control and monitor the system operation. Through the web page which can be viewed in Figure 7 shows some screens created to consult the user activity and all charging parameters. In the screen shown in Figure 7.a it is possible to download the user activity, and some charging parameters, charging time and energy consumption. In Figure 7.b is shows another screen where it is possible to add new users information. In Figure 7.c it is possible to check the state of the solar e-bike charging station, as well as the energy supplied.

8. Conclusions

This article describes the development and construction of an e-bike charging station. It is a system with photovoltaic production, interconnected with the grid, with energy storage system. The selected architecture features centralized control allowing efficient management of the various resources and can apply a set of predetermined constraints and priorities. Implementations of these systems mitigate some mobility problems, particularly in large cities and metropolitan areas, making them quite effective compared to other means of transport.

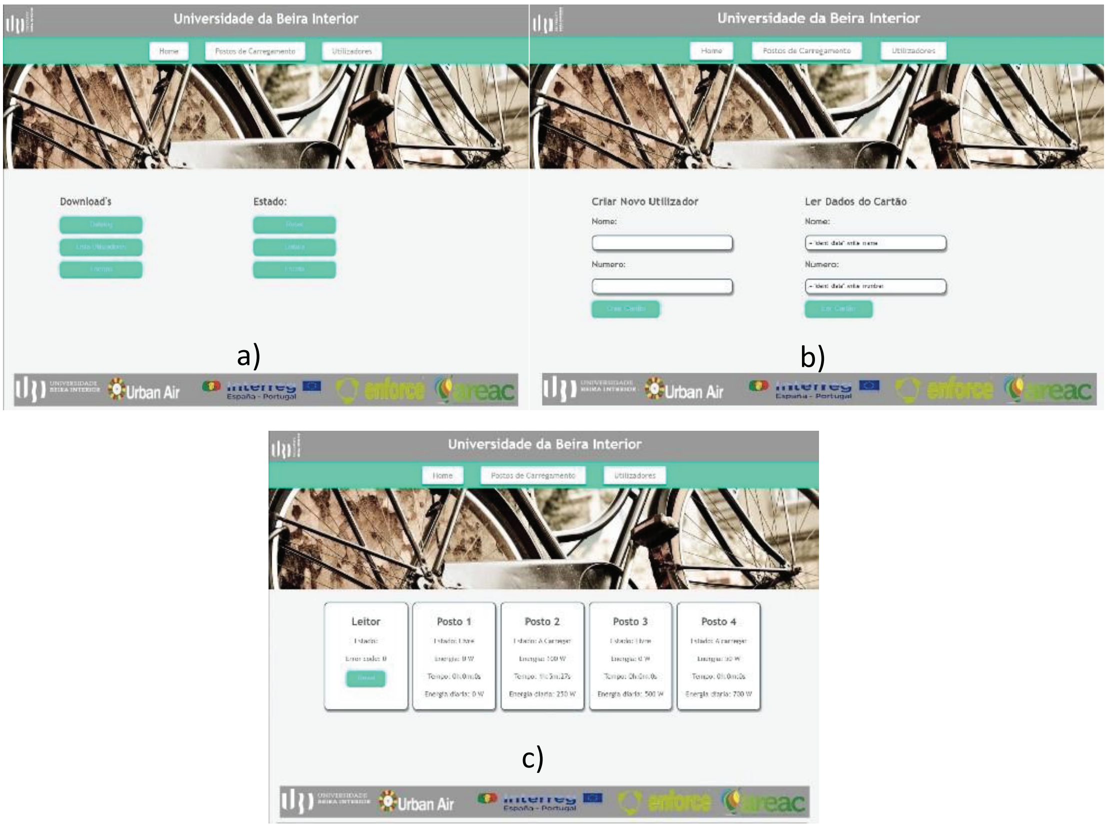


Figure 7: Some of the screens represented on the webpage

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