Optimization and Evaluation of Solar Powered Electric Rickshaw

Final Presentation

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Outline

Introduction

Battery electric vehicles

- completely electric
- no tailpipe emissions

Problems for the widespread adoption of electric vehicles (Delloite 2018)[1]

- range
- cost
- charging infrastructure

Range anxiety – fear that the driver has of not being able to cover the distance needed to reach its intended destination because of the finite range of the vehicle.

Figure: Range anxiety problem taken from Buedot (https://thebluedot.co/what-is-range-anxiety).

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How to alleviate range anxiety?

[1] Deloitte. Deloitte Global Automotive Consumer Study. Pages 1–4 , 2018.

Vehicle Integrated Photovoltaics (VIPV)

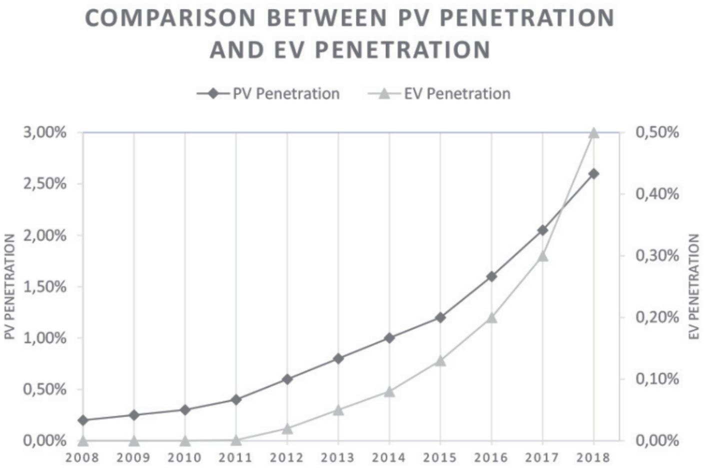

Figure: PV and BEV Penetration (IEA-PVPS-Task 12 2019).

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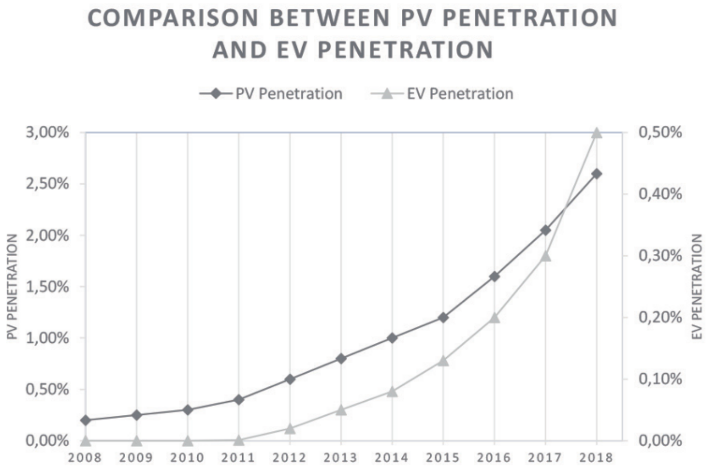

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Motivations

- Adding onboard PV is cheaper and lighter (thus more efficient) than adding more battery capacity – **increased range**.
- Reducing 'fast' charging from the grid increases convenience and battery lifetime.
- Reduces peak demand from the grid.

Objectives of this Study

Goals & methodology

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   - range extension - reduce range anxiety
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3. Select a new battery pack for the proposed system

Vehicle Modeling

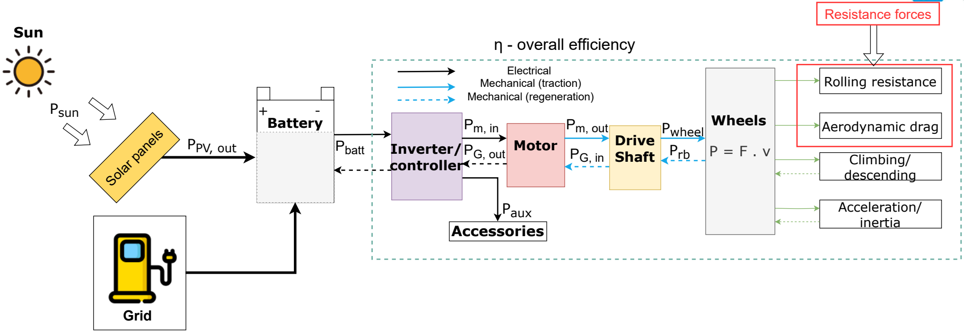


Figure: Schematic representation of the panel-to-wheel and wheel-to-battery energy flows of the BEV.

$$\eta_{tot}(\omega, T_l) = \frac{P_{wheel}}{P_{batt}}$$

- P_{wheel} - power seen on the wheels
- P_{batt} - power measured at the battery terminals

How to estimate P_{wheel} ?

Longitudinal Dynamics Model

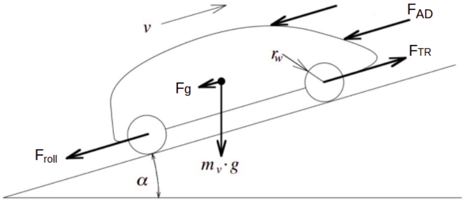


Figure: Relevant forces acting upon on an vehicle moving on an inclined road (L. Guzella)[3].

Parameter	Value
m (kg)	903 kg
f_{rr}	0.013
$C_d \cdot A_f(m^2)$	1.75
$1+\varepsilon_i$ (kg)	1.05

$$m = \underbrace{829.4}_{vehicle\ mass} + \underbrace{3 \times 21.2}_{panel\ weight} + \underbrace{10}_{support\ structure\ weight} = 903\ kg$$

Very simple approach. All forces act at the center of the vehicle mass. It estimates mechanical power at the wheels provided by the motor. Applying Newton's second law of motion we get the main equation that governs this model.

$$m(1+\varepsilon_i)\frac{dv(t)}{dt} = F_{te}(t) - F_{res}(t)$$

$$\begin{cases} F_{res}(t) = F_{ad}(t) + F_{rr}(t) + F_g(t) \\ F_{ad} = \frac{1}{2} C_d A_f v^2 \quad - drag\ force \\ F_{rr} = f_r mg \cos\alpha (1 + \frac{v}{44.4}) \quad - roll\ force \\ F_g = mg \sin\alpha \quad - gravitational\ force \end{cases}$$

Vehicle's Trip Energy Consumption

$$F_{te} = m(1+\varepsilon_i)\frac{dv(t)}{dt} + (F_{rr} + F_g + F_{ad})$$

- To find the energy spend on a trip, one needs to integrate the traction force over the length traveled by the vehicle.

$$E_{wheel} = \int_{s_i}^{s_f} \left[m(1+\varepsilon_i)\frac{dv(t)}{dt} + (F_{rr} + F_g + F_{ad}) \right] \cdot ds$$

  - E_{wheel} - corresponds to the variation of energy in the batteries but also the energy provided to the motor to move forward.
- Energy Balance: here neglecting auxiliary power, P_{aux}.

$$E_{batt} = \begin{cases} \eta_{tot}(\omega, T_l) \cdot E_{wheel} - E_{solar} & \textit{During the day} \\ E_{grid} & \textit{Overnight} \end{cases}$$

Electric Rickshaw Properties

✓ Environmentally friendly

1. 24 $LiFePO_4$ 180 Ah batteries, $V = 76.8$ V
2. 7 kW three-phase Induction Motor
3. Expected range of 100 km.
4. Capacity to transport up to 5 people plus the driver.

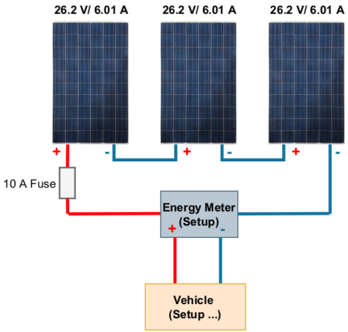
Characterisitc	Value
Seat capacity	6 seats
Rear tire size	155/80R13
Front tire size	145/70R12
charger specification	10A
Battery voltage	76.8 V
Weight(w/o PV)	829.4 Kg
payload	300 Kg (max)
Energy consumption	13.8 kWh/100 km
Maximum velocity	45 km/h
Gear ratio	10:1

Table: Vehicle data for the **E-rickshaw Limo GT** as specified by the manufacturer[2].

[2] E-Tuk Factory. e-Tuk Limo GT Brochure https://www.etukfactory.com/limo Online 2020.

Solar Electric Rickshaw

$V_{tot} = 26.2 \times 3 = 78.6\ V > V_{batt} = 76.8\ V$
$I_{tot} = 6.01\ A$ under STC



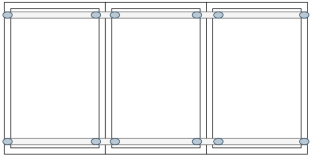


Figure: Setup of the solar photovoltaic panels support.

Building Data Acquisition System

Raspberry Pi 3

- credit-card-size computer (56 $\times$ 85 mm board).
- possible to connect with a variety of sensors to interact with the physical world.

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GPS 18 x Garmin sensor

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- transmit data in NMEA 018 format through RS-232

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Battery Management System (BMS)

- keep batteries protected from over over (dis)charging
- has capability of communicating with a mobile phone via Bluetooth.
- data though serial communication

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PZEM sesnor

- measure current up to 50 A
- exchanges information through built-in RS-485 interface using ModBUS RTU protocol

Experimental set-up

✓ Data collected from three sensors

1. **GPS receiver** - information concerning the position of the vehicle and its velocity over all times of its movement.
2. **BMS** - provides data concerning the battery pack, such as the battery voltage, current, power but also State of Charge (SOC).
3. **PZEM** – provides data concerning the solar photovoltaic panels output, i.e., instantaneous current, voltage and power and accumulated energy produced as well.

To collect all these information, software was built in Python under the paradigm of Obejct Oriented Programming building one individual class for each acquisition sensor.

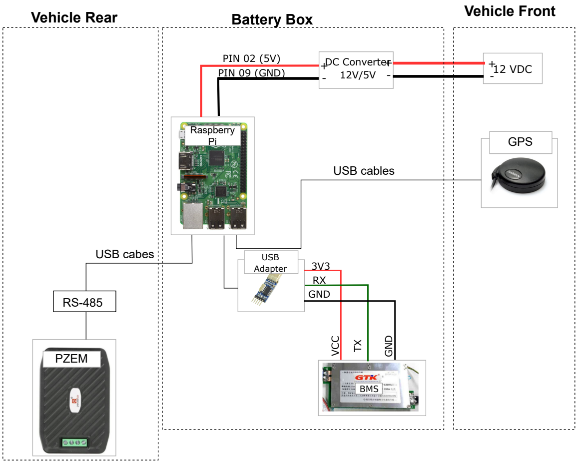
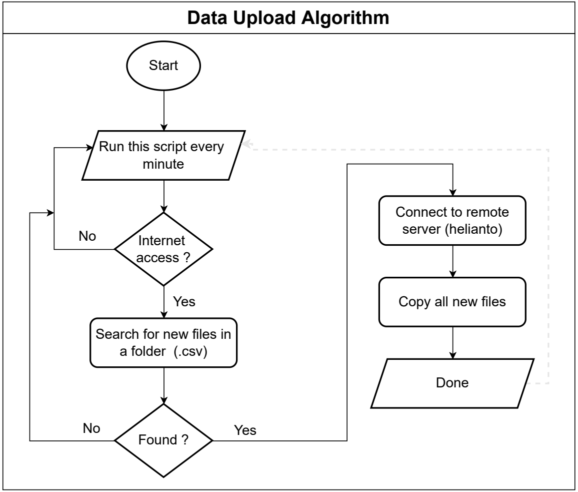


Figure: Wiring diagram for connecting the GPS receiver, BMS and PZEM sensors to the Raspberry Pi.

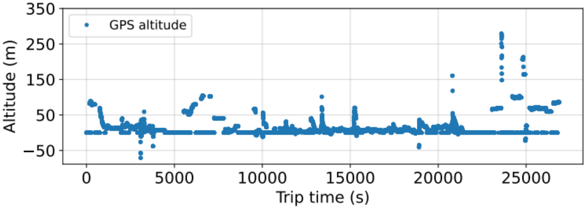
Data upload

How to accessing the data acquisition saved in the Raspberry Pi ?



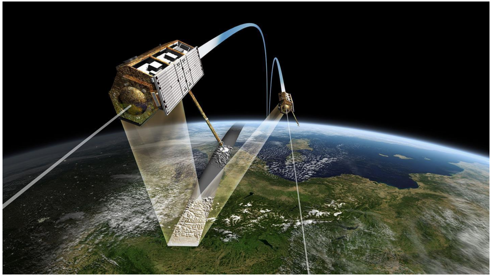
1. check if Raspberry Pi has internet access
2. search for every new files saved in a folder
3. connect to remote server (helianto)
4. push those files on there
5. run the script every minute

Preliminary analysis of the data collected



- Altitude values contained a considerable amount of error
- Inconsistent compared to the real altitude values

Digital Elevation Map (DEM) for Lisbon city center



Copernicus DEM: 30 meter dataset now publicly available

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1 Year Ago

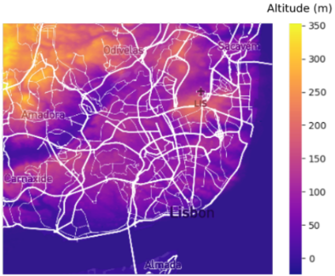
ESA is pleased to announce that, in addition to the Copernicus Digital Elevation Model (DEM) GLO-90 released in December 2019, the access rights for the Copernicus DEM with global coverage at 30 meter resolution (GLO-30) have now been extended and the dataset is openly available to any registered user.

Shuttle Radar Topography Mission (SRTM) and Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER)[3]. Both data sets provides one altitude measurement for every 900 m^2.

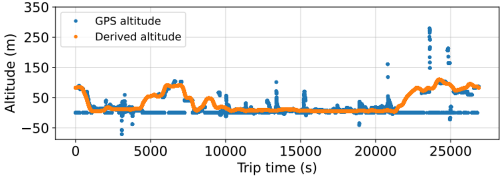
[3] OpenTopography. Shuttle radar topography mission (srtm) global, 2013.

Fixing GPS-recorded-altitude data/Road slope estimation

Topographical map for Lisbon city center using Mapbox-terrain RGB API



Altitude values measured using the GPS receiver (blue), and predicted using the topographical map (orange)



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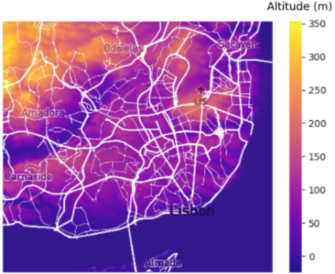
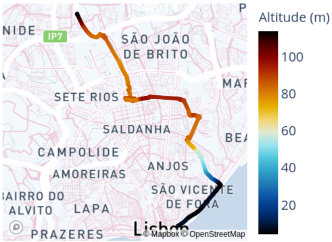


Geographical distribution of the height values



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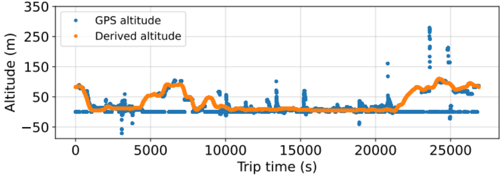
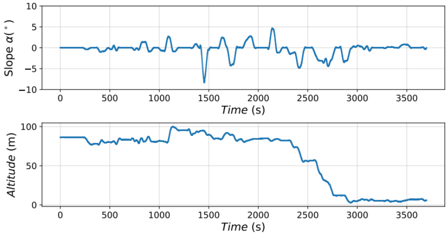
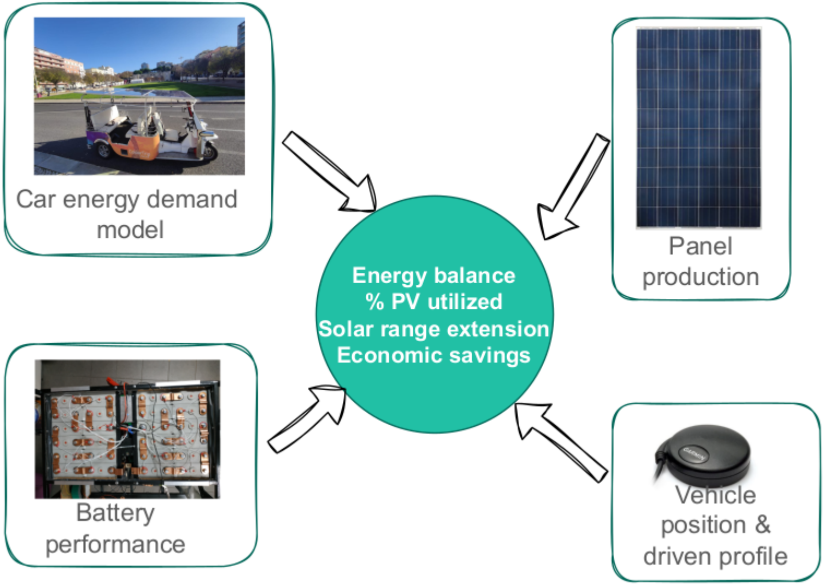
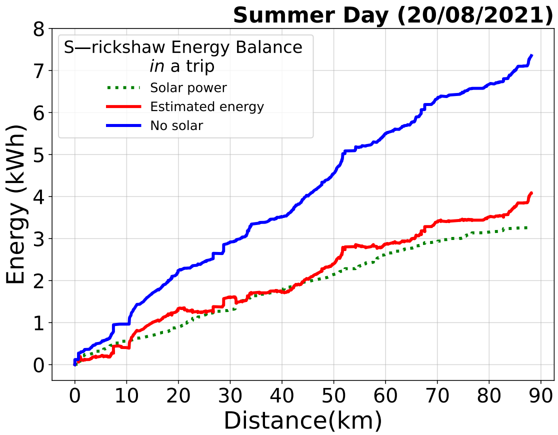


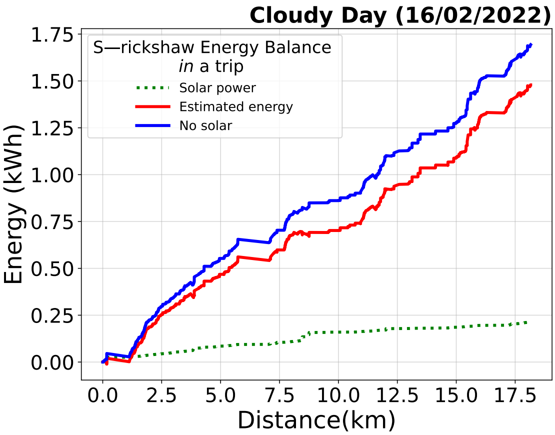


Solar Vehicle Energy Consumption Model



How far can we drive with solar power ?

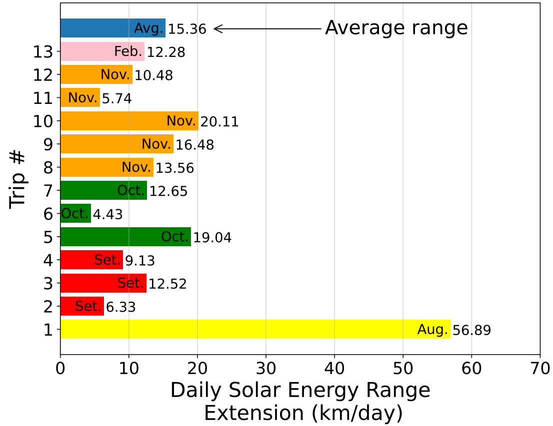


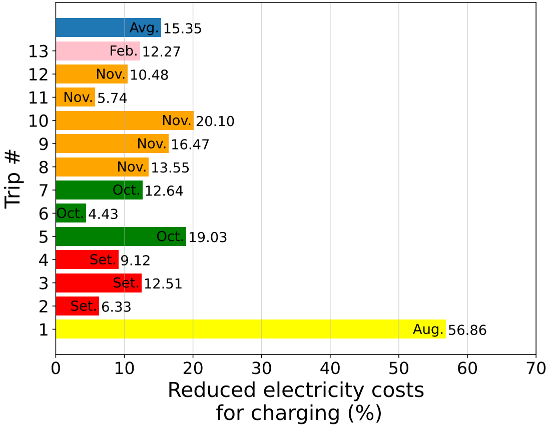


- Reduction of 35% of the energy consumed in the vehicle.
- Range extension of 56 km.
- Solar power can only contribute to 12 km due to environmental Factors.

Solar Improvements

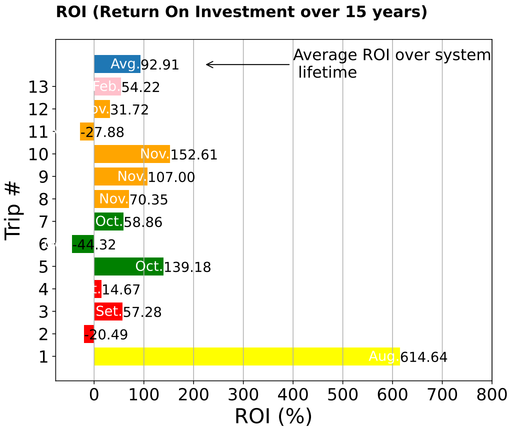
Assumption: constant grid charging cost - 0.23 €/kWh

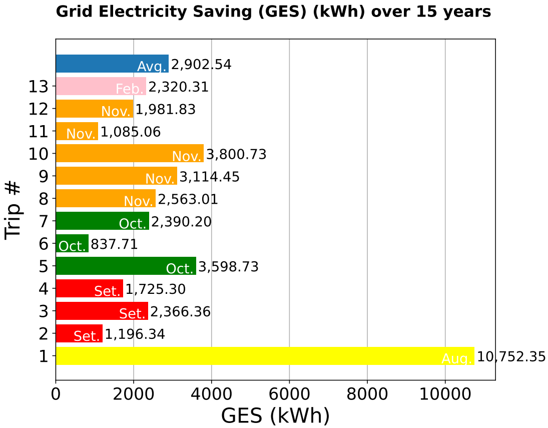




- Average daily solar energy range extension of 16 km.
- Average daily reduced electricity cost of 15%.

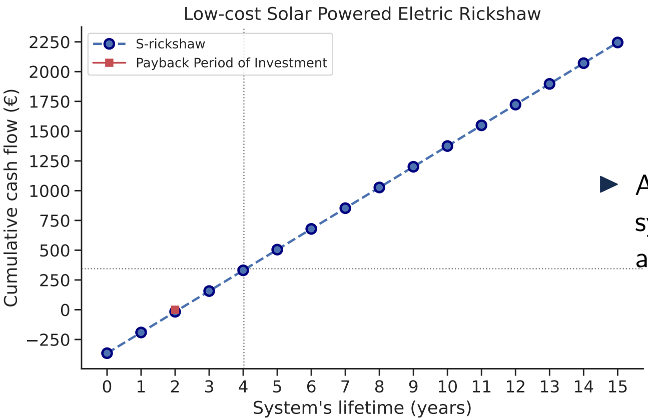
Economic Benefits





- Average ROI of 92% over the system's lifetime, which represents 1.93 $\times$ investment cost
- 44 € of average revenue during summer times.

Payback Period of investment



- After 4 years of implementation of this system, the driver piratically gets some amount of energy for free.

Battery selection

Summer vehicle

- Energy consumption = 35% solar $\rightarrow$ 8.7 $kWh/100km$
- New battery capacity should be 117 Ah, but to be conservative we chose 135 Ah because of the insufficiency of data collected

Parameter	**LiFePO4**	**New pack**
Nominal voltage	76.8 V	76.8 V
Capacity	180 Ah	135 Ah
Mass	135 Kg Ah	63.12 Kg
Energy density	102 Wh/kg	164 Wh/Kg
Cost/pack	186 €	132 €

- 8% in vehicle weight reduction which will make the vehicle more lighter and thus would allow it to drive even more rapid.

Recap: What we learned from this Master Thesis

✓Summary of important points

- Solar power can cover up to 35% of the energy consumed in the vehicle on a typical sunny day.
- ROI of 185% throughout the vehicle lifetime and a payback period of 4 years after the implementation of the project.
- The battery pack in the vehicle was reduced from 180 AH to 135 Ah. As a result, the vehicle weight was reduced to 8%.

The way forward

✓Recommendations for future work

- Adding the possibility of replacing the solar panels with a new one of greater efficiency (flexible, thin-films).
- Incorporate an MPPT in order to increase the power extract out of the solar panels' array for charging the battery pack.
- Add internet connection to the system so that the vehicle can be accessed at all time of its motion. With this, a **Dashboard** can be created to display key performance indicators during trips.
- To improve the performance of the models, it will be necessary to collect data for a whole year. This data could be used to forecast the power of solar panels.
- Add tests in the vehicle to better estimate its parameters.

Master Thesis Project

Optimization and Evaluation of
Solar Powered Electric Rickshaw

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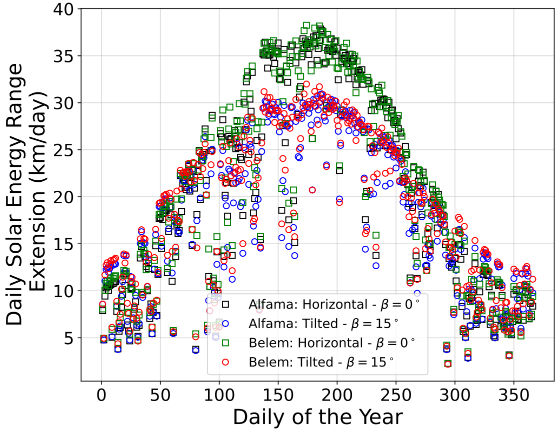
github.com/edild/phd_defense

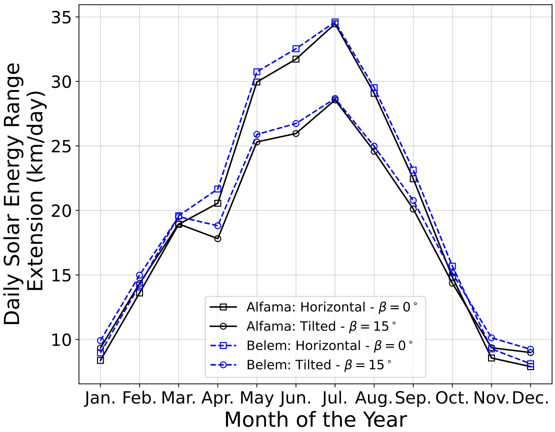
github.com/edild/phd_thesis

Solar Resource in Lisbon

Case study: Belém and Alfama

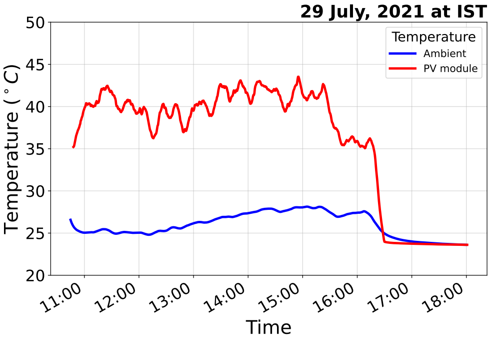
$$D_{\text{max}} \left[\frac{\text{km}}{\text{day}}\right] = \frac{E_{\text{solar}}\left[\frac{\text{kWh}}{\text{day}}\right]}{\text{E}_{\text{EV,non-solarEV}}\left[\frac{\text{kWh}}{100\text{ km}}\right]} \times 100.$$

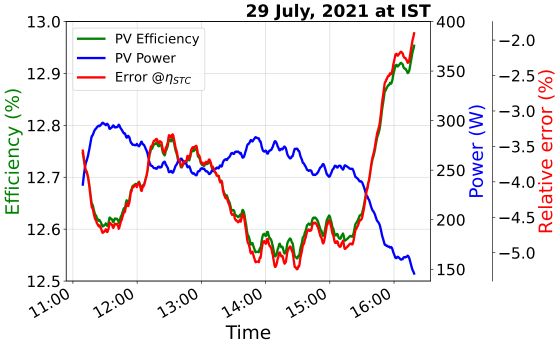




Temperature effect

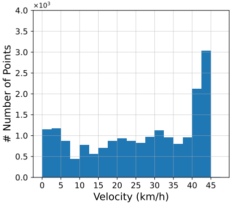
Assumption: Temperature model under NOCT condition

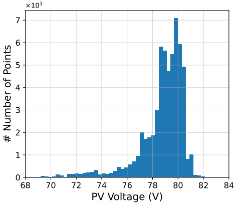


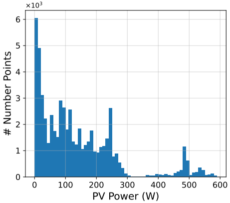


- zones of higher temperatures correspond to zones where the panel production are the highest.
- the higher the temperature the lower the power output thus the efficiency

Feature distributions

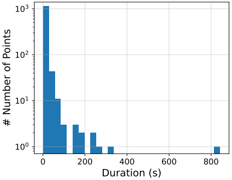




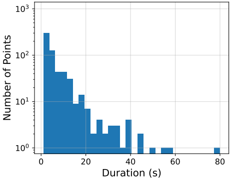


Battery characterization

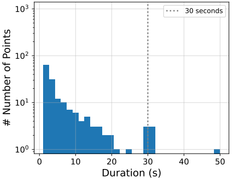
C-rate	Current (A)	Time (min)
0C - C/2	0 - 70	120
c/2 - C	70 - 135	60
C - 2C	270	30



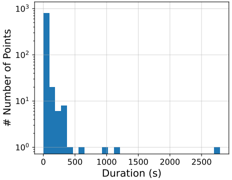
(0C;C/2)



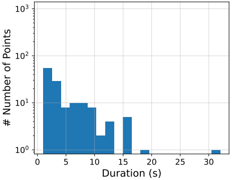
(C/2; C)



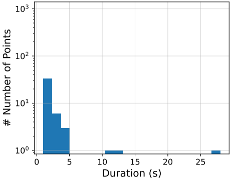
(C; 2C)



(-C/2; 0C)



(-C ; -C/2)



(-2C; C)

Software availability

Stable versions on CRAN, dev versions on github.

webchem `github.com/ropensci/webchem`

taxize `github.com/ropensci/taxize`

Best practices for Software:

- open source (permissive MIT License)
- version control (git)
- automated tests (Travis-CI)
- in source documentation (roxygen)

Many Thanks To

- My supervisors Prof. Dr. Ralf. B. Schäfer (for support, openness, opportunities & discussions)
- My colleagues & collaborators (too many to list here)
- German Environment Agency (for funding & collab)
- My parents Anca & Helmut (for their support)
- My girlfriend Anja (for everything)