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Smart Island Energy Systems

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Table of contents

Table of contents **2**

List of Figures **5**

Acronyms and abbreviation **7**

1 Introduction **8**

1.1 Related Pilots **8**

1.2 Objectives **8**

1.3 Related Tasks **8**

2 Pilot 3 – Getting Started with Electric Vehicles and Smart Charging **10**

2.1 Pilot site **10**

2.1.1 Tukxi Tours 10

2.1.2 Infrastructure 11

2.2 Equipment **11**

2.2.1 Control Module 11

2.2.2 Energy Monitor 11

2.2.3 Gateway 12

2.2.4 Mobile Application 13

2.2.5 Application Programming Interface 14

2.2.6 Administration tool 15

2.3 Installation and Deployment **16**

2.3.1 Installation of the network 16

2.3.2 Installation of the Control Module, Gateway and Energy Monitor 17

2.3.3 Deployment of the Mobile application 17

2.3.4 Updates to the Mobile application 17

2.3.5 Deployment of the Admin tool 18

2.3.6 Smart Charging Algorithms 18

2.3.6.1 Smart Charging: Charge Schedule Optimization 19

2.3.6.2 Smart charging approach 20

2.3.6.3 Integration of the Smart Charging Algorithms 20

2.3.7 Starting of the smart-charging pilot intervention 21

2.3.8 Maintenance 21

2.4 Timeline of the pilot development, installation and validation **22**

2.5 Limitations to the evaluation **23**

2.5.1 Reduction of the Tukxi Tours EV fleet size 23

2.5.2 Halt in tourism operation from 15th of March 2020 onwards 23

2.6 Implementation of the contingency plan **23**

2.6.1.1 Modelling the local data 24

2.6.1.2 Travels and battery consumption 25

2.6.1.3 Charging 26

2.6.1.4 Affluence 28

2.6.1.5 Summary and observations 28

2.6.2 Development of the Simulator 28
2.6.2.1 Simulator's Gateway 30
2.6.2.2 Data models 30
2.6.2.3 Web Client 31
2.6.2.4 Running the simulation 31
2.6.3 Integration with Route Monkey's algorithms 35
2.7 Evaluation 36
2.7.1 Technical evaluation 36
2.7.1.1 Charging infrastructure 36
2.7.1.2 Simulation 37
2.7.2 Smart charging 37
2.7.3 Running a fleet of EVs 38
2.8 Discussion 39
2.8.1 Charging equipment and infrastructure 39
2.8.2 Contingency Plan 39
2.8.3 The Simulator 40
3 Pilot 4 – Electric Vehicles are our Future 42
3.1 Pilot site 42
3.1.1 The EEM garage 42
3.1.2 Number of charging points 43
3.2 Equipment 43
3.2.1 Control and Communication Module 43
3.2.1.1 Controlling the charging duty cycle 44
3.2.2 Coordinator 45
3.2.3 Network 47
3.2.4 Web interface 47
3.2.4.1 Evolution and maintenance 50
3.2.5 Application Programming Interface 51
3.2.6 Smart Charging Algorithms 51
3.2.6.1 Integration of the smart charging algorithms 51
3.2.7 Installation 52
3.3 Operation 52
3.4 Deployment 53
3.4.1 Maintenance 53
3.4.2 Evaluation 54
3.4.3 Challenges 56
3.5 Evaluation 56
3.5.1 Technical 56
3.5.2 Challenges 57
3.5.2.1 Technical challenges 57
3.5.2.2 Operational challenges 57
3.6 Discussion 58
3.6.1 Technical solution 58
3.6.2 Smart Charging 60
3.6.3 Smart charging scenario 60

4 Conclusions 61
4.1 Project Tasks 61
4.2 Challenges 61
4.3 Future Opportunities 62
5 References 63

List of Figures

Figure 1: Left: Public parking lot, which accommodates the Tukxi Tours charging site. Left: Tukxi Tour's Tuk scooters charging 10
Figure 2: Different components part of the Control Module. Left: CE16 female socket; Middle: control module with the smart-plug fitted: Right: CE16 Male socket 11
Figure 3: Energy Monitor and Gateway installation at TukxiTours 12
Figure 4: Summary of the communication between the different software and hardware components of the Getting Started With Electric Vehicles and Smart Charging pilot 15
Figure 5: Left: Enerspectrum-alerts chatbot which communicates the status of the installation to the partners; Right: Administration tool for the Getting Started With EV's and Smart Charging pilot 16
Figure 6:Left: First version of the MyTukxi mobile application. Right: Current version of the MyTukxi application that is currently in use by Tukxi Tours drivers. 17
Figure 7: Update to the MyTukxi application with the new input methods for Tuks and sockets 18
Figure 8: Example of one of the available routes in the Administration tool, and its documentation 18
Figure 9: Timeline of progress regarding the Getting Started with Electric Vehicles and Smart Charging Pilot 22
Figure 10: Sample of 10 trips generated by the Simulator 26
Figure 11: Relation between the distance travelled and the battery consumption, represented by the dots. The line represents the developed model 26
Figure 12:Ten samples of charging period in minutes as generated by the Simulator 27
Figure 13: Ten peak charging values as generated by the Simulator 27
Figure 14: Average number of trips by hour of the day according to the collected data during the pilot 28
Figure 15: Overview of the Architecture of the Simulator 30
Figure 16:Fluxograms that presents how the simulation handled the travels (left) and charging operations (right) 32
Figure 17: Overall process of how the simulator advances throughout a given simulator run 33
Figure 18: Sample configuration used during the simulation 35
Figure 19: Battery state of charge for two scooters during a simulation run (without smart charging). Each line represents a different scooter present in the simulation 35
Figure 20: Consumption of one of the charging points during a simulation run (without smart charging) 36
Figure 21: Number of charging events by week during the pilots' duration 37
Figure 22: Aggregated number of events by hour during the period of the pilot 37
Figure 23: Battery state of charge for two scooters during a simulation run (with smart charging). Each line represents a different scooter present in the simulation 38
Figure 24: Consumption of one of the charging points during a simulation run (with smart charging) 38
Figure 25: General representation of the components part of the type 2 Smart charging procedure 43
Figure 26: Control and communication module developed in SMILE 44
Figure 27: Type 2 plug (left) and socket (middle and right) 45
Figure 28: Left: Relation between the current demand and vehicle duty cycle; Right: Example of the PWM signal used to modulate de charging duty cycle 45
Figure 29: Coordinator gateway developed for Electric Vehicles are Our Future pilot 46
Figure 30: EMS service directed at the EVs from the Electric Vehicles are Our Future pilot 48
Figure 31: EMS charging consumption information, for one of the developed charging points 48
Figure 32: Scheduling functionalities as presented by PRSMA'S EMS 49

Figure 33: Two charging modes offered by the EMS. In the manual charging mode, the user needs to input the maximum desired charge. 49
Figure 34: Example of four possible error messages displayed by the EMS when it detects errors in the charging procedure 50
Figure 35: Output from the smart charging algorithm proposed by RouteMonkey. 52
Figure 36: Communication architecture of the different hardware and software components part of the Electric Vehicles are Our Future pilot 53
Figure 37: Control and Communication Module with the charging cables (left). And directly connected to the grid (right) 54
Figure 38:Timeline of progress regarding the Electric Vehicles are Our Future pilot 55
Figure 39: Daily load for charging point 6. The smart charging command is visible between 9 and 12:00 aproximattely 57
Figure 40: Sample Day with unusual high energy consumption from the charging at EEM 59
Figure 41: Vehicle charging at EEM garage. The CCM bypasses the load from the wall box before it reaches the vehicle 59

Acronyms and abbreviation

AC: Alternating Current
API: Application Programming Interface
CCM: Control and Communication Module
CERTH: The Centre for Research & Technology Hellas, partner of the SMILE project
CRUD: Create, Read, Update and Delete operations
EEM: Empresa de Eletricidade da, partner of the SMILE Project the Madeira demonstrator
EMS: Energy Management System
Endpoint: Uniform Resource Locator of a logical service provided by an API
EV: Electric Vehicle
ICE: Internal Combustion Engine
IEC: International Electrotechnical Commission
M-ITI: Madeira Interactive Technologies Institute, partner of the SMILE Project the Madeira demonstrator
PWM: Pulse Width Modulation
QR code: Quick Response code, type of two-dimensional bar code
RPC: Remote Procedure Call, communication protocol for distributed systems
RS485: Standard used in serial communications
Schuko: Trademark name of the CEE 7/4 sockets common in Portugal and other European countries
SIM: Subscriber Identification Module
SoC: State of Charge
Tuk: Motorbike that usually can carry between 2 and 4 passengers plus the driver
URL: Uniform Resource Locator, unique address for a network resource
UPS: Uninterruptible Power Supply
Smart Charging Event: Period during a vehicle charging in which the battery charging is completely based on the output of a smart charging algorithm

1 Introduction

The overall scope of SMILE project is to demonstrate, in real-life operational conditions, a set of both technological and non-technological solutions adapted to local circumstances targeting distribution grids to enable demand response schemes, smart grid functionalities, storage, and energy system integration with the final objective of paving the way for the introduction of the tested innovative solutions in the market in the near future. To this end, three large-scale demonstrators have been implemented in three island locations in different regions of Europe with similar topographic characteristics but different policies, regulations, and energy markets: Orkneys (UK), Samsø (DK) and Madeira (PT).
The Madeira demonstrator involves five pilots addressing three main aspects:

a) Optimization of self-consumption of PV production (pilots 1 and 2);
b) EV smart charging (pilots 3 and 4).
c) Voltage control (pilot 5)

1.1 Related Pilots

This document reports on the installation and evaluation tasks related to the Smart Charging pilots in the Madeira demonstrator of the SMILE project. Namely, the **Pilot 3 "Getting Started with Electric Vehicles and Smart-Charging"** and **Pilot 4 "EVs are our Future**." This document will be divided into two significant chapters, one for each pilot, each chapter presents the motivation, and the developed hardware and software for each intervention. Furthermore, the evaluation, results and discussion are also presented separately for each pilot. To finalize the conclusion chapter presents the overall lessons learned from Pilot 3 and 4 and future steps for research.

1.2 Objectives

The goal of this document is to present all the hardware and software components for the smart charging pilots considering the Madeira Island demonstrator. Particular detail will be given to elements that have not been discussed in previous deliverables. The integration and installation efforts of smart charging infrastructure are also reported. Finally, an analysis of the results from the two pilots is provided.
In summary, the content presented in this report, together with the smart charging sections of D4.2 and D4.6 [1], [2] should provide a full specification of the smart charging pilots at the Madeira island demonstrator allowing the replication of the proposed pilots.

1.3 Related Tasks

This document relates to the SMILE tasks presented below:

- **Task 4.6**: Case study specification and assessment of EV with smart charging (M1-M6)
- **Task 4.7:** Kick-off of the Madeira pilot for EV with smart charging (M6-M54)
    - Sub-task 4.7.1: Installation of communication infrastructure
    - Sub-task 4.7.2: Hardware installation and systems integration
- **Task 4.8:** Evaluation of EV smart charging (M36-M54)

The overall goal for the smart charging pilots was defined in Task 4.6, and its outputs influenced the design of the infrastructure and installation reported in this deliverable. Task 4.7. and its subtasks directly relate to the content presented in this report, as it encompasses all the installation and integration efforts for the smart charging pilots. Finally, Task 4.8 defined the next actions after the installation of all the equipment was finalized, and in this deliverable the evaluation of the EV smart charging was reported.

2 Pilot 3 – Getting Started with Electric Vehicles and Smart Charging

Pilot 3, **Getting Started with Electric Vehicles and Smart-Charging**, was focused on low consuming EVs such as scooters. Even though the individual consumption of such vehicles is small, it can be significant once aggregated. Besides the cost of electricity, other issues are relevant once a high amount of low consumption EVs are aggregated. The case study for Pilot 3 was focused on the Tukxi Tours business, a small guide tours company that operates a fleet gasoline and electric Piaggio scooters. This case study provided other challenges for the Smart-Charging solution, which are unique for a business, such as the availability of the scooters and drivers or the needed range for a particular tour.
All the decisions presented in this summary of the intervention were laid out in a meeting in **June 2017** in Madeira, where the local partners and Route Monkey visited several potential sites and brainstormed the intervention. This first meeting provided general guidelines to all the decisions that eventually resulted in the installation presented in the following subsections.

2.1 Pilot site

In this section, the selected participants and the existing infrastructure before the intervention are presented.

2.1.1 Tukxi Tours

The Tukxi Tours charging site is situated on the -1 floor from a closed public parking lot (see Figure 1 left). The business has approximately ten parking slots reserved for their vehicles (EVs and ICE). There is also a small storage room nearby that Tukxi Tours uses to store equipment needed for their day-to-day operation (for example, publicity fliers). There is also a private electric installation separated from the main parking lot building, which is used and owned by Tukxi Tours (to charge the EV scooters).

Figure 1: Left: Public parking lot, which accommodates the Tukxi Tours charging site. Left: Tukxi Tour's Tuk scooters charging

2.1.2 Infrastructure

The existing infrastructure before the pilot started was as follows:

- 6 Charging points
- 6 Piaggio Ape Calessino EV
- 5 drivers (the number of drivers increased during periods of high demand)

2.2 Equipment

Different hardware/software solutions had to be developed for Pilot 3, to solve challenges particular to the pilot specification (for example remotely turning ON/OFF charging points), or significant to the Tukxi Tours business needs (for example visualizing which scooters are charging at every moment). In the sub-chapters below, the development and deployment of all the equipment used for Pilot 3 are briefly described. A detailed description of each component can be found at Deliverable 4.6 and 4.2 [1], [2]. The hardware was first installed in **March of 2018**.

2.2.1 Control Module

This module allows the control of the ON/OFF state of each charging point. As explained above, the Tukxi Tours infrastructure is composed of a set of CE16 sockets (see Figure 2). Since there is no available inexpensive hardware to control the state of these sockets (apart from using contactors which has a high purchasing and installation cost), it was decided to use commercial smart plugs (PlugWise circle). These smart plugs are compatible with the schuko standard, and therefore in this control module, the necessary conversions are implemented. Altogether, the control module is enclosed in a junction box, with a male CE16 socket (which connects to the existing charging point), and a female CE16 socket (which the scooters connect to). Finally, each control module has a QR code that uniquely identifies it (the QR code was later changed to a numerical identifier to each plug and socket, as suggested by participants, see section 2.2.4). Table 1 shows a breakdown of the Control Module components and their cost.

Figure 2: Different components part of the Control Module. Left: CE16 female socket; Middle: control module with the smart-plug fitted: Right: CE16 Male socket

2.2.2 Energy Monitor

A Carlo Gavazzi 340 energy monitor is used to measure the aggregated consumption, this monitor is the same as used for other pilots, and it collects the aggregated charging infrastructure consumption (see Figure 3). The monitor allowed to gather more precise consumption information (for example, frequency or power factor) since the plugs only return real power. The data collected by this system is useful to assess the overall charging infrastructure during the smart charging intervention.

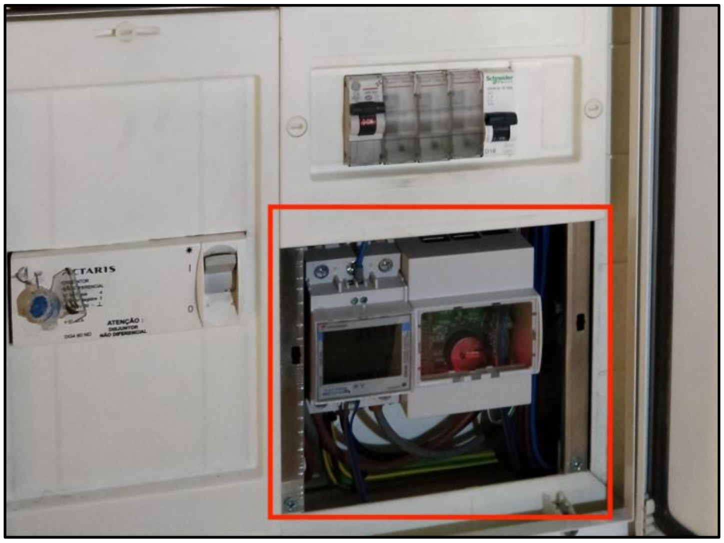

Figure 3: Energy Monitor and Gateway installation at TukxiTours

2.2.3 Gateway

A custom-made Gateway is used to control the infrastructure at the site (see Figure 3). This device is similar to the one developed for Pilot 1 and 2 (see Table 1 for the cost breakdown of the Gateway). For this pilot, it is used to:

1. Query the consumption data from the energy meter
2. Query the consumption data from the smart plugs
3. Forward the ON/OFF commands to the smart plugs
4. Cash data when the connection to the EMS is not possible.

The table below lists all the components present in the **Getting Started With EVs and Smart Charging** pilot gateway:

Table 1: Cost of the Gateway used at the site

Component	Unit Cost	Quantity	Cost
Raspberry Pi 3	€33,90	1	33,90 €
Raspberry Pi 3 Charger	€7,65	1	7,65 €
Raspberry Pi 3 SD Card	€12,99	1	12,99 €
JUICE4HALT module ● UPS ● Realtime Clock ● RS485 converter	62€	1	62€
Male Headers (1x20)	€0,22	1	0,22 €
Female Headers (1x20)	€0,47	3	1,41 €

Male 3 Pins Block	€0,27	1	0,27 €
Female 3 Pins Block	€0,93	1	0,93 €
RS485 to RS232 Converter	€3,90	1	3,90 €
Total:			96,07 €

Table 2: Breakdown of the cost for the control module developed for EV pilot 1

Component	Unit Cost	Quantity	Cost
Box	€2.35	1	€2.35
CE16 female socket	€3.8	1	€3.8
CE16 male socket	€3.8	1	€3.8
Shucko socket	€1.57	1	€1.57
Plug Wise Circle[1]	€39	1	€39
Total:			49.52 €

2.2.4 Mobile Application

A mobile application developed for the Android operating systems allows the collection of different metrics related to the utilization of each Scooter. The application is called MyTukxi Lite, and it is directed to the employees of Tukxi Tours, which drive the scooter. In summary, this application interacted with the drivers to collect information that is not made available by the scooter or by the charging infrastructure:

- Battery SoC at the pick-up (when a driver first takes the scooter)
- Battery SoC at the drop-off (when a driver leaves the scooter)
- Battery SoC when the driver starts charging the scooter
- Battery SoC when the drivers remove a scooter from charging
- Battery at the start of a tour
- Battery at the end of a tour
- Total Kilometres travelled in each tour
- Total Kilometres travelled between tours
- The driver responsible for each tour
- Timestamps of each start and end of the tour
- Timestamps of each pick-up and drop-off of a Scooter

To collect the data above, this user needs to specify which vehicle is being picked up, dropped off, and also she/he needs to specify which vehicle she/he put to charge or removed from charging. It is also

[1] Price for a single Plug Wise Circle smartplug, for SMILE these components were purchased in kits, which resulted in a lower cost per unit.

necessary to state which charging point was used. The identification of these items is made through unique QR codes placed at the charging points and at the keychain of every scooter.
The collected data was used to infer driving habits, which were used for the proposed smart-charging algorithms.

2.2.5 Application Programming Interface

The **Getting Started With Electric Vehicles and Smart Charging** hardware components (for example the gateway and drivers mobile application), communicate with PRSMA'S Energy Management System (EMS), which is also responsible for assuring the communication in the opposite direction, from 3rd parties to equipment in the pilot (see Figure 4). For example, directing a charging command from Route Monkey algorithms to a charging point. For this pilot, a new front-end of the EMS was developed (see Administration tool, next section). However, back-end infrastructure is the same used for all the local pilots.
The API allows the access to query all the pilots' data, that way, the services are used by:

- **The front end of the EMS** to access data to display in the implemented visualizations.
- **Third parties to access**, per charging point consumption, total consumption, kilometres travelled for each vehicle, kilometres travelled for each driver, GPS coordinates of each travel, status of each charging point, and actions performed by the vehicles (when it started charging, when it stopped, etc).
- **The MyTukxi Lite** mobile application, to get the user information, the fleet status (which cars are charging), the list of routes offered by Tukxi Tours, and the status of each charging point.

The API also provides endpoints to push data into the EMS or to control hardware equipment in the pilot. These services are crucial for:

- **Third parties**, to carry out the direct control needed to execute the smart-charging commands
- **The MyTukxi Lite** application to push all the collected metrics (see section 2.2.4)

It is important to note that all the services presented above are provided over encrypted HTTPS requests, furthermore only authenticated users can access the API endpoints. Currently, only CERTH and Route Monkey partners have access to this service (apart from PRSMA's development team). The table below (Table 3) summarizes all the services offered by the API:

Table 3: Endpoints served by the EMS for the Getting Started With Electric Vehicles and Smart charging pilot

Entity	Method	Endpoint
auth	POST	/auth/token
	GET	/auth/token
driver	GET	/drivers
	GET	/driver/{driver_id}/actions
	GET	/driver/{driver_id}/travels
plug	GET	/plugs
	GET	/plug/{plug_id}/actions
	GET	/plug/{plug_id}/state
	POST	/plug/{plug_id}/state/{state}

	GET	/plug/{plug_id}/historical-consumption/{start}/{end}/{non_0}
car	GET	/cars
	GET	/cars/status
	POST	/car/{car_id}/action/{action_type}
	GET	/car/{car_id}/actions
	POST	/car/{car_id}/travel/start
	POST	/car/{car_id}/travel/{travel_id}/points
	POST	/car/{car_id}/travel/{travel_id}/end
	GET	/car/{car_id}/travels
route	GET	/routes
travel	GET	/travel/{travel_id}/points

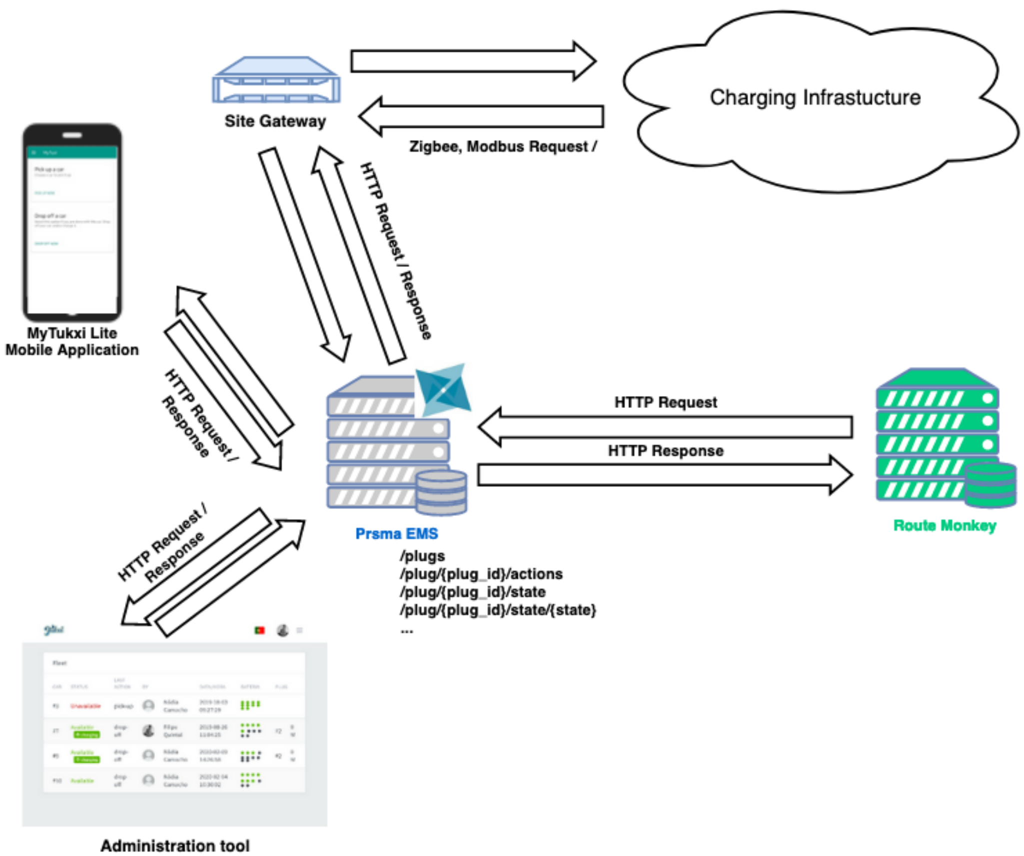

Figure 4: Summary of the communication between the different software and hardware components of the Getting Started With Electric Vehicles and Smart Charging pilot

2.2.6 Administration tool

An administration tool was also developed. The service running at **PRSMA's EMS** provides an overview of the pilot. For example, the administrator can check the status of each car (if it is charging, and the last battery input), he/she can also query the past trips, or visualize the trips made by each driver (see Figure

5 right). The administration tool is also an interface for developers, hosting the API documentation page where developers can try the different services provided to third parties. The administration tool was deployed in August of 2018, and it has been continuously updated to improve stability or to address comments from the partners. For example, on the **26 of June 2019,** the service that allows direct control over the charging points was added.
The **Getting Started With EV's and Smart Charging** pilot was also integrated into the local partners' slack service. A bot notifies the interested partners about different conditions of the pilot, for example, if any hardware goes offline, or if it is collecting repeated data (see Figure 5 left)

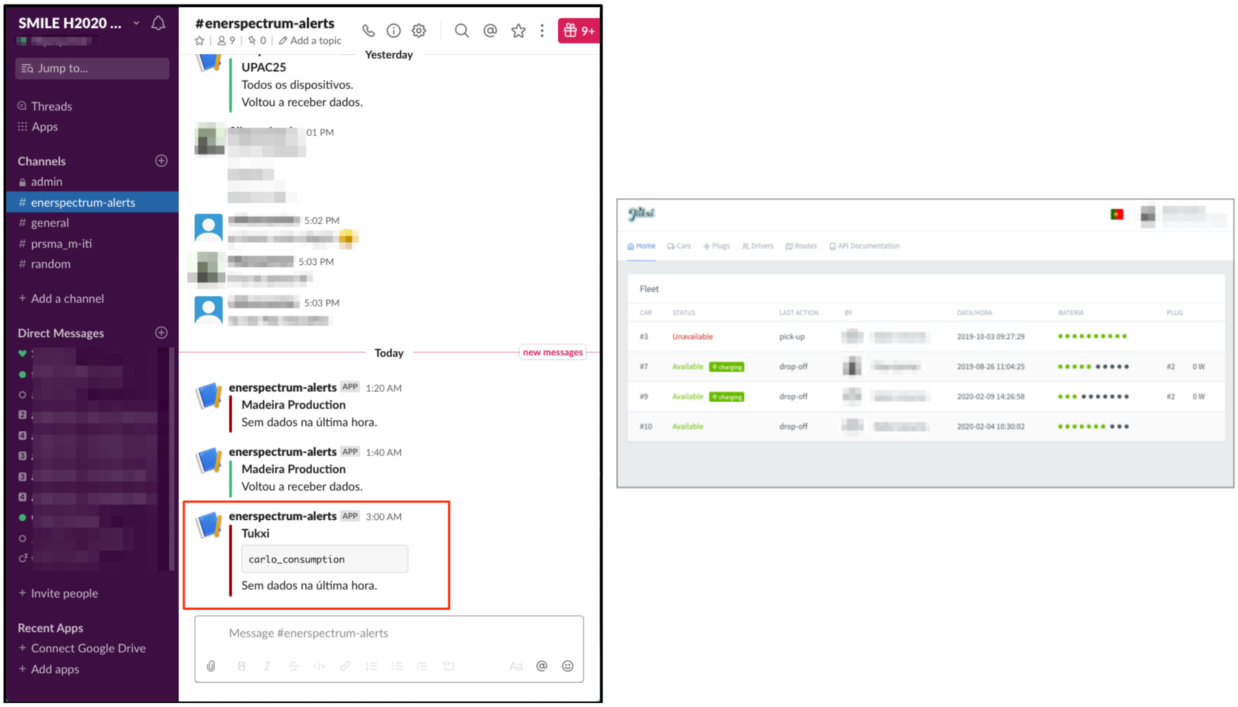

Figure 5: Left: EMS' alerts chatbot which communicates the status of the installation to the partners; Right: Administration tool for the Getting Started With EV's and Smart Charging pilot

2.3 Installation and Deployment

The installation and deployment of the equipment described above did not happen simultaneously since several solutions were developed with the input of the pilot's participants and other partners during the project. In this subsection, the deployment and installation of all the equipment are described, following a chronological order. Starting from the beginning of the project. Moreover, other essential pilot Milestones that were crucial to reach the pilot goals are presented too.

2.3.1 Installation of the network

One of the requirements for the charging infrastructure was the need for a reliable internet connection at the site. At the start of the project, it was decided the best approach was to install a dedicated internet connection with a router that could cover the parking area for the Tuk scooters. The local project coordinators set up a partnership with a Portuguese internet service provider, which installed the required equipment free of charge during the duration of the project.

2.3.2 Installation of the Control Module, Gateway and Energy Monitor

The Control Module, Gateway, and Energy Monitor components were installed at the same time. The Energy Monitor was installed by bypassing the mains at the site circuit box. The Control Module equipment was installed at one of the sockets used to charge the vehicles

2.3.3 Deployment of the Mobile application

Once the hardware was installed at the selected site, the project team started to develop a mobile application to infer the usage of Tukxi Tour Electric vehicles (see Figure 6). The development of this software was already reported at [1].

The mobile application was installed in a smartphone with a 4g SIM card that was provided by the project, and it was given to one of the drivers in **November of 2018**. In the first **4** months, several tests were performed to improve the stability and usability of the application. Afterward, the application was delivered to the Google Play app store to facilitate the distribution and maintenance of this component.

The testing phase ended in **April 2019** when the phone was collected from Tukxi Tours. After this stage, several improvements were implemented, considering the drivers' feedback. A newer version of the application was deployed in **May 2019** and installed on the phones of two drivers. Additionally, the project also provided two new phones to the remaining drivers. In the first weeks of this phase, some bugs had to be fixed, especially considering incompatibilities with the drivers' phones. It was also mentioned that the project phones could be used by anyone if they had an account in the Tukxi Tours EMS sub-system.

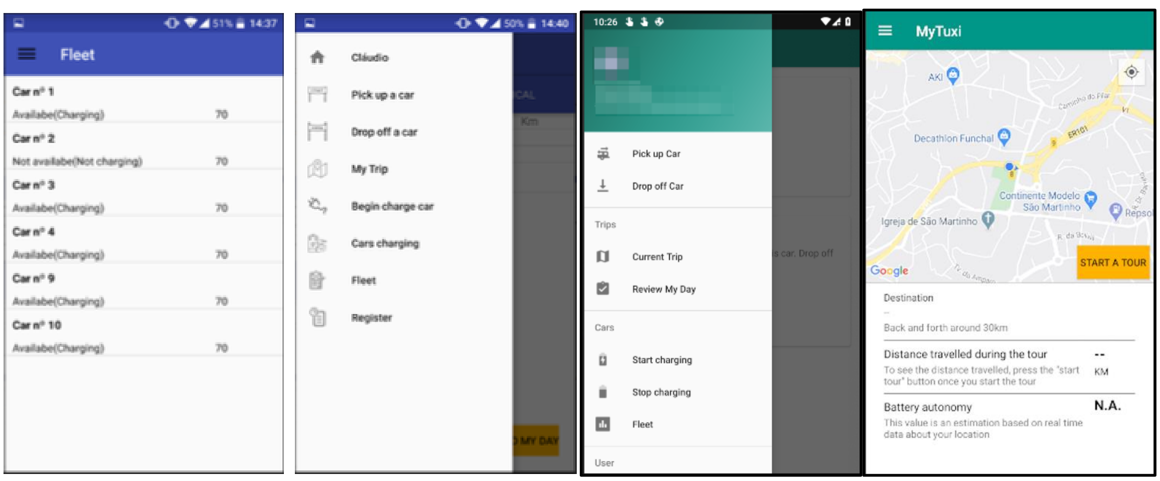

Figure 6:Left: First version of the MyTukxi mobile application. Right: Current version of the MyTukxi application that is currently in use by Tukxi Tours drivers.

2.3.4 Updates to the Mobile application

After 2 months, the project team contacted the drivers to gather more feedback regarding the usage of the application. In general, the application was working correctly, and the most significant issue was regarding the QR code approach to read the Scooters and Plugs. Since the charging infrastructure is situated in a parking lot, the lighting conditions are sometimes not ideal for reading the QR codes. The drivers suggested that, if possible, they would prefer to select the id of the vehicle directly.

This change was implemented at the mobile application. A new version was uploaded to play store in **June 2019,** and this update was pushed to the driver's phones in the following days [2](see Figure 7)

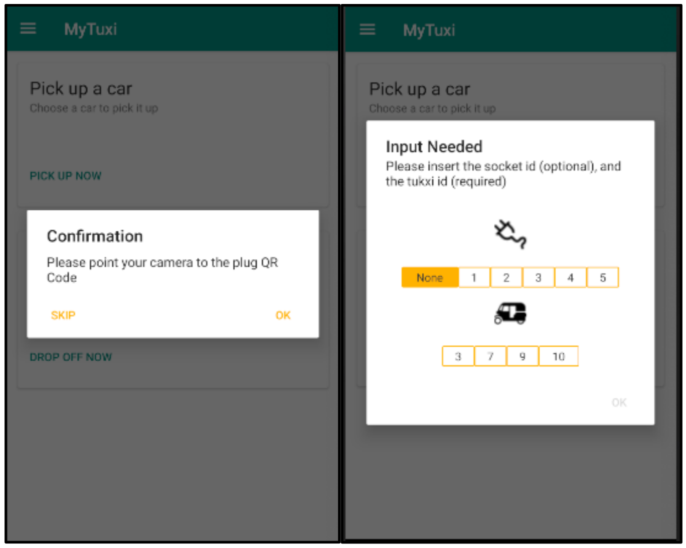

Figure 7: Update to the MyTukxi application with the new input methods for Tuks and sockets

2.3.5 Deployment of the Admin tool

The administration tool (see section 2.2.6) was also provided to the administration of Tukxi Tours. It was referred by the drivers, that the administration was interested in knowing the most popular tours and other metrics such as average kilometres travelled by day. Therefore, the administration application was provided to the administration of Tukxi Tours in **October of 2018**. This application also allowed Tukxi Tours to add new users (drivers) to the application.

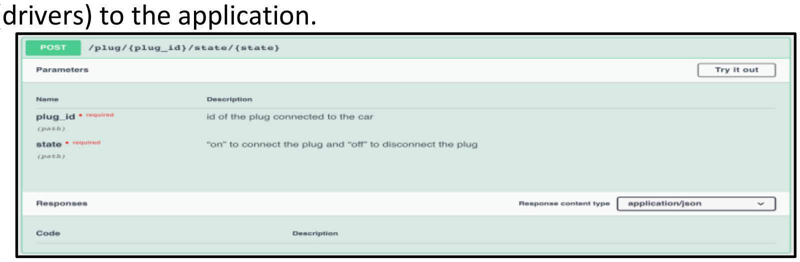

Figure 8: Example of one of the available routes in the Administration tool, and its documentation

2.3.6 Smart Charging Algorithms

The 'bread and butter' of smart charging is the *charge session S*, which has the following attributes:

- *R*, the amount of kWh required by the user;
- *P*, the power level, in kW, provided by the charge-point when it is switched on;
- Tstart and Tend, the start (plug in) and end (plug out) times of the session;

So, a session can be denoted as *S* = (*R, P, Tstart, Tend*)).

[2] https://play.google.com/store/apps/details?id=smartcharging.prsma.com.mytuxi

A charge *schedule,* SC, can then be modelled as, in general, a sequence of modulations $M = (m1,m2,…mN)$, associated with a series of timeslots $T = (t1, t2, …, tN)$. That is, $SC = (M, T)$. From here on, the common assumption that each timeslot is 15 minutes is made. Meanwhile, a 'modulation' is simply an instruction to the charge-point to modulate its power level; so a single modulation can be modeled as a proportion; e.g. '1' means fully on (e.g., where a 22 kW charge-point would deliver kW in that timeslot), and '0.5' means 50% (e.g., a 7kW charge-point would deliver 3.5 kW if modulated at 0.5). In most cases, however, the only possibilities for modulation are 1 and 0; for simplicity, only 1 and 0 are assumed to be available from now on, although the algorithms are easily modified to account for more complex modulations.

2.3.6.1 Smart Charging: Charge Schedule Optimization

In a standard scenario without smart charging, the requirements of a session

S = (R, P, Tstart, Tend)

would be met by a charge schedule that looks like this:

(1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0)

This simply means that the charge-point will be turned on at *Tstart* and continuously charge at *P* kW for as long as is necessary to deliver the *R* kWh required by the vehicle, and then be switched off (or deliver deficient 'trickle charge') for the remainder of the session until it ends at *Tend*.
In contrast, in a *smart charging* scenario, we will typically have a different distribution of modulations. This is, in fact, the essence of smart charging: instead of a simple 'leading 1s' charge schedule, the charging is distributed over time in order to optimize one or more objectives while meeting one or more constraints. In the above case, we may instead have a smart schedule as follows:

(1, 1, 0, 0, 0, 1, 1, 0, 0, 1, 1, 1, 1, 0, 0)

The shape of that schedule may reflect several factors at play: for example, the electricity price may be cheaper in slots 8—15. Hence, the hour of charging towards the end of the session (slots 10—13) is driven by cost. But an initial half-hour of charging is done for pragmatic reasons (despite the cost, ensuring that the driver has some charge if the vehicle is needed again sooner than expected). Further, some charging is done at slots 6 and 7 (rather than cheaper slots 14 and 15) may reflect the fact that the electricity cost is reduced in that period.
A central algorithm in smart charging is, therefore, the optimisation, subject to constraints, of the charge schedule according to one or more objectives. It is natural to represent an objective as a value per timeslot, aligned with the charge schedule. For example, the series of contrived costs below would correspond to the example scenario above:

(22, 22, 22, 22, 22, 22, 22, 15, 15, 15, 15, 15, 15, 15, 15)

However, we may instead, or in addition, be interested in how 'green' the electricity in those slots is. The objective represented below, for example, may represent the percentage of renewable sources in the grid mix at each timeslot:

(18, 20, 21, 21, 20, 20, 20, 20, 18, 18, 16, 15, 12, 10, 10)

In this case, the 'leading 1s' schedule would actually be the greenest, but also the most expensive.

More formally, if we have *k* objectives, each represented by a timeslot aligned vector of costs *Ck*, then the task of a smart charge optimisation algorithm is to minimise:

$$\sum_k wk\,(M \cdot Ck)$$

where *wk* represents the importance attributed to objective k, subject to the constraint:

$$P.\sum_k mk = R$$

i.e. that the sum of kWh delivered over the timeslots meets the requirement; and also subject to other constraints that may apply.

This optimization task in itself is not a challenging one – in most scenarios, we can simply sort the timeslots by weighted cost and then choose the best-weighted slots until we have met the charge requirement. It becomes more challenging when intermediate levels of modulation are allowed or where we cannot assume a 'flat' charge curve. However, in general, this is an optimization task that can usually be achieved in real-time.

However, the much more challenging tasks involved in smart charging come from the uncertainties around the charge sessions and the objectives themselves. This is particularly difficult, for example, in the context of the Tukxi pilot, given the small number and volatile demand nature of these tourist vehicles. If we know when the session will start and how long it will last, and what the objective values will be throughout the session, then the optimization task is achievable, as indicated above. But in general (i) we do not know when a charge session will start, and (ii) we do not know how long it will last, and (iii) for many of the objectives of interest, we do not know for sure what the values will be in advance. However, for the SMILE pilots, forecasting algorithms for charge sessions are in place where appropriate, and as has been described in the deliverables, 5.2 and D5.3 [3], [4].

2.3.6.2 Smart charging approach

Route Monkey have integrated the above-described smart-charging approach directly with the forecasting of charge sessions, in a back end which continually (i) accesses the current charge-session forecasts; (ii) accesses the current associated environmental forecasts (e.g., for Madeira, this is the renewables forecast for the Madeira grid supply) (iii) accesses current EV status information (for Madeira, this is via an API provided by PRSMA), (iv) calculates ideal charge session schedules; (v) outputs associated session control information (v) (for Madeira, this is again via an API provided by PRSMA).

2.3.6.3 Integration of the Smart Charging Algorithms

The integration with the smart charging algorithms was straightforward. The API described in section 2.2.5 allowed a complete separation of responsibilities between the measurement and control and the algorithms (see Figure 4). As the API evolved, interested partners were given access to more detailed data and more capable services. For example, at the start, only total consumption and per charging point consumption were available at the API, afterward the possibility to query a specific date was added. Finally, direct control over the charging points was also added.

The changes made to the API were decided based on what PRSMA predicted would be needed in the future of the pilot, but in certain situations, interested partners (Route Monkey and CERTH) would request a feature to ease the integration with the EMS API.

2.3.7 Starting of the smart-charging pilot intervention

In **July of 2019,** the API endpoints affected to the **Getting Started With Electric Vehicles and Smart Charging** pilot, and its documentation (see section 2.2.5) were updated with routes that allowed direct control over the charging points (see Figure 8).
This update was communicated to Routemonkey in **July of 2019** and to CERTH **in November 2019**. In the first stage, a testing charging point was developed by M-ITI and PRSMA to allow partners to test the communication protocol without interfering in the regular charging schedule of Tukxi Tours. Instructions on how to use the test charging point were then sent to partners. In **December of 2019,** partners were also informed that they could immediately start testing commands for the actual charging infrastructure. The proposed algorithms were deployed in **February of 2020**, Route Monkey's system used the data collected from the API (see section 2.2.5) to train their model. The output of that model is then translated in charging or stop-charging commands, which are forwarded to the appropriate endpoints of the API. The smart charging intervention was stopped to halt on **February 2020**, due to the Covid-19 pandemic, the smart charging intervention was replaced by the development of a Simulator, all these developments are presented in sections 2.5 and 2.6

2.3.8 Maintenance

The maintenance of the different components of the pilot happened as needed throughout the pilot. The most common issue was related to the communication between the Control Module and the gateway, sometimes as the driver handled the charging cable, the Control Module would come loose, and the communication (and electricity flow) was lost. As soon as the local partners were notified, they would inform Tukxi Tours of the issue. Usually, an employee from the company would quickly fix the Control Module in place, in other situations, an employee from M-ITI or PRSMA would pass by and fix the Control Model in place. Eventually, it was decided to use zip ties to lock the Control Module in place. Future iterations of this device could use locking sockets to prevent the issue presented above.
Other maintenance issues were mostly software related, especially updating the mobile application (see section 2.3.4). At the first stage, these updates were scheduled with drivers, a member from PRSMA would meet them and individually install the application in their phones. Once the application was published in the Google Play Store, these updates were made automatically. Nevertheless, the drivers were informed by phone about the update.

2.4 Timeline of the pilot development, installation and validation

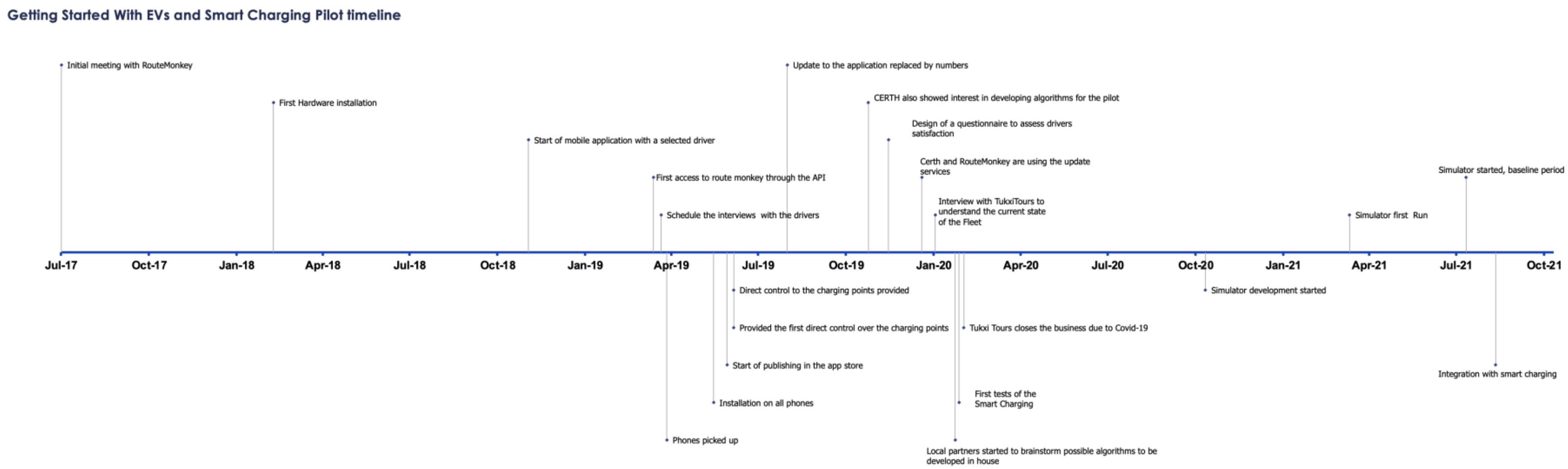

Figure 9: Timeline of progress regarding the Getting Started with Electric Vehicles and Smart Charging Pilot

2.5 Limitations to the evaluation

During the period of the installation for this pilot, two main events occurred limiting the scope of the assessment. Both of these events are external to the project but have the potential to hinder some of the most ambitious goals for the **Getting Started With Electric Vehicles and Smart Charing** pilot.

2.5.1 Reduction of the Tukxi Tours EV fleet size

When the project started, Tukxi Tours possessed a fleet of 6 electric Piaggio Tuks, which were approximately 50% of their fleet. Since then, the fleet was reduced as the EVs were malfunctioning and needed maintenance, and when the smart-charging algorithms were deployed, the fleet consisted of only two EVs. The reduction in the number of EVs was subject to evaluation (see section 2.7.3).

2.5.2 Halt in tourism operation from 15th of March 2020 onwards

On the 18th of March 2020, Tukxi tours halted its tourism operation following recommendations from the Regional Government of Madeira. This fact limited the ability to perform the pilot intervention since it relies on the drivers picking up tourists and conducting their planned tours. It also narrowed the future of the intervention since, even after the restrictions were lifted, it was expected that the tourism industry would have taken some time to recover.

2.6 Implementation of the contingency plan

Following what was established during the second review meeting at M36 a contingency plan was defined for **Pilot 3 – Getting Started with Electric Vehicles and Smart-Charging**. The proposed approach replaced all the physical elements from the pilot (scooters, charging points, and people) with a simulation. This simulation also modelled all the needs from the entities mentioned above. From this point onward this platform will be known as **the Simulator**.

There are simulation solutions available that fit different scenarios. Still, they consist of either academic, proprietary solutions, or limited/specific solutions to a particular context that require a significant effort from researchers/practitioners to customize them to their intended context [5],[6].

Furthermore, the literature review carried before the implementation of the contingency plan disclosed that, in terms of architecture, the existing solutions are usually made in a monolithic way, containing a single code-base and leading up to more rigid solutions and challenging to adjust/customize as intended by the end-user. Besides that, technologically speaking, there are not many available frameworks that integrate this kind of simulation while being open-source, extensible, and easy-to-use [5], [6], which obstructs its reusability or customization in other contexts. To overcome this, a simulation platform allowing researchers to simulate any set of smart-charging algorithms in different conditions has been developed. The aim was to build such a solution with enough abstraction to fit any charging simulation context. Making the Simulator another output from Pilot 3.

The solution consisted of an open-source system that simulates smart-charging algorithms, developed in an abstract way able to consider any context and a variable set of data models. Simply put, it employs modularly both in terms of simulation algorithms (smart-charging algorithms) and in terms of simulation components (described by a user-defined set of data models - e.g., battery, charger, charging time).

Besides that, this simulation system contains three other components:

- Data Server (to expose the simulation data in a Web Server
- Web Client (to provide an interactive dashboard regarding this simulation system
- Slack Webhook (to send notifications to a Slack channel regarding the start/stoppage of simulations and possible errors/exceptions that may occur in the system)
- REST API, which allows for 3rd parties to interact with the simulation (see Table 4)

Table 4: Summary of the endpoints provided by the Simulator

Endpoint	Description
/plugs	Get the current simulation's list of plugs
/plugs/{plug_id}	Fetch info about a given plug of the current simulation
/plugs/{plug_id}/set_status/{new_status}	Set a new status for a given plug of the current simulation
/export	Export the entire database into .csv files
/is_simulation_running	Get the current simulation state
/start_new_sim	Start a new simulation, if there is a simulation running that simulation is stopped and a new one is started
/get_sim_data_by_id/{simulation_id}	Fetch info about a given simulation

2.6.1.1 Modelling the local data

The main goal of the work presented in this sub-section consists of creating the data models to use in Simulator. The process presented below illustrates how to integrate data from different data sources into the proposed platform. This demonstration serves as another proof regarding the flexibility of the solution.

In the remainder of this sub-section (and its sub-sub-sections), the modelling process of different aspects of **Pilot 3 – Getting Started with Electric Vehicles and Smart-Charging** will be described. In practical terms, the process here consisted of:

1. Extracting the data from its data source
2. Processing the data in an analysis tool
3. Forming the mathematical models' formulas

Technically speaking, the gathered data came from the SMILE Tukxis' API located at PRSMA's EMS, which contains information related to the available Tukxis (e.g., its drivers, its travels). The data came out to be categorized into the following data models:

- Travels and battery consumption
- Charging
- Affluence

The first data model embodies the information related to the travelled distances during the TukxiTours' routes, alongside their battery consumption. In the same way, the second one involves the data regarding the Tukxis' charging periods – the duration, peak value (in terms of its toll on the electrical network). The third model comprises the information linked to the travels' affluence during the day.

After the development of the models mentioned above, the Simulator allows to simulate the whole smart-charging process. In other words, it can simulate the three subprocesses behind it: the travel process, the charging process, and the determination of the travel rate (depending on the time of day). The following subsections present in detail the modelling process for each data model.

2.6.1.2 Travels and battery consumption

As mentioned above, this data model is composed of the travelled distances and their battery consumption. For its modelling, the procedure was the following:

1. Fetching the list of cars - via API endpoint '/cars'
2. Fetching the travels of each car - via API endpoint '/car/{car_id}/travels'
3. Filtering the travels, by the following criteria:
    i. Initial battery > 0
    ii. Final battery > 0
    iii. Initial battery >= Final battery
    iv. Battery consumption > 0
    v. Travelled distance was registered (client-side distance > 0 OR server-side estimated distance > 0)
    vi. Travelled distance > 1 km
    vii. Travelled distance < 40 km
4. Calculating the average travelled distance in Km and its standard deviation
5. Calculating the average battery consumption per km and its standard deviation. The gathering and processing of this data lead up to the following calculations shown below in Table 5.

Table 5:Travel distance and battery consumption data model calculation

Calculation	Value	Standard Deviation
Average travel distance (km)	~12.421	~8.967 km
Average battery consumption (per km, in %)	~0.504	~0.676

Concerning the travel distance, its calculations resulted in the formulas below:

$$t_{dist} = avg_{dist} \pm std_{dist}$$
$$t_{dist} = 12.421 \pm 8.967 \quad (1)$$

$t_{dist} = Traveled\ Distance\ km$
$avg_{dist} = Average\ traveled\ distance\ (km)$
$std_{dist} = Standard\ deviation\ of\ the\ average\ traveled\ distance\ (km)$

$$f_{bat} = i_{bat} - i_{dist} \times (avg_{cons} \pm std_{cons})$$
$$f_{bat} = i_{bat} - i_{dist} \times 0.504 \pm 0.676) \quad (2)$$

$f_{bat} = Final\ Battery\ (\%)$
$i_{bat} = Initial\ Battery\ (\%)$
$t_{dist} = Traveled\ distance\ (km)$
$avg_{cons} = Average\ battery\ consumption\ (in\ \%)\ per\ km$
$std_{cons} = Standard\ deviation\ of\ the\ average\ battery\ consumption\ (in\ \%)$

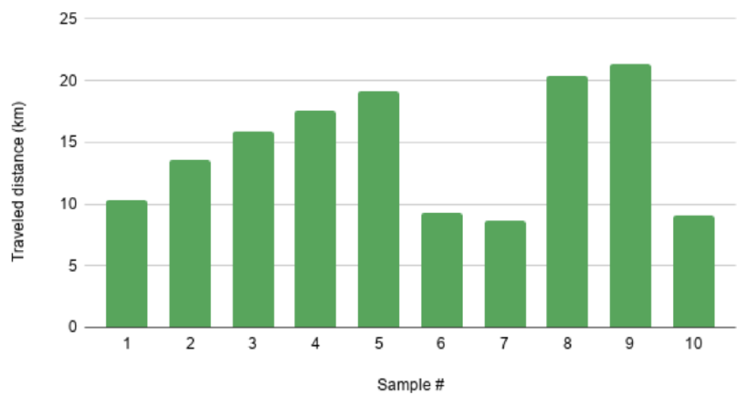

Figure 10: Sample of 10 trips generated by the Simulator

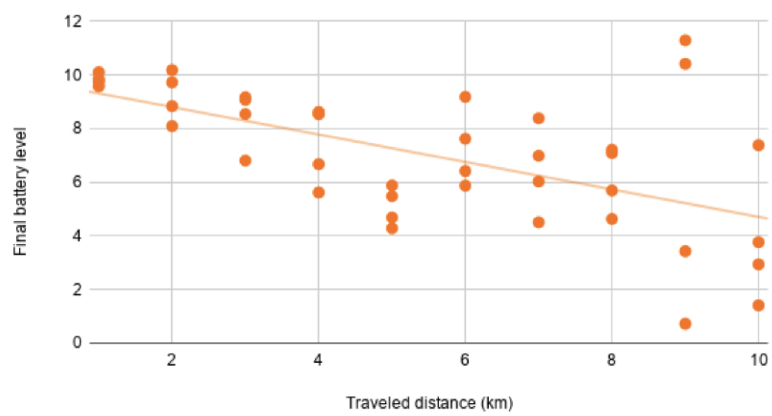

Figure 11: Relation between the distance travelled and the battery consumption, represented by the dots. The line represents the developed model

2.6.1.3 Charging

Regarding this data model, it comprises the data of the charging periods (their duration and their peak value). The modelling process went by the next set of steps (the result is presented at Table 6):

1. Fetching the **energy consumption data** - via the API endpoint
2. **Filtering** the energy consumption data, according to the following criteria:
    - Energy consumption > 50 W
    - Battery charged > 0
3. Calculating the **average charging period duration** (in minutes) and its standard deviation
4. Calculating the **average charging peak value** (in W) and its standard deviation

Table 6: Battery charging peak value and duration data model calculation

Calculation	Value	Standard Deviation
Average charging period duration (minutes)	~142.889	~44.898
Average charging period peak value (W)	~2666.817	~221.847

Which can be translated to the following formulas:

$$d_{cperiod} = avg_{d_{cperiod}} \pm std_{d_{cperiod}}$$
$$d_{cperiod} = 142.889 \pm 44.898 \quad (3)$$

$d_{cperiod} = Charging\ period\ duration\ (\ minutes)$
$avg_{d_{cperiod}} = Average\ charging\ period\ duration\ (minutes)$
$std_{d_{cperiod}} = Standard\ deviation\ of\ the\ average\ charging\ period\ duration\ (minutes)$

$$pk_{cperiod} = avg_{pk_{cperiod}} \pm std_{pk_{cperiod}}$$
$$pk_{cperiod} = 2666.817 \pm 221.847 \quad (4)$$

$pk_{cperiod} = Peak\ value\ of\ the\ charging\ period\ (W)$
$avg_{pk_{cperiod}} = Average\ peak\ value\ of\ a\ charging\ period\ (W)$
$std_{pk_{cperiod}} = Standard\ deviation\ of\ the\ average\ peak\ value\ of\ a\ charging\ period\ (W)$

The charts bellow present 10 different outputs of charging periods and peak values as generated by the Simulator

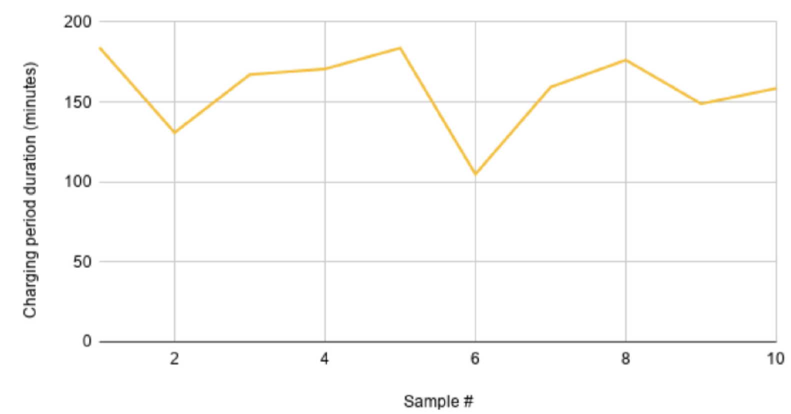

Figure 12:Ten samples of charging period in minutes as generated by the Simulator

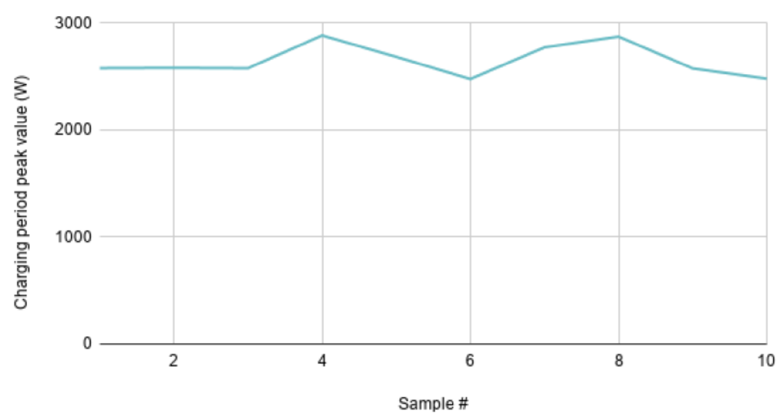

Figure 13: Ten peak charging values as generated by the Simulator

2.6.1.4 Affluence

This last model embodies the travel affluence data of a given hour of the day. It reused the data extracted regarding the travels, in which we gathered the travel affluence per hour of day. By looking at that same data, we can state that the travels occur mainly in the early morning and the early afternoon. This affluence is shown with more detail in Figure 14. The model consists of a simple table look-up for the average affluence for a certain period. This approach works well for Pilot's 3 scenario since the cruise ships arrive and leave the island at stable time schedules. However, with the flexibility of the Simulator this model could be easily replaced by a more advanced solution adapted to a different location.

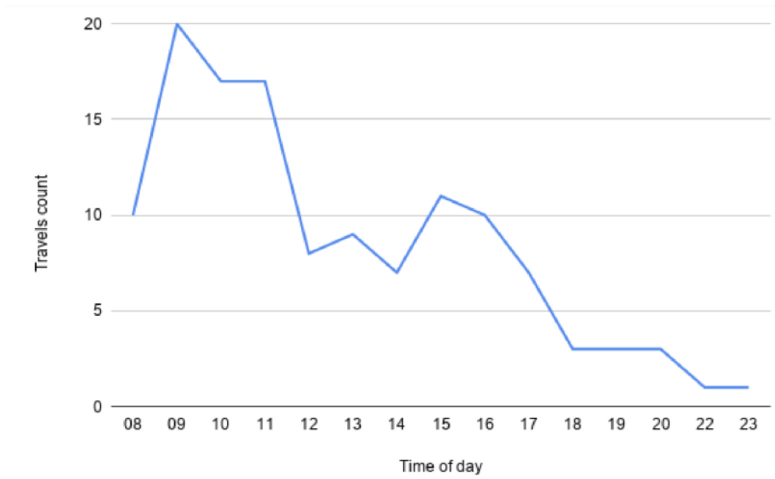

Figure 14: Average number of trips by hour of the day according to the collected data during the pilot

2.6.1.5 Summary and observations

For matters of simplification, the following assumptions were made:

- The travels will be roundtrip (they start and end in the same location)
- If a car ends up under 2 (that is, 20% battery), it means that then the car will be charged up (based on the charging data model).

Regarding the charging periods, its model was formed using the plug energy consumption history's endpoint since the history endpoint leads to less variability.
Besides that, the travels extracted from the API were used as templates for possible travels to be done in the simulator, and their trajectories will be represented accordingly in the simulator's map.
The data models presented here serve as a simple illustration of the process of integrating and modelling data from any external data source into the Simulator. That is, reinforcing the concept of flexibility and versatility designed for this solution since it will easily incorporate data from any data source. In other words, if any area needs to be simulated or if any other data source needs to be considered in the simulations, it can be accomplished by following the process described above.

2.6.2 Development of the Simulator

The architecture proposed by the Simulator consists of the following modules (separated by Docker containers, running independently, as illustrated in Figure 15):

- Simulator
- Gateway
- Data models
    - Travel - Affluence
    - Travel - Distance
    - Travel - Duration
    - Travel - Final battery level
    - Charging period - Duration
    - Charging period - Energy spent
- Web client

The simulator's core is implemented in the **Simulator** class, that serves as a wrapper class to the main functionalities of this system, such as the start/stoppage of simulations, the WebSocket message receival/sending process, and the database export.
Additionally, the core also contains the following set of helper classes: **DataServer** (that takes care of the exposure of the external REST API endpoints), **ConfigurationHelper** (that wraps the operations concerning the configuration file), **Logger** (that unifies the logging process), **WebhookHelper** (that handles the whole notification process through a Slack Webhook), **DBHelper** (that abstracts both the initialization of the database and the export of its data), **DebugHelper** (that provides some utility functions targeted for debugging purposes), **SingletonMetaClass** (a Python metaclass made for the creating of singleton classes) and **StatsHelper** (that encapsulates the logic involved in the preparation of the simulation statistics).
Furthermore, the data objects involved in the simulation process are implemented in the following classes: **Simulation, Car, Plug, Log, Stat, Travel and ChargingPeriod**. Recurring to ORM classes, each of these objects has its respective model class that inherits the BaseModel class (that inherits from the SQLObject class), that will handle its CRUD operations with the database. In other words, for each database table, there is a corresponding subclass of BaseModel, its table columns correspond to class attributes and that each instance represents a row of its table. Concerning their business logic, the model classes have a corresponding subclass of BaseModelProxy, in which this logic is implemented.

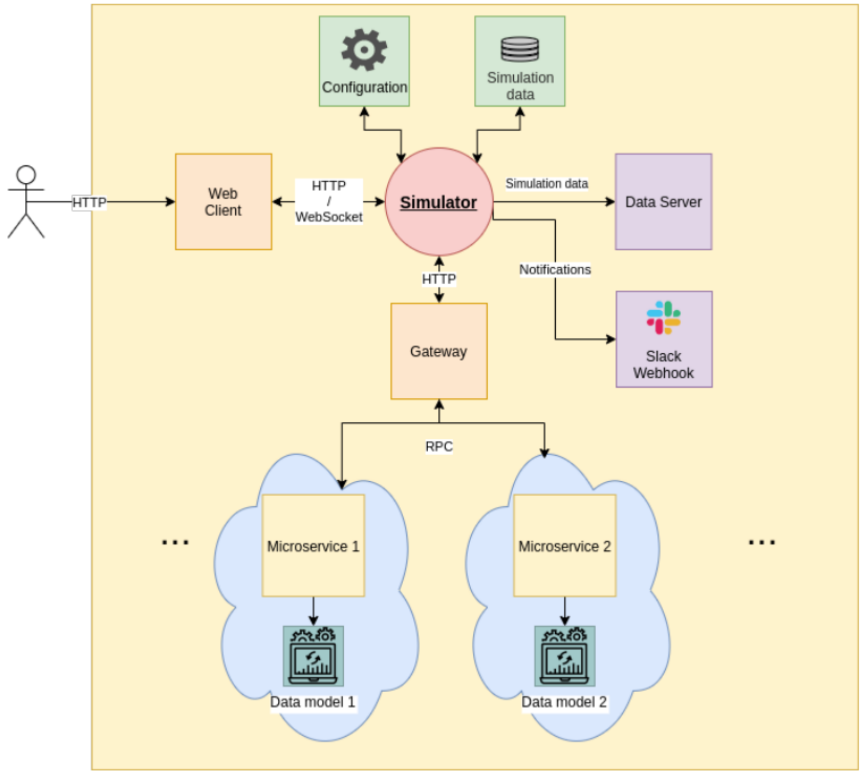

Figure 15: Overview of the Architecture of the Simulator

2.6.2.1 Simulator's Gateway

The gateway is used to centralize the communication between the simulator and the data models. In other words, it comes up as a microservice that serves a set of HTTP endpoints that, when called, delegates its logic to its respective data model (via its respective RPC proxy). Afterwards, the corresponding data model handles the request and return a response accordingly to its business logic. In technical terms, the gateway service contains the implementation of each entry point and their associated RpcProxy instances (used to delegate the entry points' handling).

2.6.2.2 Data models

The data models' architecture can be easily described by its name (used to distinguish and instantiate the respective RpcProxy from the gateway) and its clean and encapsulated business logic implementation. More specifically, regarding the travels' affluence, its model (represented in Figure 14) consists on the calculation of the travel affluence according to a certain hour of day as an input. Equally, its distance model is implemented simply through the formula presented above (equation 1). In the same way, the logic related to its duration model plainly revolves around a generation of a travel duration from equation 1. Similarly, the model concerning the final battery level of a car in the end of a travel consists of a model that, based on an initial battery level and a travel distance as input, generates a final battery level for the car (see equation 2). Furthermore, regarding the charging periods, its duration model's implementation is described as a generation of the duration value (see equation 3). Concerning its energy expenditure model is capable of, based on the charging period's progress (in percentage), generating its energy expenditure value (see equation 4).

2.6.2.3 Web Client

The web client interacts with the simulator and consumes its data. The web client is composed of controllers (inheriting from a base controller with plenty of utility functions), a customized UI control, and two helper classes.
A base controller (named BaseController) implements several common methods regarding functionalities such as UI handling and general data handling. Inheriting this controller, the client has a controller for its core and one for each view, following a MVC architecture. Each controller handles UI operations such as UI events (such as the click event handling for a given button) and view-specific UI formatting. Moreover, the control StatsChart was developed to render the charts related to the simulation. Likewise, two helper classes (MessageHelper and SocketHelper) were built to encapsulate both the parsing process of the messages received through the simulator's WebSocket and the WebSocket handling revolving its connection and messages sent through the client, respectively.

2.6.2.4 Running the simulation

The simulator is composed by the following processes: **simulations**, **travels** and **charging periods**. To help understanding them, each is illustrated in flowcharts (Figure 16 and Figure 17 respectively).

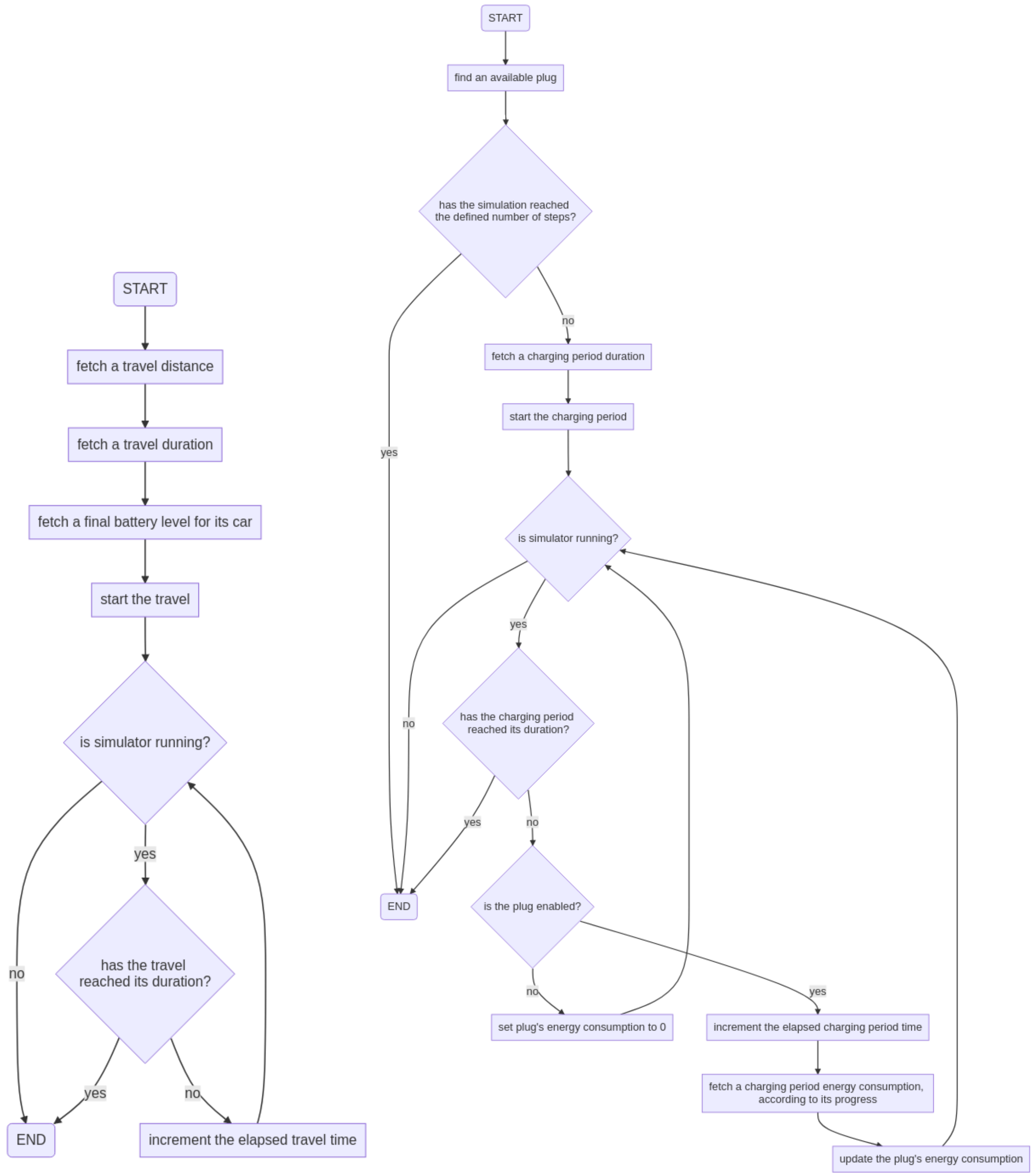

Figure 16:Fluxograms that presents how the simulation handled the travels (left) and charging operations (right)

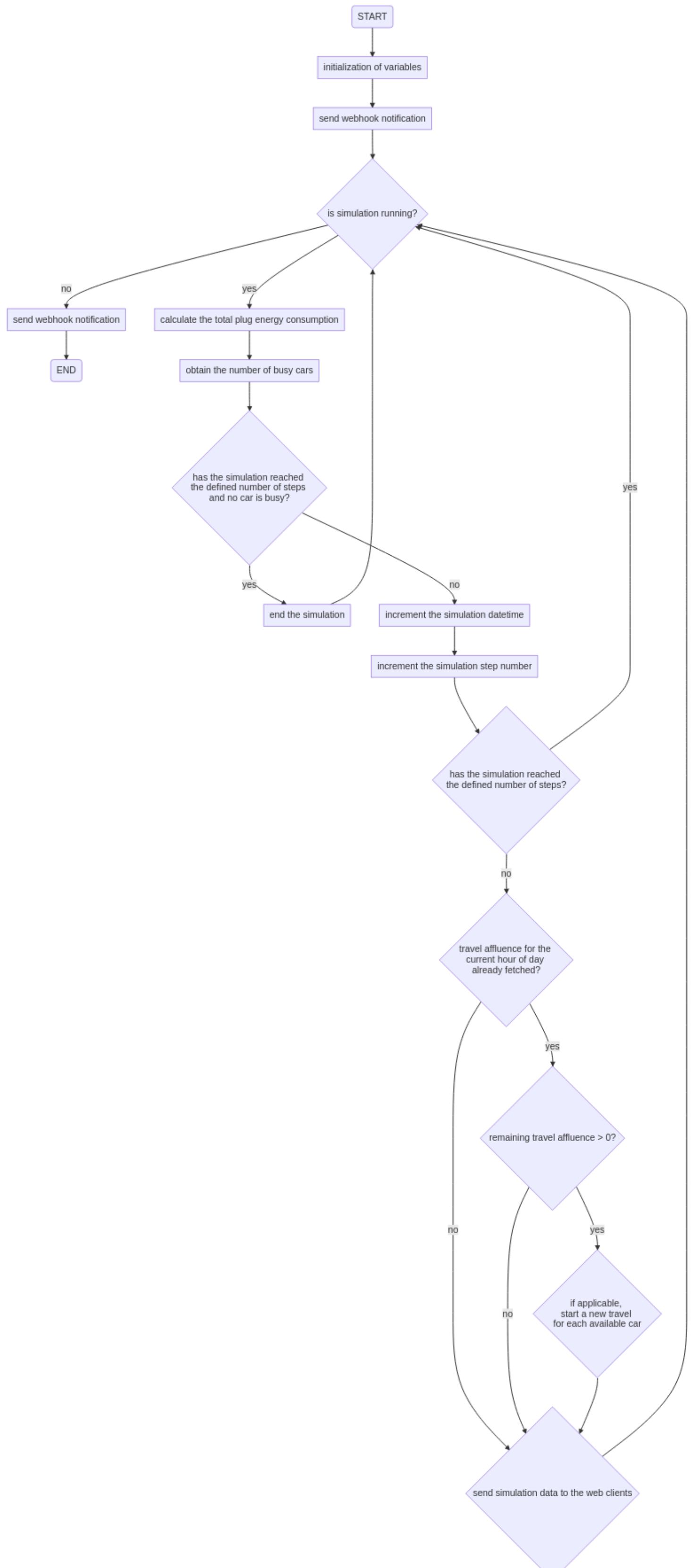

Figure 17: Overall process of how the simulator advances throughout a given simulator run

The web client contains a configuration file which sets up several factors of the simulation (see Figure 18), like for example the sleep time between septs, number of steps for each simulation, simulated minutes per step. To simulate the **Pilot 3 – Getting Started with Electric Vehicles and Smart-Charging** the following setup was used. The simulation starts every day at 00:00 and finishes at 23:45, the starting and stopping of the simulation is assured by a cron job which calls the appropriate endpoint of the REST API. An explanation of each configuration item is presented at Table 7.

Table 7: Configuration keys description and default values

Configuration key	Description	Default value
Number_of_cars	Number of vehicles per simulation	10
number_of_charging_plugs	Number of charging plugs per simulation	4
sim_sampling_rate	Sampling rate between each simulation step	900000
travel_affluence_multiplier	Travel affluence multiplier (default=1, half the affluence=0.5)	1
minutes_per_sim_step	Number of minutes that each simulation step represents	15
number_of_steps	Number of steps per simulation	96
gateway_request_base_url	Gateway URL template	http://***************************
enable_debug_mode	Enable/disable debug/verbose mode	False
webhook_url	Slack notification webhook URL	http://***************************

```
Configuration (User)
{
  "number_of_cars": 10,
  "number_of_charging_plugs": 4,
  "sim_sampling_rate": 900000,
  "travel_affluence_multiplier": 1,
  "minutes_per_sim_step": 15,
  "number_of_steps": 96,
  "gateway_request_base_url": [redacted]
  "enable_debug_mode": false,
  "webhook_url": [redacted]
}
```

Figure 18: Sample configuration used during the simulation

2.6.3 Integration with Route Monkey's algorithms

This contingency plan was implemented to evaluate the integration of the infrastructure with external charging algorithms, in this case the algorithms developed by Route Monkey. After the decision of moving forward with this plan the partners at the Madeira Demonstrator informed Route Monkey of the next steps namely:

- Development of models for the different elements of the pilot
- Development of a communication protocol with third parties
- Testing
- Running the simulation for one month

The development of the models started in the November 2020 resulting in the models already presented above, parallel to this period the team developed a protocol supported by the API (see Table 4): Route Monkey queried the API for consumption at charging points with the /plugs endpoint, this information was used in for their internal algorithms, then the actuation was accomplished by accessing the /plugs/{plug_id}/set_status/{new_status} endpoint to turn the Plug ON/OFF.

The simulation first started in July 2021, when it was clear that TukxiTours business would have not been recovered in time to perform the adequate evaluation, after 2 weeks of testing in which small configuration issues were addressed, the simulation was restarted in August 2021 and ran continuously for 61 days until the end of September 2021. The results in the remaining of this document report the data obtained during this period.

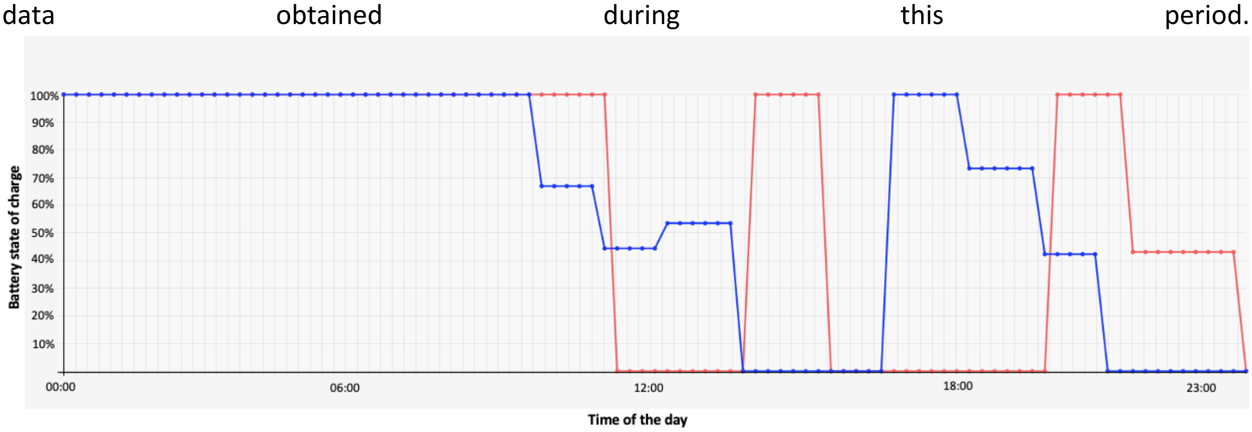

Figure 19: Battery state of charge for two scooters during a simulation run (without smart charging). Each line represents a different scooter present in the simulation

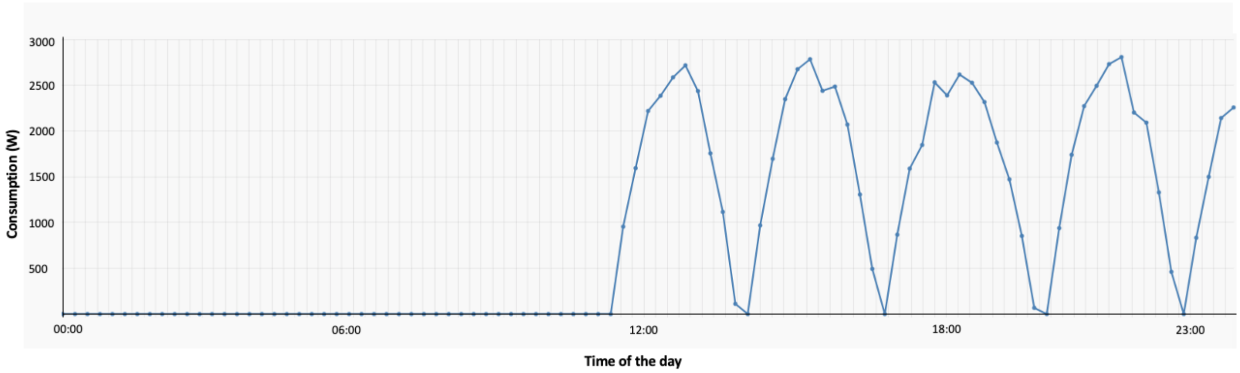

Figure 20: Consumption of one of the charging points during a simulation run (without smart charging)

2.7 Evaluation

The evaluation of **Pilot 3 – Getting Started with Electric Vehicles and Smart-Charging** was focused in three main points, the technical evaluation of the charging infrastructure (pre-Covid-19), evaluation of the Simulation (post-Covid) and Evaluation from the business point of view with Tukxi Tours. The evaluation of the mobile application used by the drivers was reported in deliverable 4.13 [7].

2.7.1 Technical evaluation

To understand if the deployed infrastructure disrupted Tukxi tours charging routines, an event detector algorithm which counted the number of events per-plug from the March 2019 to the February 2020 was employed.

2.7.1.1 Charging infrastructure

There were 1596 charging events detected by this method Figure 21 and Figure 20 presents the evolution of events during the analysed period. Figure 22 presents an average of charging events per day. As it is noticeable most charging events happened between 11:00 and 17:00. The overall charging infrastructure, which was measured by the Carlo Gavazzi meter was able to acquire 99.9% of the expected consumption points.

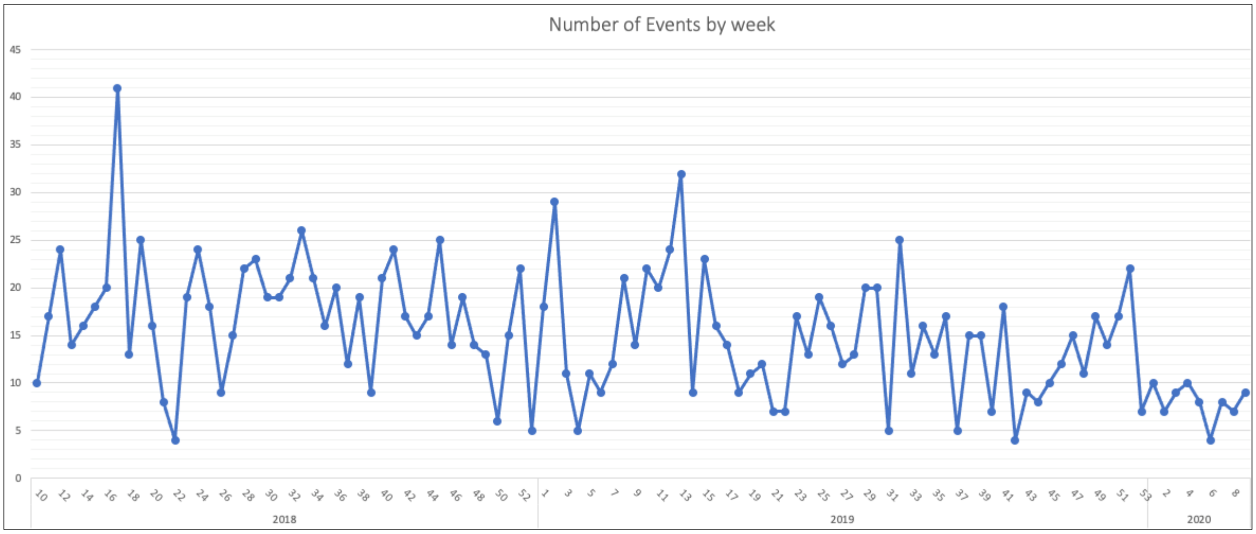

Figure 21: Number of charging events by week during the pilots' duration

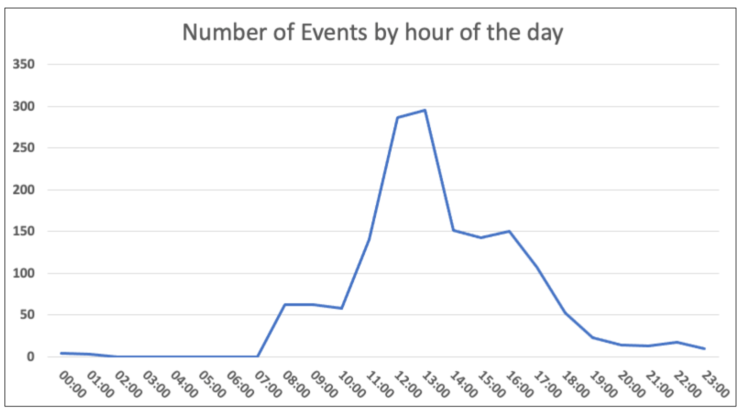

Figure 22: Aggregated number of events by hour during the period of the pilot

2.7.1.2 Simulation

During the evaluation of **Pilot 3 – Getting Started with Electric Vehicles and Smart-Charging** the Simulator completed 61 full cycles of days, it received 1208 charging commands and generated more than 58 thousand consumption points. After one week of testing the simulation ran continuously without any issues. Figure 20 and Figure 23 shows the visualization of the different parameters recorded during the simulation. The Simulation started on the 1st of August 2021 and ended on the 30th of September, the whole month of August was used as baseline (without smart charging), and the smart charging was introduced the during the whole month of September.

2.7.2 Smart charging

As mentioned above, during the simulation there were 1208 instances of smart charging events. These are, simply put, an ON or OFF command forwarded by RouteMonkey based on the output of their algorithm (see section 2.3.6.2), which tries to maximize the renewable usage at the whole island level. In simpler terms, there were more than 300 charging hours that were shifted according to the weather forecast and other inputs used by RouteMonkey. The commands significantly affected how the charging happened during the period of the simulation, Figure 19 and Figure 23 present how the battery SOC evolved during tow (random) runs of the simulation, with and without smart charging. The same comparison is presented at Figure 20 and Figure 24, again the difference between the charging pattern at the charging point is quite visible. In which the consumption happened in shorter bursts.

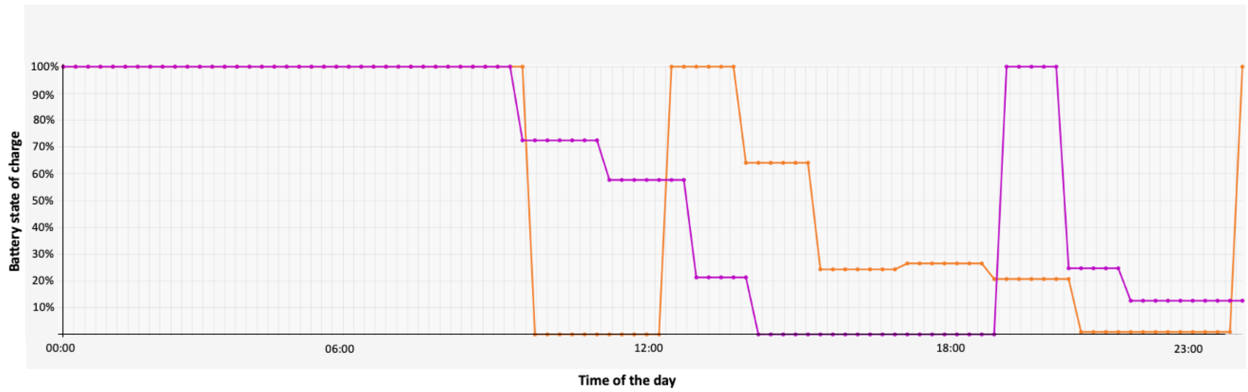

Figure 23: Battery state of charge for two scooters during a simulation run (with smart charging). Each line represents a different scooter present in the simulation

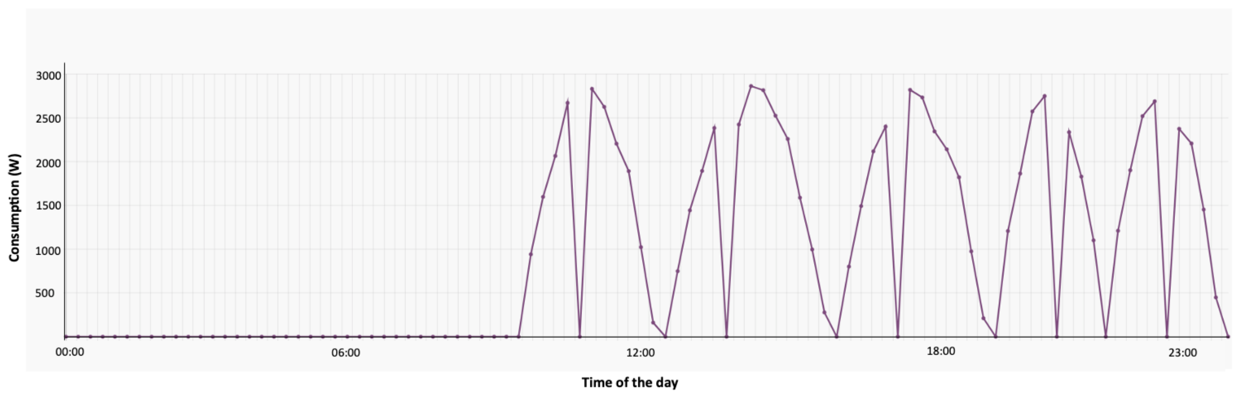

Figure 24: Consumption of one of the charging points during a simulation run (with smart charging)

In general, the data shows that there were, fewer charging periods when the smart charging was active, 612 compared to 655 without smart charging, on the other hand the charging lasted in average 10 minutes longer with smart charging. This observation can be explained by the fact that the actuation was cutting the power, which could result in a longer charging period during the smart charging. These were periods in which the algorithm "decided" to turn off the power from the charging points, delaying or postponing the charging according to its inputs, which again is focused on the renewable energy availability. This allowed to validate the smart charging algorithms, even considering the physical infrastructure was replaced by a simulation, the algorithm performed as expected controlling the charging of the vehicles.

2.7.3 Running a fleet of EVs

As part of the contingency plan it was decided to deepen the understanding of the motivations and difficulties when running a business with EVs. For this throughout the pilot the team collected several impressions from TukxiTours.

TukxiTours created the business with internal combustion engine (ICE) scooters in mind. However, an opportunity emerged to acquire 10 Electric Tukxi scooters. At the time, the TuxkiTours speculated that

offering tours with EVs could be good for the company's perception. It also hypothesized that the EVs could be used to perform tours next to Monte, a popular tourist attraction in Madeira. And since the scooters were so smooth and quiet they could go inside the popular Monte gardens.
As an early adopter of the technology, one aspect was the maintenance of those vehicles, since the company did not have any know-how in the technology. During the operation of the vehicles Tukxi Tours encountered certain issues related to the infancy of the technology (batteries locking the charging, problems unlocking the batteries, procuring parts needed for repair, finding qualified assistance without having to send the scooter back to the manufacturer). Even with the aspects presented above, EVs are considered to present some advantages for their business. Moreover, the company made another investment in Lisbon with another fleet of electric scooters. However, for that fleet, the company decided to purchase a different model, with older technology (led acid batteries), which provide less range but is expected to be much more reliable.

2.8 Discussion

The discussion of the results from this pilot are focused in three main aspects, the developed infrastructure, the contingency plan after Covid-19, and the new outcome from this pilot, The Simulator.

2.8.1 Charging equipment and infrastructure

The infrastructure preparation for the **Getting Started with Electric Vehicles, and Smart Charing** demo followed the main ideas discussed in the initial meeting with Route Monkey in 2017. The overreaching goal for this pilot was to provide smart charging, at a low cost for vehicles which generally are not the target of such interventions.
This way, all the decisions within this pilot are responses to that challenge. The deployed infrastructure fully meets the initial criteria, the solution allows the control of individual charging points, and it also allowed to assess the overall consumption of the charging infrastructure. The collected data showed that retrofitting the proposed infrastructure in TukxiTours did not change the drivers routines in any way, which was one of the concerns at the beginning. Furthermore, our human-centric approach allowed us to rely on the input of drivers to collect metrics that are normally not available in these types of vehicles.
The infrastructure meets the second goal of keeping the costs low. We used mostly off-the-shelf equipment together with custom-made hardware. When comparing with commercial solutions for the same problem, it is easy to understand that there is no solution to this exact problem (for example we did not find any smart-plug that could connect to a CE16 socket), the closest available approach for the fine-grained control our solution offers, would be to install contactors "behind" each charging point, this would, of course, result in much higher costs of purchase and especially installation.
We also believe the decision of fully integrating the control of the pilot with the overall API used for all the demonstrators at Madeira Island was successful. All the information from the pilot was made available to the third parties involved in the solution development and evaluation, and even the actuation into the charging loads is possible to authenticated third parties. This flexibility allowed, for example, to parallelly feed data to two interested partners in the project (CERTH and Route Monkey). It would also allow us to test different smart charging algorithms without any changes to the charging or software infrastructure.

2.8.2 Contingency Plan

The Covid-19 pandemic was very tough for the tourism industry, unfortunately the whole TukxiTour business was stopped to a halt days after the smart charging intervention started. All the local partners monitored this situation closely, making sure that the charging and monitoring infrastructure was kept running without any issues, so that the pilot could be quickly resumed once the tourism business recovered. Lamentably, this recovery never seemed to be close, so it was decided to implement a contingency plan, which would allow us to evaluate the communication and integration with RouteMonkey while also giving us a limited opportunity to evaluate the smart charging actuation. With this plan we also reinforced the user engagement evaluation by taking into account the feedback from the different individuals' part of TukxiTours. In hindsight there are no doubts this was the best approach, although the tourism recovered in Madeira and the summer of 2021 saw the arrival of many tourists, the first cruise ship, which are the main customers of TukxiTours, docked at Funchal on the 21 of September of 2021, which was already too late to conduct an adequate evaluation.

Another catalyst for the development of the Simulator was related to the reduction of TukxiTours fleet size, which would hinder the real-world evaluation of the pilot. This issue was the main subject of the evaluation with the business owner discussed above.

From the business point of view, it was clear that the selected EVs did not provide the outcome TukxiTours hoped. Technical difficulties outside SMILE hindered the operation of the scooters. However, the management understands that this type of vehicle can return some benefits in driving and tours offered. Furthermore, the company continued the investment in EVs in a second site in Lisbon. This way is reasonable to conclude that although the developed charging infrastructure and motivation of SMILE were in place for the normal operation of the EVs, the technology previously acquired by TukxiTours was not mature enough. Yet, it is crucial to note that besides the mentioned issues, the deployed infrastructure was extensively used as proven by the number of detected charging events.

2.8.3 The Simulator

The simulator was an unpredicted output from **Getting Started with Electric Vehicles, and Smart Charing** pilot. We believe that this outcome is important in the scope of the pilot. From the practical standpoint, studies involving smart-charging algorithms are feasible yet difficult, expensive, and could be dangerous, since it requires complex management and coordination in terms of the electric power and road transport systems [8]. Thus, to successfully analyse/predict the integration of EVs in the electrical networks and also (very importantly) for the grids' safety, these studies are usually firstly conducted recurring to simulations [8].

From the data standpoint, the lack of data is also an issue when it comes to evaluating algorithms and machine learning in general [9], being that simulations will also help in augmenting/enlarging the datasets and improving decision-making/prediction in this kind of systems[10].

Not to mention the additional impact of the Covid-19 pandemic has had on the lack of data, particularly in areas such as energy and transportation, since there are not many drivers, cars, and travels to evaluate the proposed algorithms. Therefore, as usual in the area of smart-charging (and because of the reasons mentioned previously), the lack of data (or the lack of non-noisy data) leads up to the testing being done based on simulation of factors such as the usage of EVs, the grid's load, the cost of energy and the charging of batteries in general [11]–[14].

There are simulation solutions available that fit different scenarios. Still, they consist of either academic, proprietary solutions, or limited/specific solutions to a particular context that require a bit of effort from the researchers/practitioners to customize them to their intended context (even if the required changes are minimal) [5], [6]. Furthermore, the literature review carried out during the development of the simulator disclosed that, in terms of architecture, the existing solutions are usually made in a monolithic way, containing a single code-base and leading up to more rigid solutions and challenging to adjust/customize as intended by the end-user. Besides that, technologically speaking, there are not many available frameworks that integrate this kind of simulation while being open-source, extensible, and easy-to-use [5], [6], which obstructs its reusability or customization in other contexts.

To overcome this, we developed simulation platform that allows researchers to simulate any set of smart-charging algorithms in different conditions. This approach was validated in the context of this pilot, however we believe that this completely open platform is an important outcome of the Project that could be easily adapted to other pilots, by simply changing the models of the different components.
Considering the specific application within **Getting Started with Electric Vehicles, and Smart Charing** it is important to reiterate that although the simulation completely replaced the physical infrastructure it was deployed in a new server, and with slightly differences in the communication protocols. This meant that RouteMonkey also had to implement small changes in their approach for this pilot. Those changes were carried out smoothly, and the integration was seamless which further validate the robustness and flexibility of our approach.

3 Pilot 4 – Electric Vehicles are our Future

The EV and smart charging pilot focused on providing a smart charging solution using standard chargers by taking control of the ON/OFF status of the charge. This fact means that infrastructure and installation efforts for this pilot were significantly higher than for the **Getting Started with Electric Vehicles and Smart Charing** pilot. The scooters part of the **Getting Started with Electric Vehicles and Smart Charing** pilot , charged using a simple ON/OFF modality. For the **Electric Vehicles are Our Future** pilot, considering that the objective is a fully-fledged EV, simply cutting and feeding electricity to the charger will not be enough for the fine-grained control we are aiming.

In this chapter, it is presented how the different components were developed, installed and evaluated in the selected site. For more information regarding the motivation and infrastructure development, please refer to deliverable D4.2 and D4.6 [1], [2].

The overarching goal of this pilot is to retrofit existing installation with hardware/software, which would allow controlled charging. The focus is also on scenarios where more than one EV are under charge at the same time (for example, a common parking lot at an apartment building). These are especially challenging situations since more than one vehicle could "compete" for rights to charge. Or the charging must consider the physical limits of an outdated electricity installation. In summary, the interest is on implementing a smart charging approach based on:

- Range need for every vehicle
- Power limit of the infrastructure
- State of the charge in each vehicle
- Local and Island level renewable energy availability

3.1 Pilot site

This intervention was focused on the garage of EEM, which is one of the partners from SMILE. It has been considered an appropriate location for this pilot since it contains a relevant number of EVs (allowing to relate the results to other building such as apartments), and there is easy access to the chargers and drivers (to assess the social aspects of the smart charging). Furthermore, it is also noteworthy to mention that the EEM garage electricity installation/contract is over-dimensioned. Therefore, we were not limited by that factor during the project.

3.1.1 The EEM garage

EEM garage contains the following EV on a "permanent daily basis"

- **5 Renault ZOE (GEN3)** with a 65 kW (maximum net power) 100% electric engine + 22 kWh battery capacity;
- **3 Nissan Leaf** with an 80 kW (maximum net power) 100% electric engine + 30 kWh battery capacity;
- **1 Mitsubishi iMiEV** with 49 kW (maximum net power) 100% electric engine + 16 kWh battery capacity.
- **1 Renault Kangoo EV**

There are also 3 **Renault ZOE (GEN3)** that can visit/charge at EEM garage for different periods.

The infrastructure before the pilot was 3 EVs charging stations providing a total of 6 EVs charging points, each charging station has 2 charging points, and each charging point delivers 22 kW of power to the EVs.

This EV charging infrastructure was used to retrofit new hardware, by adding new infrastructure to allow the control of the EV charging session.

3.1.2 Number of charging points

The previous EV charging infrastructure has the MAGNUM CAP charging station to provide energy to the EV. On this charging station, a custom charging station was retrofitted that provides the same power delivery as the previous charging station. A total of 3 charging stations were installed to provide 6 charging points to deliver each 22 kW of power to the EVs.

3.2 Equipment

Different hardware/software solutions had to be developed for the **Electric Vehicles are Our Future** pilot, to solve challenges particular to the pilot specification. To remotely turning ON/OFF charging points and manage the EVs power consumption by applying a smart charging algorithm.
In the sub-chapters below, the development and deployment of all the equipment used for the **Electric Vehicles are Our Future** pilot are briefly described. The motivation for this pilot was discussed at Deliverable D4.1 and D4.6 [1], [2].The hardware was first installed in **February of 2019**.

3.2.1 Control and Communication Module

The charging infrastructure already in place at EEM was studied before the development of Control and Communication Modules for each EV charging session. According to the IEC 62196 standard, the EV charging infrastructure allows conductive AC charging though a type 2 socket, also known as Mennekes, using the charging mode 4 (see Figure 25), representing fast charging.

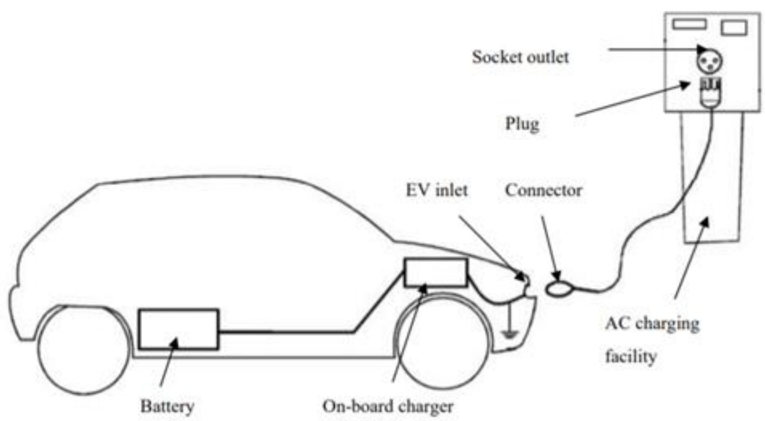

Figure 25: General representation of the components part of the type 2 Smart charging procedure

Table 8: Type 2 charging EV states

EV state	Description
A	EV Not connected
B	EV connected

C	EV charge
D	EV charge (area ventilation required)
E	Error
F	Unknown / Error

The Control and Communication Module (Figure 26 and Figure 37) was developed according to the IEC 62196 [15], [16] and IEC 61581 standards. The IEC 61581 standard is for the EV communication, which specifies a PWM signal that is sent to the EV to control the charging session by controlling the power consumption, the start, and end of charging.

To prevent a short circuit and electric shock outbreak, the charging station has safety features. One of those features is a circuit breaker to avoid the wiring to catch fire, caused by the high current needed to charge the EV, and a ground fault circuit breaker to detect the imbalance between the outgoing and incoming current that can be provoked by an electric shock (for example, electric shock caused by human error).

With all the safety features and standards, a Carlo Gavazzi 340 energy monitor is used to measure the aggregated consumption allowing to gather more precise information (for example, frequency, power factor, active power, voltage, current, etc.) and will be useful to assess the smart charging intervention.

Figure 26, below, shows the Control and Communication Module station with two charging points capable of providing each 22 kW of power to the EVs.

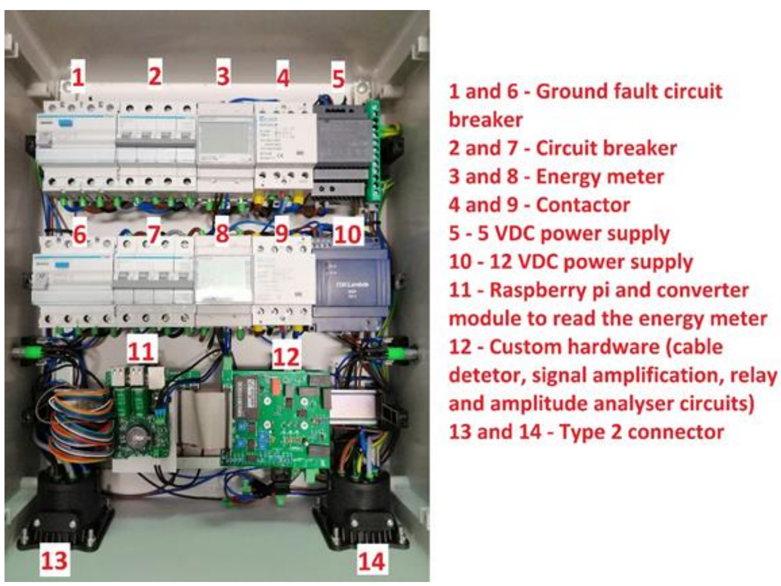

Figure 26: Control and communication module developed in SMILE

3.2.1.1 Controlling the charging duty cycle

One of the biggest challenges regarding the Control and Communication Module was to modulate the electricity consumption during the charging procedure. As mentioned above, this is accomplished through the IEC 61581.

Nearly all EVs that has rolled off the assembly line in the last decade supports the IEC61851 standard to allow the connection between the charging station and the EV[17]. The control pilot pin in a type 2 connector (see Figure 27) is used to communicate a series of EV states. When the EV is connected to the charging station, it enters the B charging state, meaning that the connection has been accepted. When charging is needed, the EV enters in the charging state C or state D when auxiliary exterior ventilation is required. If an error occurs, the EV shifts to the charging state E or F, meaning that an error occurred in the charging session. These charging states are presented in table Table 8.

Figure 27: Type 2 plug (left) and socket (middle and right)

Additionally, the IEC61581 protocol allows defining a charging duty cycle. By default, once a car is connected to a charger, it will attempt to charge with the maximum power available at the charger (100% duty cycle). This fact is, of course, not ideal for implementing a smart charging algorithm or complying with pilot scenarios defined at deliverable D4.1 and D4.6 [1], [18]. Since there are situations in which its ideal to reduce the power demand to meet external conditions (renewables in the grid or limitations of the infrastructure). This control is accomplished by modulating the period of a PWM wave sent to the EV by the CP line (see Figure 27 right). The graph below (Figure 28 left) presents the relation between the duty cycle and the consumed current. In the EEM garage scenario, the maximum duty cycle allowed was 57%, which consumes 32A of power, this is a limitation of the already installed Magnum Cap chargers. A breakdown of the components and their cost is presented in Table 9.

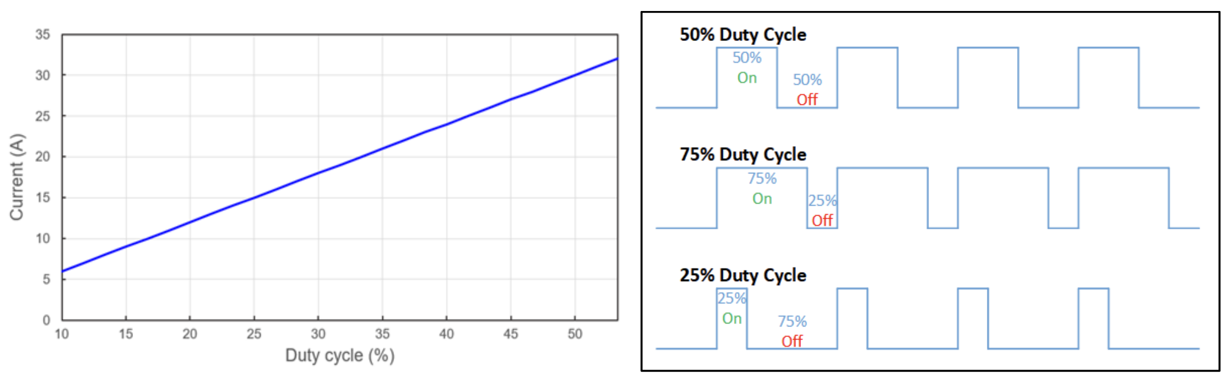

Figure 28: Left: Relation between the current demand and vehicle duty cycle; Right: Example of the PWM signal used to modulate de charging duty cycle

3.2.2 Coordinator

A custom-made gateway (called the Coordinator - Figure 29, in the scope of the **Electric Vehicles are our Future** pilot), is used to aggregate all the charging stations' energy and manage the command parameters at the site. This device is similar to the gateway developed for Pilots 1 and 2 (see Deliverable 4.1 and

4.2[2], [18]). It receives commands from the server to apply to a charging station when an EV is charging. For this particular pilot, the coordinator is used to:

1. Query the energy information parameters from the charging stations
2. Forward the commands from the server to the charging stations
3. Cash data when the connection to the server is not possible.

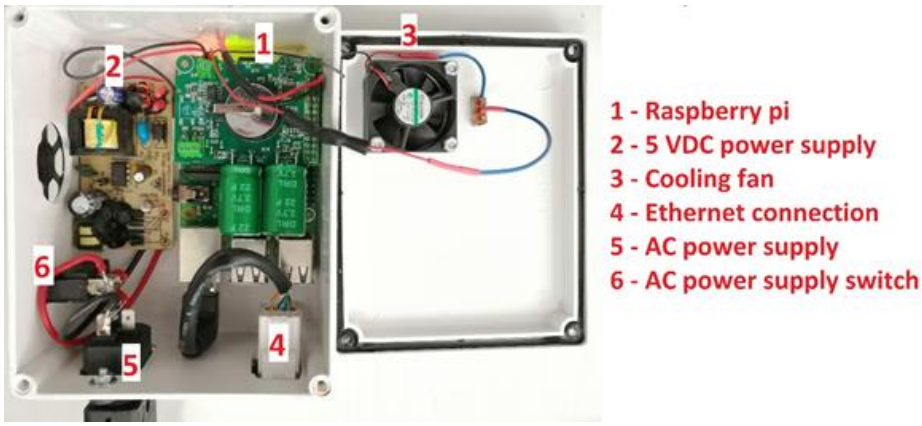

Figure 29: Coordinator gateway developed for Electric Vehicles are Our Future pilot

Table 9: Breakdown of the components and cost for a CCM equipment capable of controlling the charge in 2 EVs

Component	Unit Cost	Quantity	Cost
Raspberry Pi 3	€39,90	1	€39,90
Transformer 5V	€47,42	1	€47,42
SD Card	€17,9	1	€17,9
JUICE4HALT module ● UPS ● Realtime Clock ● RS485 converter	€62	1	€62
Transformer 12V	€16,96	1	€16,96
EV type-2 socket	€72,68	2	€142,36
EV type-2 socket locker	€20,48	2	€40,96
EV type-2 cable	€127,00	2	€254,00
EV Cable Bucin	€1	2	€2
Circuit breaker	€45,99	2	€91,98
Ground fault circuit breaker	€36,99	2	€73,98

Relay	€83,91	2	€167,82
Energy meter EM340	€102,00	2	€204,00
LED 230VAC	€11,03	2	€22,06
Locker switch	€3,53	2	€7,06
Custom board	€100,00	2	€200,00
Box	€130,00	1	€130,00
Box chassis	€147,00	1	€147,00
Earth line 13 pinouts	€3,45	1	€3,45
Total:			€1 670,85

3.2.3 Network

One of the requirements for the charging infrastructure was the need for a reliable internet connection at the site. At the start of the project, it was decided the best approach was to install a dedicated internet connection with a router that could cover the site area. The local project coordinator set up with a Portuguese Internet Service Provider to install the required equipment to provide a secure and reliable internet connection during the duration of the project. This equipment was installed in **September 2019**

3.2.4 Web interface

To be able to control the EV charging session remotely, the web interface (see Figure 30) provides input parameters to all user interaction:

1. Finish – Terminates the EV charging;
2. Schedule – Set the charging session start and end time;
3. Automatic charging mode - Applies the smart charging algorithm;
4. Manual charging mode - User defines the charging power.

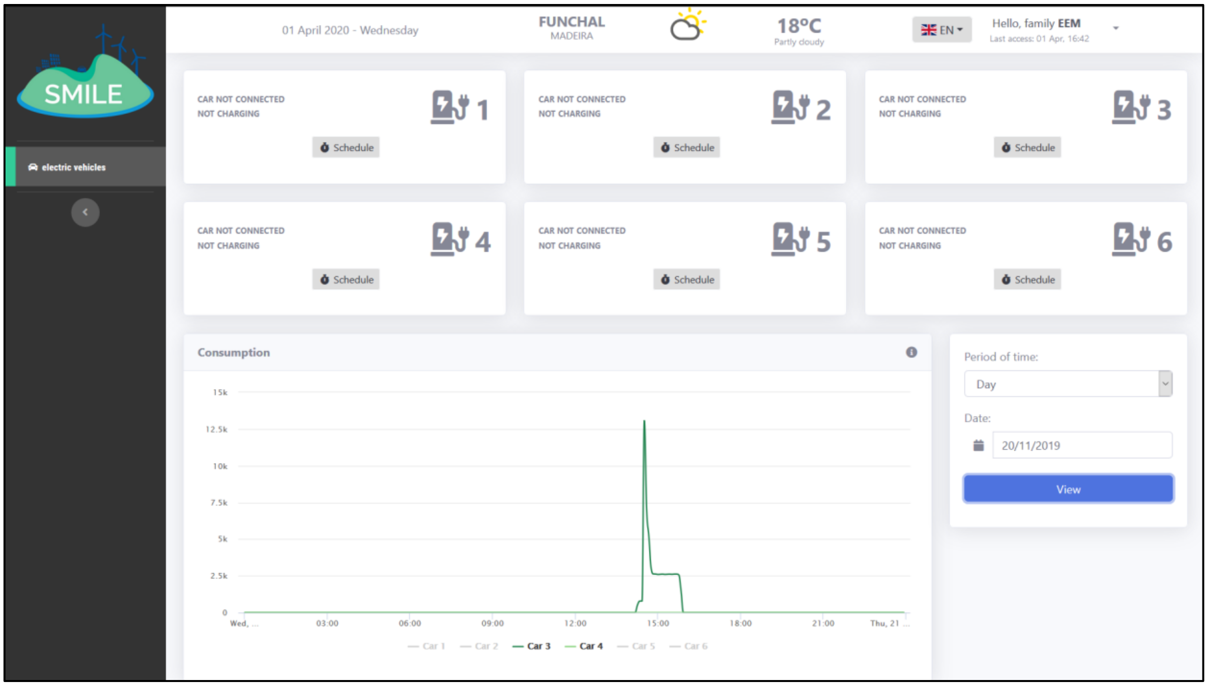

Figure 30: EMS service directed at the EVs from the Electric Vehicles are Our Future pilot

When an EV is charging, the web interface shows the EV power consumption, the charging station number, the charging finish button, the schedule, and the charging mode, which has the automatic and manual mode, as shown in Figure 31 below.

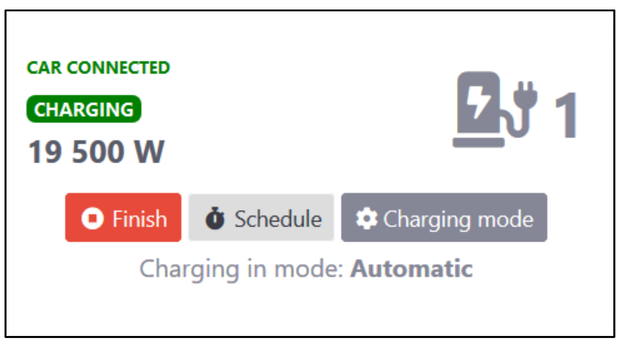

Figure 31: EMS charging consumption information, for one of the developed charging points

The charging schedule has a start and end time inputs, as shown in Figure 32, below. However, before any EV is connected to the charging station, the charging schedule start parameter must be set by the user.

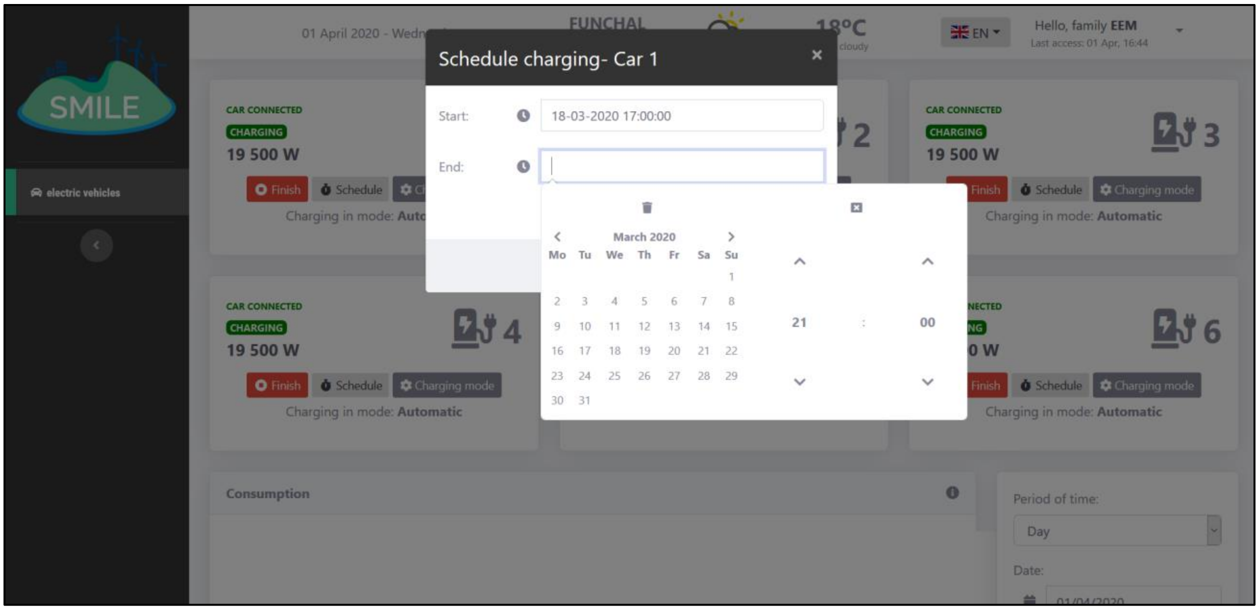

Figure 32: Scheduling functionalities as presented by PRSMA'S EMS

The system provides two charging modes to the user, the automatic and manual charging options. The automatic charging applies one of the developed algorithms in SMILE, and it schedules the charging periods and the consumption in those periods. On the other hand, the manual charging does not apply a smart charging algorithm. Still, it gives the control of the power that the EV is consuming to its user to manage the EV charging session, which is already a step up from the traditional charging procedures. Figure 33, shows the EV charging modes.

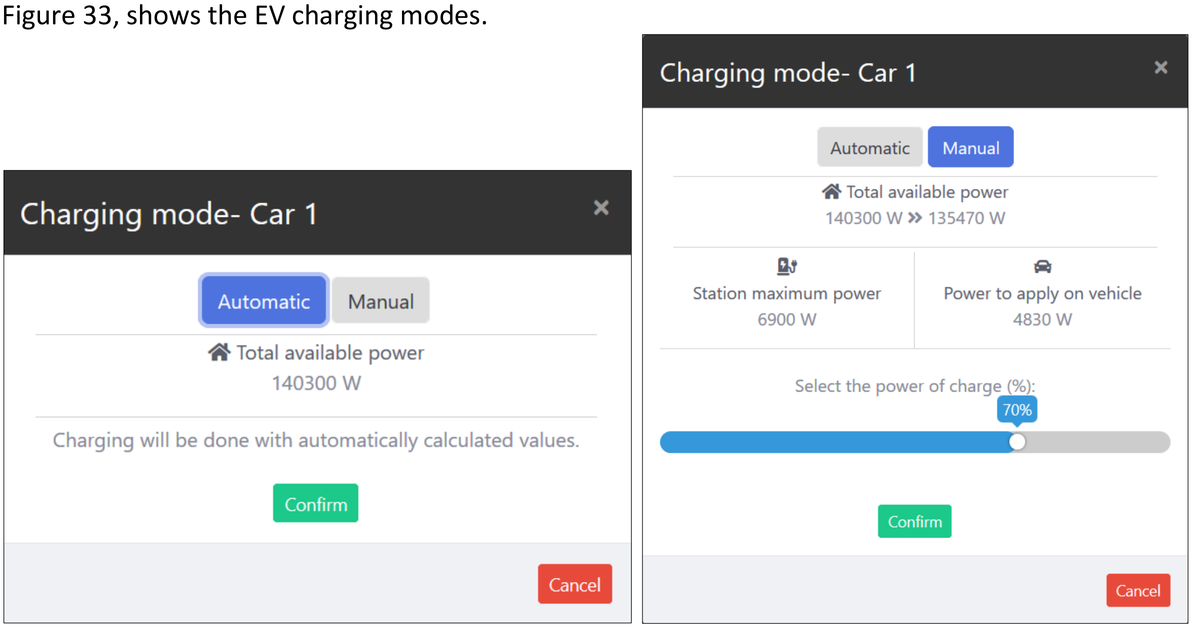

Figure 33: Two charging modes offered by the EMS. In the manual charging mode, the user needs to input the maximum desired charge.

The web interface also provides error messages if an error occurs on the charging station, which prevents the charging or triggers an error in the vehicle. Figure 34, shows the error messages and steps to follow to fix the issues.

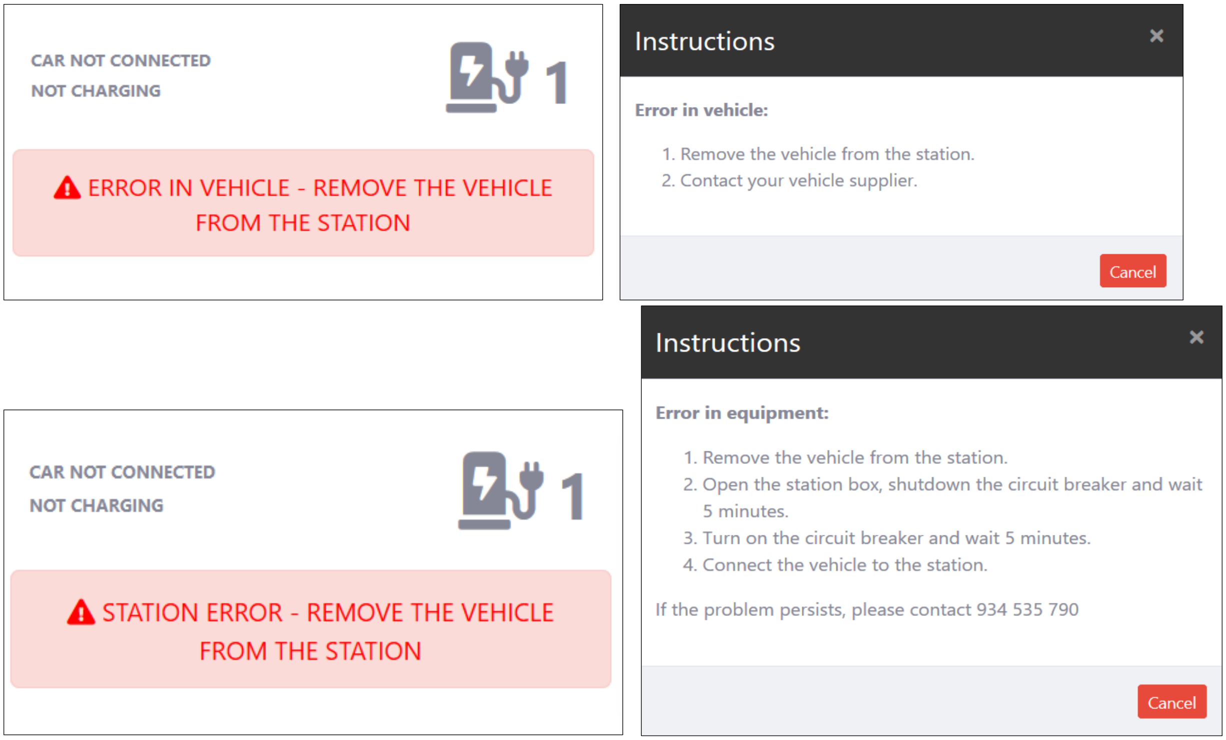

Figure 34: Example of four possible error messages displayed by the EMS when it detects errors in the charging procedure

All the functionality presented above was accessible by EEM garage users by using a credential specific for this pilot. We also installed a tablet in the garage so that the garage manager could interact with chargers.

3.2.4.1 Evolution and maintenance

As mentioned above, the web interface was released in September 2019. However, the notable human engagement aspect of this pilot meant that the system was continuously evolving as the users got familiar with the web application and with the general smart charging concept, below we describe the most significant changes implemented in the web interface for the **Electric Vehicles are Our Future** pilot:

- **4th of May 2020**: Instructions were added with the necessary steps to solve technical issues with chargers.
- **23rd of July 2020**: The EMS started to record the interactions with the EV web application to evaluate the user engagement.
- **26th of September 2020**: A simpler Normal/Smart charging toggle was introduced to replace the duty cycle selection presented in Figure 33.
- **17th December 2020**: The charging station label was changed to clarify (station 1, 2,... instead of car 1,2,...)
- **April 2021**: Integration with Route Monkey algorithms
- **July 2021**: Forced standard charging on Fridays by request of EEM management.

3.2.5 Application Programming Interface

PRSMA's EMS provides an API to access and control the relevant variables part of the **Electric Vehicles are Our Future pilot**. In broader terms, the API allows project partners to query consumption data, and then directly control the duty cycle of each one of the charging points.
In summary, the API provides services for:

- Schedule a charging
- Stop the charging
- Get last charging state of a charging point
- Define the duty cycle

Of course, each request and response to the API will provide more details like, for example, timestamps, charging states, devices id, etc.

3.2.6 Smart Charging Algorithms

The overall approach for the smart charging algorithms is the same as presented for the **Getting Started With EVs and Smart Charging** pilot, therefore the information can be found in section 2.3.6.1.

3.2.6.1 Integration of the smart charging algorithms

The integration of the smart charging algorithms is similar to the approach presented to the **Getting Started With EVs and Smart Charging pilot** (see section 2.3.6.3). The API provided by PRSMA EMS allowed a complete separation of responsibilities (see Figure 36). Therefore, no complications were encountered during the integration.
Every 15 minutes RouteMonkey updated an URL with the proposed charging schedule for the current day, with a granularity of one point per 15 minutes. The EMS then reads the URL at the same frequency and actuates into the charging points, forcing the charging duty cycle proposed by the algorithm. This operation only happens for chargers in which the normal/smart toggle is set to smart. Most of the duty cycles proposed by the algorithm used 0, 20 and 100% of the 22kW available at the charger. Figure 35 presents the output of the algorithm, the duty cycle is identified at the **powerPercentage** field, each charging point is identified by the **device** field. By default (with the normal charging) all the vehicles are charged with a duty cycle of 100%.

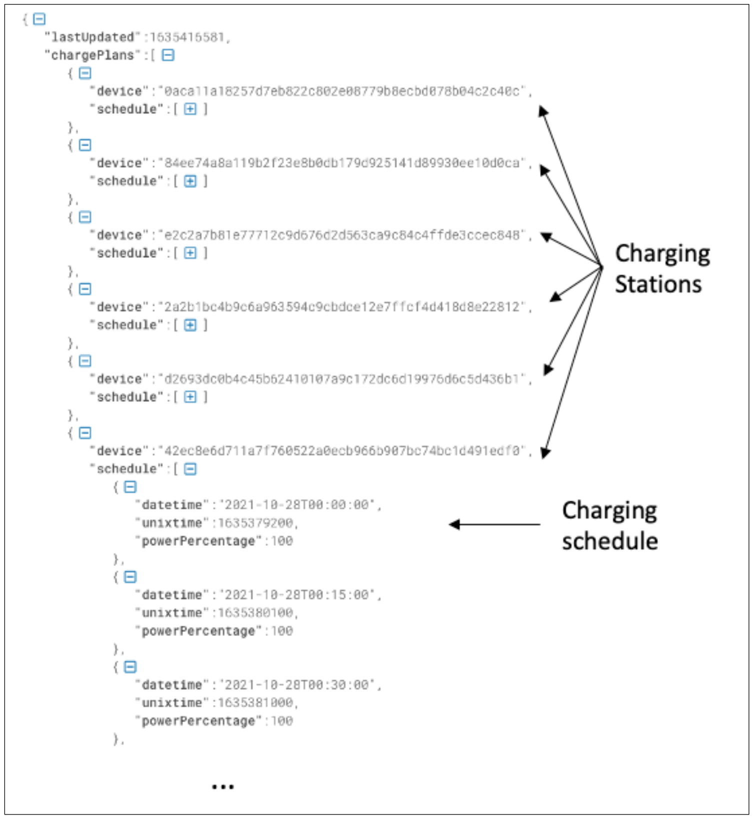

Figure 35: Output from the smart charging algorithm proposed by RouteMonkey.

3.2.7 Installation

Once the hardware was installed at the site, the project team started to develop a web interface to infer the usage of EVs. The web interface was introduced to the EVs drivers and manager of the garage, and in the first 3 months, several tests were performed to improve the stability and usability of the web interface. The testing phase ended in **November of 2019** when data was collected from EVs, and after this stage, several improvements were implemented, considering the drivers' feedback (see section 3.2.4.1). The final version of the algorithms started to be used at **the beginning of April 2021,** after the removal of lockdowns from COVID-19, which did not directly affect EEM but affected all the other local partners and suppliers, which could not access EEM's garage.

3.3 Operation

The EV charging system handles the EV charging based on a server connection with a web interface. This system is composed of the charging station, which communicates with the EV to delivering the desired charge, the coordinator, which is responsible for sending and receiving data from the server and the charging station, and finally, the server, which is responsible for managing the EV charging session. The server also exposes services that were used by the project partners to apply the proposed smart charging algorithms.

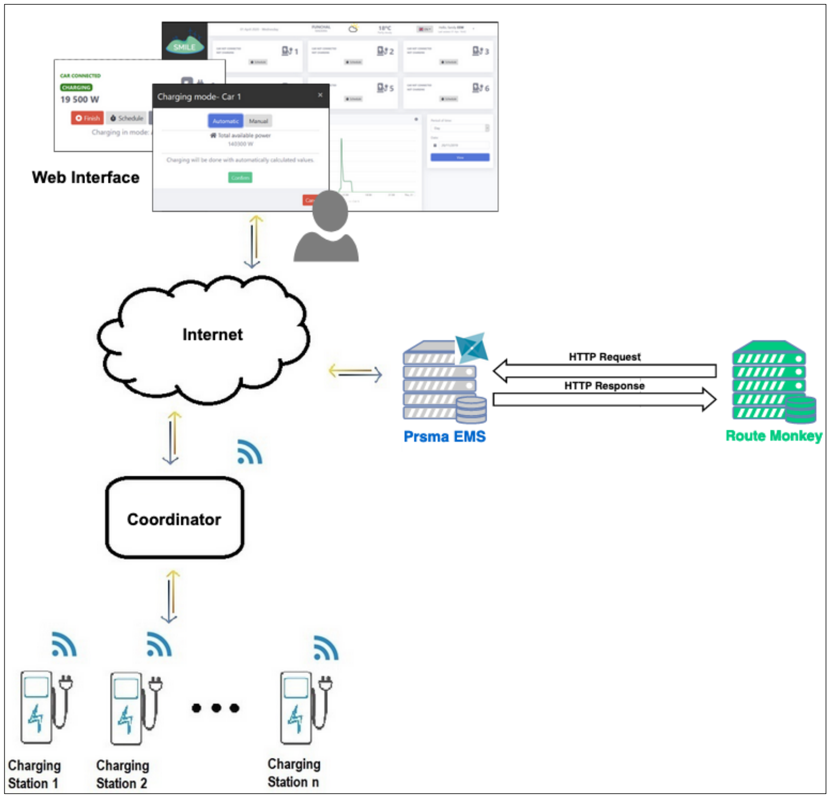

Figure 36: Communication architecture of the different hardware and software components part of the Electric Vehicles are Our Future pilot

When the EV is connected to the charging station (see Figure 41), it initializes the communication with the EV, reads the electricity consumption information and forwards that data to the gateway. The gateway stores it into a local database and sends the data to the server. Once the server receives the charging station data, the server reads the user inputs and forwards the charging commands according to the selected mode. The communication is mediated by the Coordinator, which receives the instructions from the server, stores them in a local database, and finally forwards them to the charging stations. The commands sent by the Coordinator are received by the charging station and are applied on the EV through the communication line in the type 2 cable (see Figure 27 left).

3.4 Deployment

The deployment of the equipment described above was not processed at the same time, since several solutions were developed with the input of the pilot's participants and other partners during the project. Only one charging station was implemented first to check the communication with the EV, and once the communication was confirmed, the coordinator and the other charging stations were installed, a summary of deployment timeline is presented at Figure 38.

3.4.1 Maintenance

The maintenance of the different components happened as needed throughout the pilot. The most common issue was related to the SD card of the charging station, since it was often corrupted, and they had to be physically replaced by an employee from PRSMA or M-ITI.

Other maintenance issues were mostly software related, especially updating the web interface and the implementation of smart charging algorithms (see section 3.2.4.1).

Figure 37: Control and Communication Module with the charging cables (left). And directly connected to the grid (right)

3.4.2 Evaluation

To evaluate the concrete effects of this pilot, three scenarios were proposed in Deliverable D4.6 [1] . A quantitative assessment of the smart charging algorithms, assessment of the drivers/user satisfaction with the deployed hardware/software, and finally, assess the intervention from the business point of view.

Scenario 1 - Recharging based on the locally available power: This scenario focused on understating the charging infrastructure limitations, such as power consumption and limit, and optimizing the charging according to available energy.

- Studying the charging infrastructure and developing algorithms that recommend charging schedules that consider the physical limitations of the local grid, and the needs of the vehicles.

Scenario 2 - Maximising value to the EV user according to energy tariff: The objective of this scenario is to assess with the user the impact of charging the vehicle in the overall energy tariff.

- Develop simulations based on genetic algorithms of different charging schedules aiming at optimizing the cost of charging. These simulations will be taken into account to discuss the monetary impact of vehicle charging on the user premises.

Scenario 3 - Optimizing the charging based on the renewables in the grid: The objective of this approach is to schedule the load when renewable energies are being introduced into the grid.

- This scenario takes into account a charging algorithm that indicates a charging schedule according to the renewable energy in the grid. This scenario will be evaluated by comparing the renewable mix in the charging loads before and after the intervention.

The developed algorithm by Route Monkey mostly focused on the optimization proposed by scenario 3, see section 2.3.6.1.

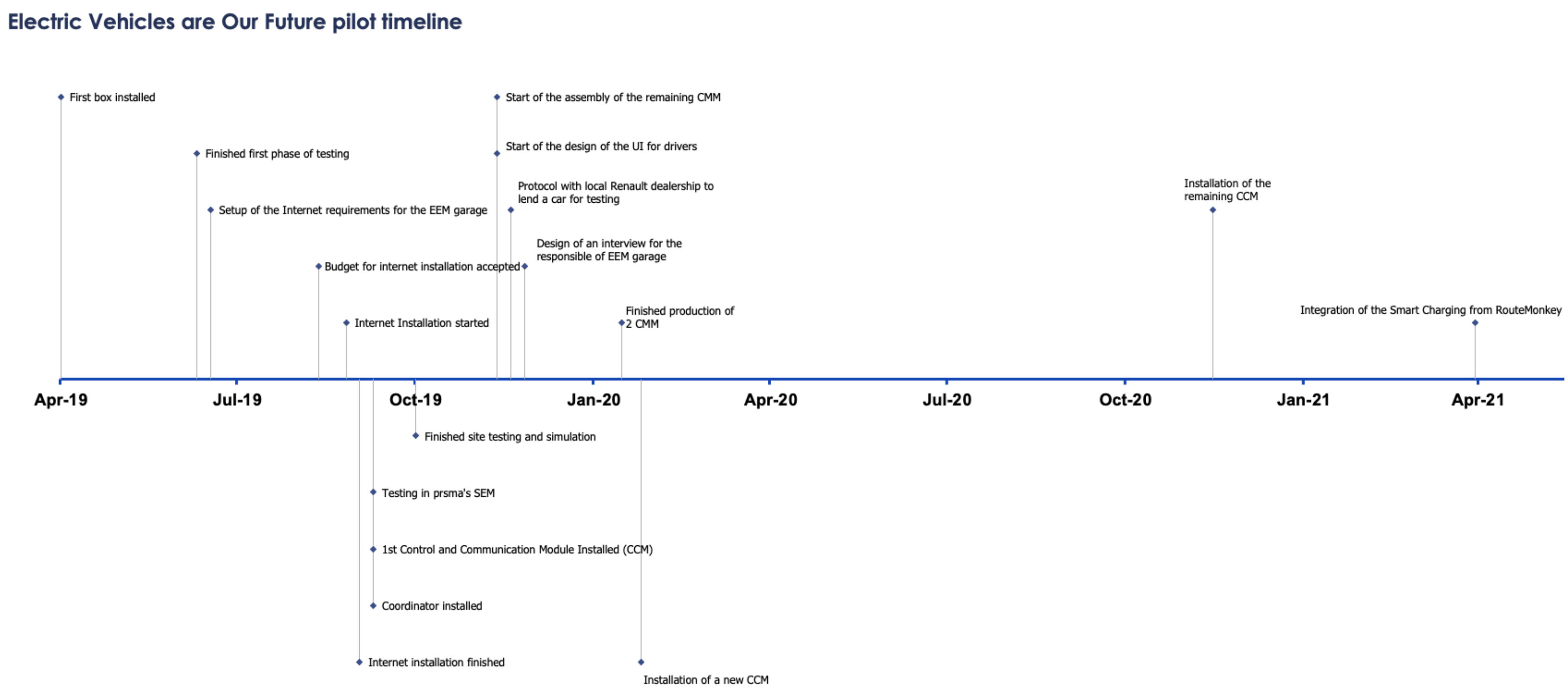

Figure 38:Timeline of progress regarding the Electric Vehicles are Our Future pilot

3.4.3 Challenges

It was decided to abandon the approach of using a contactor to control the EV loads since it would not return the fine-grained control needed to control more significant charges. Furthermore, we were also not confident in using the contactor to suddenly cut and feed power into the charges. Different vehicles could react to these events differently this would render the smart charging unreliable (for example it could trigger some safeguard in the charger or vehicle). Working at EEMs garage was also challenging, at first, we encounter limitations regarding the internet coverage. But the challenges were mostly related to installing equipment in a work environment with all the inherent restrictions, such as access to the site, time limits for testing, and of course, the need to assure the charging service.

3.5 Evaluation

This section will present the evaluation of the whole **Electric Vehicles are Our Future** pilot. We will focus on the technical evaluation but also consider the smart charging algorithms and the proposed smart charging scenarios.

3.5.1 Technical

The technical goals of the Project were accomplished, the developed charging stations were able strictly actuate into the charging loads with a granularity lower than 5% of the duty cycle. Furthermore, the proposed solution deployed local (the coordinator) and remote (the EMS) control units that allowed to separate the development of the algorithms from the actuation, this approach also enabled to develop control strategies which consider more than one charging point (as mentioned by the smart charging Scenario 1)

Looking in detail the smart charging algorithms proposed by RouteMonkey were applied to the Madeira pilot from the period between **April of 2021** to **September 2021.** During this period more than 17084 smart charging events happened, which average at approximately 2800 events or 711 hours of smart charging per charging station. In the scope of this evaluation a smart charging event is an instance of at least 15 minutes in which the charging duty is exactly the output of the smart charging algorithm. Smart charging events which were not actuated (when the smart charging toggle was set to Normal) were ignored in this evaluation.

Looking into detail, it is also important to consider the events that unequivocally had an effect in the charging, since in certain situations the system could receive a schedule from the algorithm that could not be forced (for example if the battery of the vehicle was already full), considering those cases there were 6351 charging events, which average at 1058 events or 264 hours of smart charging hours per charging point. These were situations in which the charging was 100% controlled by the algorithm. Figure 39 presents a common situation in which the smart charging influenced the charging load of a vehicle at charging point 6. In this situation after a small period in which the vehicle was charging at 100% of the duty cycle, most of the charging happened at 20%, there was also a period of approximately 50% before the end of the charging

Figure 39: Daily load for charging point 6. The smart charging command is visible between 9 and 12:00 aproximattely

3.5.2 Challenges

There were two main challenges faced during the development and evaluation part of the **Electric Vehicles are Our Future** pilot, the technical challenges associated with the development of an innovative solution, and operational challenges related to the integration of smart charging in an office building. Given the innovative nature of this pilot, it crucial to present those challenges in detail so that the lessons learned can influence future pilots in the same setting.

3.5.2.1 Technical challenges

Certain technical challenges were encountered during the development of the CCM, this device encompasses some complexity, which resulted in certain errors in configuration, setup and even malfunction hardware. Those issues were solved by visits at site. None of those issues ever affected the vehicle, in those situations the charging was reverted to regular wall boxes at the garage. There were 852 instances of faulty events detected by CCM, which equate to approximately 35h of down time per charging point caused by errors (not all these events required a visit, in certain situation the CCM could autonomously solve the issue). It is also important to note that not all errors were caught by the CCM.
The more common technical issue at the garage was the unreliable internet connection. Even though the local partners invested into a new local network provided by a local ISP, issues would still happen, that could leave certain charging stations offline. For example, if the garage was full, it was tougher to get the signal to the more distant charging points. In those situations, the charger would default to Normal charging mode.

3.5.2.2 Operational challenges

During the execution of a smart charging pilot in the real world, operational challenges are, of course expected to emerge, mainly when considering a region and targeted individuals which never had contact with such technologies. Moreover, charging stations are still new technology and issues are still common even in commercial products as an example a study from J.D. Power revealed that “The two most-often-cited problems of EVs and Plug-In-Hybrid’s owners have when visiting a charging station and being unable to power up are: the charger was out of service (58%), and no charger available/too long to wait (14%)”[19].

In the **Electric Vehicles are Our Future** pilot, those challenges were related to the different approaches of using the vehicles in a working context.
Firstly, the obstacle was making sure the developed prototype was accepted by its intended users, and after addressing initial installation and setup hurdles, the hardware installed by SMILE was functioning reliable and without issues.
Another aspect emerged once the chargers started to be used more frequently, and it was related to the output of the algorithm. Actually, before the implementation of SMILE, the vehicles were charged using the plug-and-charge paradigm, in which the vehicle charges at maximum possible duty until it reaches 100% SoC, or it is unplugged. This meant that before the smart charging, all the vehicles left EEM at the end of the day with their battery at 100% SoC. Once the smart charging intervention started there were situations in which the SoC was between 90 and 97% at the end of the day, in this context as the pilot was not moved by financial motivation, EEM requested to implement the ad-hoc measure of disabling the smart charging on Fridays, so that all the cars would leave for the weekend with a full SoC. Other concerns happened when vehicles that were plugged-in the middle of the day and were not reaching an acceptable SoC at the end of the day, or vehicles that for some unexpected reason needed to leave the offices during the working day. These situations were of course expected since the smart charging was controlling the load according to the weather and renewable availability forecast and was not considering such unpredictable events. In fact, the smart charging was performing exactly as expected and defined at 2.3.6.2.

3.6 Discussion

The discussion of the pilots' results will focus in three main aspects, the technical solution, the smart charging and the smart charging scenario proposed during the evaluation. The following sub section go deeper into these issues.

3.6.1 Technical solution

Regarding the control of the charging, which is the main focus of this pilot, we understand that the developed solution, which allows the control of the duty cycle, went beyond the approach proposed at D4.2[2]. This decision resulted in a more complex solution, which eventually delayed the installation. The followed approach needed a lot a fabrication at PRSMA and M-ITI, and several components had to be sourced from suppliers scattered around the world, which increased the time needed to complete the prototypes.
During the installation, it was decided to add a web visualization for EEM garage. This requirement goes beyond the initial pilot objectives, and it allowed us to evaluate the human impact of the intervention not only in the scope of the driver but also in the scope of a manager or supervisor of a fleet of EVs.

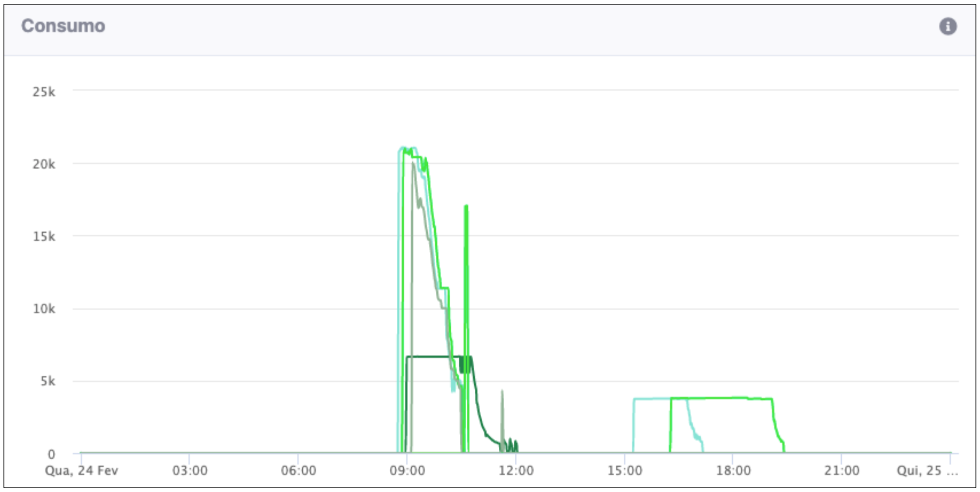

Figure 40: Sample Day with unusual high energy consumption from the charging at EEM

After a testing period the deployed chargers fulfilled their goal of providing easy to install smart charging, which was capable of a fine control into the vehicles load. Furthermore, the developed solution divided the actuation, coordination, visualization, and algorithms components into different modules which could be worked independently, or even outsourced to companies which are expert in any of the fields. Incidentally, that was exactly what happen at the **Electric Vehicles are Our Future** pilot, were Route Monkey developed the algorithms and suggested charging schedules without needing to worry about the specifications of the site, and with minimal integration costs. Another issue that is important to consider is related to the network connection to the chargers, when updating older buildings with smart chargers is crucial to consider how to connect the chargers to the internet. Often older buildings present unexpected challenges, like for example lack of space to pass ethernet cables or poor WiFi connection due to the layout of the building, our experience in the pilot showed us that those issues are important and can affect the adoption of smart charging.

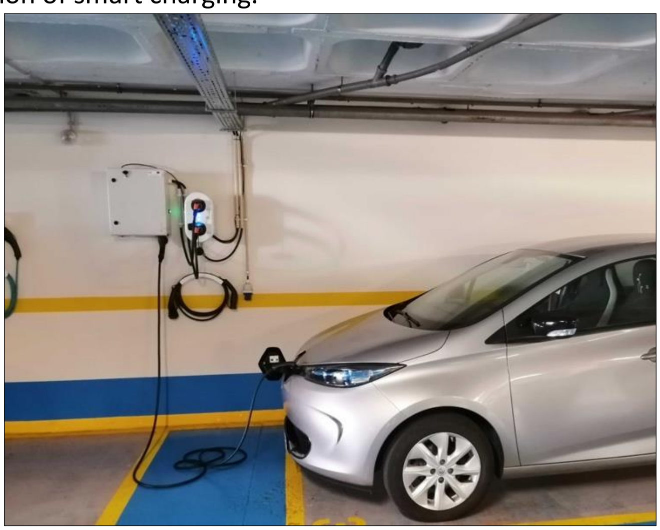

Figure 41: Vehicle charging at EEM garage. The CCM bypasses the load from the wall box before it reaches the vehicle

3.6.2 Smart Charging

The pilot was able to implement smart charging, and as presented at the evaluation section there were several instances in which the vehicle charging was completely controlled by the output of the smart charging algorithm from Route Monkey. The hardware agnostic solution meant that Route Monkey never had to deal with issues related to the chargers or vehicles protocol. It acquired data and actuated into the chargers just by interacting with the EMS.

At the start of the project, EEM had without a doubt the biggest, and only, EV fleet of that size at Madeira, furthermore as a partner in the project, it was possible to have easy access to their installations to test the project solutions, for example, during the project, 3 different monitoring equipment at the garage (EmonTx, Energy analyser and the CCM) were installed. EEM was without a doubt the best site to deploy the first smart charging pilot at Madeira. The interventions encountered some challenges related to the adoption of the smart charging, as the first smart charging pilot at Madeira those issues were expected. Notwithstanding, the algorithms were able to control the loads based on the renewables, while still maintaining the service, which only slightly reduced the vehicles' SoC available at the end of the day, while it is true that, as discussed before, it caused request to halt the smart charging on Fridays, it is important to consider the user sample not familiar with smart charging. This way the intervention can be considered as a fitting implementation of smart charging. It is also important to discuss the observations from EEM, which currently does not have a financial motivation for smart charging.

Yet, the scenario of an office building will always be hard to model, especially if the vehicles do not have a predictable charging pattern. Future interventions in such scenarios should consider not only the technical aspects (having chargers capable of a fine control of the load) but also the needs of the drivers and business, for example knowing when a vehicle will be needed and at what SoC of the battery, or even prioritise chargers/vehicles. Such approaches are only possible by using the drivers/managers as inputs for the smart control, and with the fine level of control developed in the pilot.

3.6.3 Smart charging scenario

The last point it is important to discuss is related to the proposed smart charging scenarios proposed at the start of the pilot (see section 3.4.2). Route Monkey's algorithm followed scenario 3. However, the results show that when considering shared garages, **scenario 1** could represent a crucial improvement, mainly considering older installations. Often the garages of office buildings or apartments are connected to a shared grid responsible for a small number of services such as elevators and shared lighting. If one tenant decides to install a charger, he/she would have 2 options, to pass a cable from its own electric installation, or to connect to the shared grid. The second approach is more common and simpler, however like it is mentioned at **scenario 1,** if a certain number of vehicles charge simultaneously the aggregated load could be impossible to meet by the local grid. This was confirmed during the pilot, at several periods the charging was demanding more than 60kW of power (see Figure 40), which would arguably be impossible at any other site not prepared for smart charging (which is the case of most office and apartment buildings). Withal it is safe to conclude that the Electric **Vehicles are Our Future** pilot confirmed this opportunity and need for smart charging.

4 Conclusions

In this chapter, an overview of the Installation and evaluation for the smart charging pilots in the Madeira demonstrator is provided. Firstly, a summary of the tasks targeted in this evaluation report is presented. And finally, the future steps and opportunities for smart charging are presented.

4.1 Project Tasks

As defined in the Grant Agreement, this deliverable mostly reports actions related to Task **4.7** and **4.8**. Below a summary is presented which portrays the development and evaluation of each task related to the infrastructure development and installation report for the **Getting Started with EVs and Smart Charging** and **Electric Vehicles are Our Future** pilots:

- **Task 4.6 Case Study Specification and Assessment of EV with smart charging:** The specifications for the case studies for the EVs pilots were defined with RouteMonkey supporting all the local partners (EEM, PRSMA and ACIF). It was decided to advance with 2 pilots which were the first ever smart charging interventions in Madeira Island.
- **Task 4.7 Kick-off the Madeira pilot for EV with smart charging**: The smart charging intervention has started for the **Getting Started with EVs and Smart Charging** pilot, as Route Monkey pushed the first charging commands in February 2020. After the interruption in activities at TuxkiTours caused by the Covid-19 pandemic, a contingency plan was specified and implemented. The **Electric Vehicles are Our Future** intervention lasted from April to September 2021. All the technical goals were achieved.
- **Task 4.8 Evaluation of EV and smart charging:** This task was finalized for both the EV pilots. Technically the evaluation returned the expected results, both the hardware, communication, integration, and execution requirements were successfully implemented. The pilot also demonstrated how smart charging could be implemented in such sites without the need to change the sites' installation, retrofitting in regular chargers or plugs. Additionally, during the pilot Route Monkey's algorithms were successfully applied in both pilots, without significantly affecting the charging service. Yet, the innovative aspect of the pilot disclosed specific challenges that should be considered for future EV interventions. To finalize, the **Getting Started with EVs and Smart Charging** pilot resulted in the Simulator an open source and modular platform for EV and smart charging simulations, which emerged from the contingency plan and COVID-19 restriction, as another output from SMILE.

4.2 Challenges

When considering the whole installation and infrastructure development for the smart charging pilot, there have been several challenges that had to be addressed. In this context, it is worth to mention the provision of the needed equipment, and getting it delivered to Madeira Island. This was especially true for the equipment in **Electric Vehicles are Our Future** since the market for specific equipment, such as the untethered type 2 sockets, is still small. Another challenge was the new approach for using electric vehicles in the pilot, which altered the traditional plug-and-charge paradigm. Altogether the pilot allowed to study the adoption of smart charging and it pointed opportunities for next steps in smart charging research.

4.3 Future Opportunities

One of the requirements from **Getting Started with EVs and Smart Charging** and **Electric Vehicles are Our Future** pilots was the ease of integration with Route Monkey's algorithms: with that goal PRSMA and M-ITI developed an infrastructure that was able to separate the decision from the sensing and actuation. This outcome can provide business opportunities for companies that work at any end of the problem. Furthermore, the Simulator resulting from the **Getting Started with EVs and Smart Charging** pilot can provide new opportunities for research into smart charging, facilitating the evaluation of algorithms for the different aspects of the problem.

The pilot at EEM garage confirmed one of the aspects similar sites could face in the near future once the EV adoption reaches apartments buildings in force: actually, the results from the pilot confirm the need for coordinated smart charging at such sites, without the need for expensive renovation interventions.

To finalize, even considering the challenges encountered, the final outcome is clearly positive. During SMILE two different smart-charging pilots were deployed, affecting more than 20 vehicles and 25 drivers in total. The local team developed smart-charging solutions from scratch taking into consideration the state of the art in the field. Before SMILE there was no smart-charging in the Island, during the project the acquired know-how allowed to identify future scenarios for smart-charging in the island that consider the limitations of the older buildings or the plentiful solar energy.

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