Available online at www.sciencedirect.com
ScienceDirect
Energy Reports 9 (2023) 216–234
www.elsevier.com/locate/egyr

TMREES23-Fr, EURACA 06–08 February 2023, Metz-Grand Est, France

Public charging infrastructure for EVs: A comprehensive analysis of charging patterns & real-world insights—Case study of Rabat City, Morocco

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Received 19 May 2023; accepted 29 May 2023
Available online 9 June 2023

Abstract

The introduction of electric vehicles (EVs) will contribute to decarbonizing our cities and make them more sustainable, which will help mitigate climate change. To ensure a successful transition to e-mobility, charging infrastructure development is considered an essential pillar. This paper presents a comprehensive analysis of electric vehicle supply equipment (EVSE) usage. It aims to understand charging patterns in urban environments and retrieve some real-world insights. By collecting a 2-years historical dataset (from 2019 to 2021) of a public EVSE based in Rabat, the methodology presented in this study covers time evolution assessment, energy delivery analysis, and users' behavior characterization. The analysis of about 2835 events showed that the average energy delivery is 12 kWh corresponding to an average charging duration of 48 min. Also, more than 95% of charging sessions consumed less than 25 kWh, which corresponds on average to 60km. The performed analyses resulted in various findings that led to a set of recommendations that could be insightful for different types of stakeholders (policymakers, grid operators, charging operators, EV drivers, etc.). Furthermore, the methodology followed in this work is reproducible and may be used as a reference for other EVSE usage analyses.

Peer-review under responsibility of the scientific committee of the TMREES23-Fr, EURACA, 2023.

Keywords: Sustainability; Decarbonization; E-mobility; EV; Charging infrastructure; EVSE; Urban environment

1. Introduction

With 7.7 GT/year of CO2 eq emissions, the global transport sector is responsible for 23% of emissions from fossil fuel combustion and 18% of all human greenhouse gas emissions (GHG) [1]. By 2050, passenger transport is

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https://doi.org/10.1016/j.egyr.2023.05.259
2352-4847/
Peer-review under responsibility of the scientific committee of the TMREES23-Fr, EURACA, 2023.

Acronyms

GHG	Greenhouse gas
IEA	International Energy Agency
ICE	Internal combustion engine
NDCs	Nationally Determined Contributions
EVSE	Electric Vehicle Supply Equipment
OCPP	Open Charge Point Protocol
BEV	Battery Electric Vehicles
HEV	Hybrid Electric vehicles
PHEV	Plug-in hybrid electric vehicle
FCEV	Fuel cell electric vehicles
CMS	Centralized management system
DERMS	Distributed energy resource management system
DR	Demand Response
IRESEN	Research Institute for Solar Energy and New Energies
ADM	Autoroute du Maroc
AMEE	Moroccan Agency for Energy Efficiency.
ONEE	National Office of Electricity
AFI	Alternative Fuel Infrastructure Directive
LMS	Load management system
UN	United Nations
V2G	Vehicle-To-Grid

estimated to be more than double and freight transport to triple [2]. This increase in activity will lead to a significant increase in emissions of up to 15 GT/year. In the Paris Agreement, countries committed to limiting global warming to 1.5 to 2 °C by 2050. To achieve this target, global transport must reduce its CO2 emissions by 3 GT/year [3].

Countries worldwide have put in place different strategies to reduce pollution and climate change. At the international level, different protocols and agreements have been concluded to define the responsibilities of all countries in this fight, such as the Kyoto Protocol, the Montreal Protocol, and the Paris Agreement [4,5]. Moreover, European Union's Green Deal program aims to reduce GHG emissions in Europe to zero by 2050 [6]. The 2030 Agenda includes themes that UN member states must put in place by 2030 regarding climate change [7].

Several studies have been conducted in recent years on new technologies and applications to reduce pollution due to the transport sector. These are usually referred to as Sustainable Transportation Practices. One of the most important applications is electric vehicles (EVs) [8]. The deployment of EVs will make an impactful contribution to the decarbonization process, considered an important step in the fight against climate change [6]. By 2030, according to the IEA (2020), the global EV fleet will have reduced GHG emissions by more than 1/3 compared to an equivalent internal combustion engine (ICE) fleet in the Stated Policy Scenario (STEPS) and by 2/3 in the Sustainable Development Scenario (SDS) [9].

In 2020, there were approximately 10 million electric cars on the world's roads after a decade of rapid growth [9]. EVs are advantageous in terms of environmental and noise pollution. However, they also have some drawbacks related mainly to the range, charging time, and the lack of infrastructure [10]. Therefore, R&D, as well as policy, must focus on battery technology development and charging infrastructure expansion to ensure a successful transition to e-mobility [11].

Publicly available chargers reached globally 1.3 million units in 2020, of which 30% were fast chargers [9]. By 2030, it is estimated that there will be 14 to 20 million slow public chargers (corresponding to an installed capacity of 100 to 150 GW) and 2.3 to 4 million fast public chargers (205 to 360 GW) [9].

In Morocco, the transport sector is responsible for 18.2 Mt of CO2 eq per year, representing 16% of total emissions and 28% of the country's energy sector emissions [1]. With the development of economic activities and the increasing use of vehicles, the country expects an increase in energy consumption and emissions of up to 350% by 2040 [12]. According to the NDCs (Nationally Determined Contributions), transport will have to contribute with 9.5% of the total reductions required between 2020 and 2030, corresponding to 50 Mt of CO2 eq [13]. The motivation for e-mobility in Morocco is therefore based on environmental, economic, and even political interests in order to limit energy dependency and reduce CO2 emissions.

The different Moroccan stakeholders are conscious that the acceleration of the transition toward e-mobility will rely mostly on the development of a charging station network adapted to different types of vehicles and an electric grid able to assume this growing demand. Therefore, several public and private projects are planned to expand the charging infrastructure with hundreds of slow and fast chargers.

Many studies analyzed electric vehicle supply equipment in specific locations. S. Hovet et al. introduced a case study of an Electric Vehicle Charging Station at the University of Georgia [14]. M. S. Athulya et al. studied a charging station scheduling in a shopping mall [15]. Guangyou Zhou et al. developed a model to optimize the location of an Electric Vehicle Charging Station [16].

Additionally, more studies focused on the large segmentation of charging stations. R. PAL et al. introduced a comprehensive study and analysis of Electric Vehicle Charging Stations in an urban area [17]. Felix Schulz and al. encountered areas where the first public charging stations were installed and based their results on annual information of the EVSE [18]. Hardinghaus et al. studied the use of the charging infrastructures in the city of Berlin [19]. Albert Y. S. Lam et al. claimed the importance of the location of the charging station and studied the EV charging station placement problem [20].

This paper is intended to understand charging patterns in urban environments, particularly in a shopping center, retrieve some real-world insights and give some recommendations. By analyzing historical data of the most used public Electric Vehicle Supply Equipment (EVSE) in the capital of Morocco (Rabat city), the study's findings are supposed to reinforce data availability and visibility in Morocco regarding EV charging, as well as give insights for future charging infrastructure projects' planning.

Additionally, the proposed methodology is the first of its kind in Morocco and utilizes ground data to retrieve some general findings and recommendations. The results of this study are mainly addressed to sensibilize the concerned Moroccan stakeholders on EVSE and they are reproducible and may be used as a reference for EVSE analysis in Morocco.

The manuscript is structured as follows. Section 2 determines the scope of the study and provides the methodology followed in the analysis part. Section 3 defines some key concepts related to EV charging fields, i.e., technology, methods, and standards. Section 4 summarizes the current and expected situation of EV and charging infrastructure in Morocco. Section 5 is dedicated to historical charging data analysis regarding various criteria (time evolution, energy consumption, and behavioral aspect), as well as the results' interpretation. Based on the findings, Sections 6 and 7 will give, respectively, some global recommendations and conclusions.

2. Methodology

Located at the parking of Marjane (a hypermarket chain in Morocco) in Rabat, the studied EVSE has been deployed since July 2019. It is supplied by a solar shade consisting of a grid-connected PV system of 14 kWp equipped with a 20-kWh battery energy storage system (Fig. 1). Note that the solar shade contains two charging stations. However, the scope of this study will be limited only to one station (7–22 kW), as the second one (7 kW) was not operational during the covered period [21].

The studied EVSE comprises two charging points and supports one-phase and three-phase supply. For charging access, EV owners can either use RFID cards or scan QR codes. Regarding data communication, the EVSE is equipped with a 4G modem and supports OCPP 1.6 protocol. The EVSE records and communicates charging events data to a central server, such as station ID, user ID, transaction ID, charging start-time, charging end-time, transferred energy, charging duration, charging type, etc. [22].

This study will cover a two-year dataset, starting from July 2019 to July 2021. The period July-19 to July-20 will be referred to as "Year 1", while the period July-20 to July-21 as "Year 2". Before addressing the data analysis, the collected data has been preprocessed and cleaned in order to obtain a relevant dataset, including temporal and energy information. This first step consisted of removing non-relevant data such as very short events and charging operations with zero transferred energy. Regarding the information that can be retrieved from the historical data, three types of analysis will be performed in this study:

Fig. 1. Charging stations of Rabat Marjane's parking.

• **Time-based analysis:** will deal with analyzing the yearly and monthly use of the charging station. Accordingly, this analysis will help assess the monthly variations and the yearly evolution of the EVSE's use.

• **Energy-based analysis:** this analysis will focus on energy information during charging events such as energy delivery by time and duration, the average amount of delivered energy, monthly variations, yearly evolution, etc. Consequently, this analysis will allow for identifying users' energy needs, the average power/current demand as well as the shape of the load curve.

• **Behavior-based analysis:** as mentioned, each charging session corresponds to a start time and an end time. This analysis will evaluate and compare users' occupancy and charging patterns over various time scales (e.g: charging times over a day, weekdays Vs. weekend days, office Vs. non-office hours).

The above-described analyses will allow, respectively, to (i) assess the monthly variations and the yearly evolution regarding the EVSE's use; (ii) identify users' energy needs, the average power/current demand as well as shaping the load curve; (iii) characterize the users' behavior and occupancy patterns. Such findings and metrics could be helpful for predicting charging patterns, designing efficient energy management strategies, as well as the upcoming charging infrastructure, among others.

It should be mentioned that, in Morocco, public EV charging is still free up to date. Consequently, all charging sessions performed in the studied period were free. Additionally, there were generally no constraints applicable on the charging duration, nor on the plug-in time (the charging station is available 24/24 all week and weekend days).

3. EV charging: Technology, methods & Standards

Electric vehicles (EVs) can be charged in different ways, depending on the location and energy needs. As a result, charging infrastructure for EVs comes in different types and is designed for different applications. The specifications and standards for EV chargers, also known as electric vehicle supply equipment (EVSE), vary from country to country, depending on the EV models available on the market and the characteristics of the electricity grid [23]. In this section, the technical concepts linked to EVSE will be explained.

3.1. EV technology

There exist different types of electrified vehicles (Fig. 2) [24]:

• Battery electric vehicles (BEVs) are all-electric vehicles, meaning that the electric motor is powered solely by electricity from a battery that must be recharged by connecting it to a charger.

• Hybrid electric vehicles (HEVs) have two complementary propulsion systems: a combustion engine with a fuel tank and an electric motor with a battery. HEVs cannot be recharged from the electrical grid and use the combustion engine as the primary power source.

• Plug-in hybrid electric vehicles (PHEVs) have, like HEVs, a combustion engine assisted by an electric motor with a battery. This battery can be recharged from the electricity grid when the vehicle is parked. Because PHEVs can use both gasoline and electricity, these vehicles have a greater range compared to BEVs.

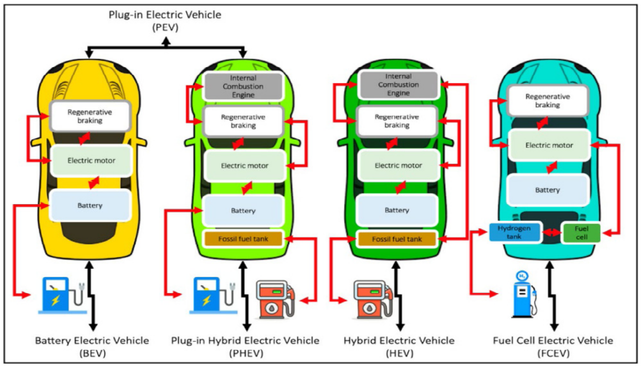


Fig. 2. Types of electrified vehicles.

• Fuel cell electric vehicles (FCEVs) use hydrogen as a fuel in combination with fuel cells to generate electricity for the electric motor. Since hydrogen is lighter than batteries, fuel cell technology may hold promise for large vehicles such as buses and trucks.

3.2. EV charging technology

3.2.1. Electrical vehicle supply equipment

Electric Vehicle Supply Equipment (EVSE) is the basic unit of charging infrastructure for EVs. The EVSE draws electricity from the local power grid and uses a control system and cable connection to safely charge electric vehicles. An EVSE control system enables various functions such as user authentication, charging authorization, registration and information exchange for grid management, and data protection and security [25].

It is recommended that EVSEs should be used for all charging purposes with at least basic control and management functions. Conductive charging or wired charging is the most used charging technology. EVSE requirements for conductive charging depend on many factors such as vehicle type, battery capacity, charging method, and power rating [25].

3.2.2. Battery specifications of various EV segments

EV charging depends directly on the specifications of the EV batteries, as energy must be supplied to the battery at the correct voltage and current levels to enable charging. Table 1 gives typical EV battery capacities and voltages for different EV segments.

Table 1. Battery specifications by vehicle type.

Vehicle type	Battery capacity (kWh)	Battery voltage (V)
Electric two-wheelers	1.2–3.3 kWh	48–72 V
Electric three-wheelers	3.6–8 kWh	48–60 V
E-cars (1st generation)	21 kWh	72 V
E-cars (2nd generation)	30–80 kWh	350–500 V

Two-wheelers and three-wheelers are powered by low-voltage batteries. The first generation of electric cars is also powered by LV batteries. However, it is likely that these will be phased out in the future, although they continue to be used in specific cases such as taxis. The second generation of electric cars, as seen in future electric car models, is powered by HV batteries [25].

3.2.3. Charging methods, standards, and power ratings

EV charging implies supplying the battery with a direct current (DC). Since power distribution systems supply alternating current (AC), an inverter is consequently required to convert DC to AC power. Based on the current type, conductive charging can be AC or DC. In an AC EVSE, AC power is supplied to the electric vehicle's onboard charger, which converts it to DC. On the other hand, a DC EVSE converts the current externally and feeds the direct current directly into the battery without the detour via the onboard charger.

AC and DC charging is then divided into four charging modes, with modes 1 to 3 making part of AC charging and mode 4 representing DC charging. Modes 1 and 2 involve plugging an EV into a standard outlet using a cord and plug. Mode 1, also known as silent charging, does not allow communication between the EV and the EVSE and is not recommended.

The portable cable used in mode 2 has a built-in protection and control function and is typically used for home charging. Modes 3 and 4, which provide for a separate charger to power the EV, have enhanced control systems, and are used for commercial or public charging (Fig. 3) [25]. Table 2 gives a classification of charging types with corresponding power levels and compatible EVs.

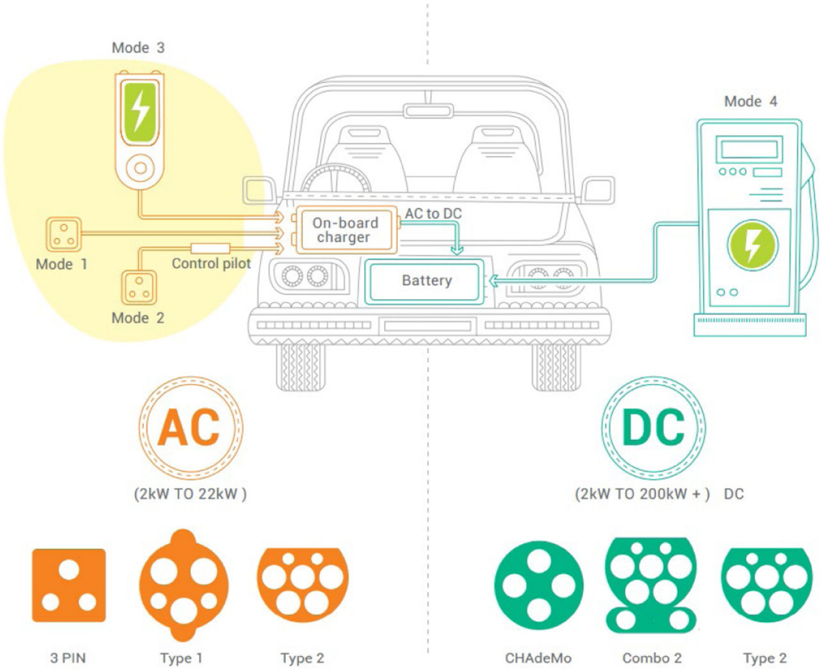


Fig. 3. Charging types and standards.

Table 2. Charging power types vs. corresponding power levels.

Charging type	Power level	Current type	Compatible EVs
Normal power charging	$P \leq 7$ kW	AC & DC	E2W, E3W, e-cars, commercial EV
	$7 \text{ kW} \leq P \leq 22$ kW	AC & DC	
High power charging	$22 \text{ kW} \leq P \leq 50$ kW	DC	e-cars, commercial EVs, buses, trucks
	$50 \text{ kW} \leq P \leq 200$ kW	DC	

Large-scale smart charging requires a unified communication architecture to enable interactions between the different layers of the system, i.e., between EVSEs and charging networks; between different charging networks; and between the centralized management system (CMS) and the distributed energy resource management system (DERMS). Table 3 and Fig. 4 give, respectively, some details and a synoptic diagram regarding communication protocols in EV charging.

3.3. Classification of EV charging infrastructure

In general, the EV charging infrastructure governance depends on its ownership and use. Broadly, as shown in Table 4, charging infrastructure for EVs can be classified as public, semi-public, and private [25].

Table 3. Communication protocols in the EV charging field.

Communication type	Protocol	Description	Supported functions
EVSE-CMS (Communication between Charging Stations & Central Management System)	OCPP (Open Charge Point Protocol)	OCPP is an open-source and free standard enabling communication between an EVSE and a CMS. It enables interoperability between different charging devices, software systems, and charging networks, allowing EV owners to use different charging networks.	- Device management, - Transaction processing, - Data security, - Smart charging.
MSP-CPO (Communication between Mobility Service Providers & Charge Point Operators)	OCPI (Open Charge Point Interface)	The OCPI protocol supports the exchange of information between e-mobility service providers (e-MSPs) and charging point operators to enable EV owners to roam automatically between charging networks.	- Charging point information, - Charging authorization, - Tariffication, - Booking, - Roaming, - Smart charging.
CMS-DERMS (Communication between Central Management System & Utility)	OpenADR (Open Automated Demand Response)	OpenADR protocol enables demand response signals between distribution utilities and EV owners. The DERMS platform helps utilities manage their distributed energy resources (DERs), including EVs.	- EV demand management, - Demand Response (DR), - Grid services.

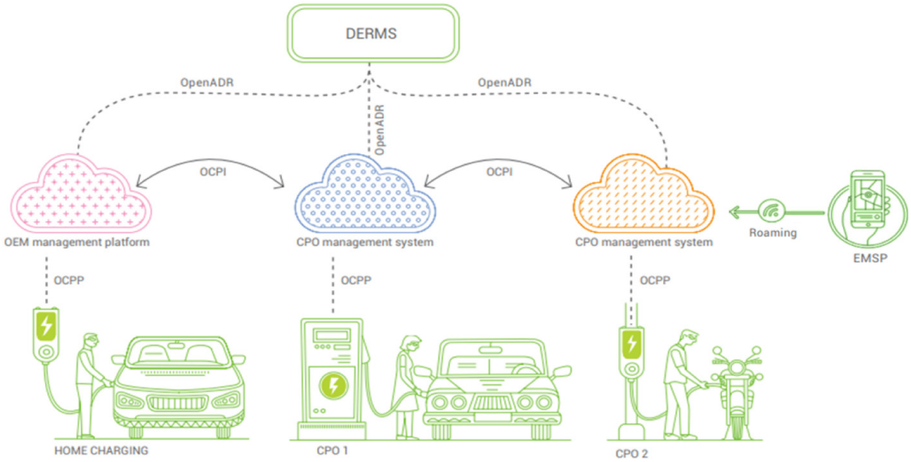


Fig. 4. Synoptic diagram of EV charging communication protocols.

Table 4. EV charging infrastructure classification.

Parameter	Private charging	Semi-public charging	Public charging
Usage	Dedicated to private users and entities	Shared service for restricted EV users	Open for all EV owners and users
Locations	Independent Homes, Private parking lots	Apartment complexes, office campuses, malls, hospitals	Public parking, street parking, petrol stations, highways
Ownership	EV owners, EV fleet owners/operators	Host properties, OEMs & CPOs	Municipal authorities, host properties, CPOs
Operation	Self-operated, or CPO managed	CPO-managed	CPO-managed

3.4. Target-setting for public charging infrastructure

Broadly, public charging infrastructure targets can be based on accessibility considerations or EV charging needs [25].

• **Access-based targets** aim to provide minimum coverage in a city or region and are typically measured in terms of “number of charge points/unit area”. They are most appropriate in the early stages of EV adoption, due to the low demand for EV charging.

• **Demand-based targets:** aim to ensure sufficient public charging infrastructure for a growing number of EVs on the road. They are based on EV penetration rates and mileage covered with EVs. Demand-based targets are useful for a planned extension of the public charging network according to the expected growth of EVs.

4. E-mobility & Charging infrastructure situation in Morocco

4.1. The e-mobility situation in Morocco

4.1.1. Current EV adoption and sales

In recent years, importers in Morocco have expanded their range of vehicles and now offer hybrid and full-electric vehicles, ranging from small city cars to large SUVs and luxury vehicles. Although EV offerings have expanded, sales are relatively low, accounting for only 2% of total vehicle sales in 2021 [26]. One reason for this slow EV uptake is (i) the limited number of public charging stations available to EV drivers and (ii) the relatively high purchase cost compared to traditional vehicles [27]. Also, there are more barriers obstructing the widespread adoption of EVs including:

• The awareness of EVs and their benefits among drivers is still low.

• The support network needed for the maintenance and repair of EVs is largely absent, as well as the local production of spare parts.

• Not all insurance companies cover electric vehicles.

• The impact of EVs on the Moroccan power grid can be a barrier to further adoption.

In 2020, there were about 350 electric vehicles registered in Morocco, while the number of hybrid vehicles was 9000. By vehicle type, there are 160 electric cars, 50 utility EVs, 130 two- and three-wheelers, and 10 e-buses. Nevertheless, electric and hybrid vehicles account for less than 1% of the total number of registered vehicles [28]. In 2022, more than 500 EV, 1200 PHEV and 14000 hydrid non-rechargeable vehicles were registred in Morocco [29].

4.1.2. Expected EV situation

Private and public stakeholders are contributing to creating powerful drivers fueling recent developments of EVs ecosystem and promoting EV uptake. In an optimistic scenario, Morocco could have 425,000 electric vehicles in the kingdom by 2030, which will represent an energy demand of 0.78 TWh [30]. Before this scenario becomes a reality, several barriers to the large-scale adoption of EVs should be overcome [30].

4.2. Charging infrastructure situation in Morocco

4.2.1. Overview of the overall charging infrastructure

The Moroccan charging network consists currently of about 112 charging stations in operation or in planning, many of which are located along the highway between Tangier and Agadir [30]. The other ones are located along national roads, on the outskirts of major cities, gas stations, rest areas, and hotels (Fig. 5).

When it comes to fast charging, five 50 kW fast chargers are located along the road from Marrakech to Casablanca. These fast-charging stations are managed by petrol providers. Most of the regular charging stations operate with a type 2 plug, the fast-charging stations offer CHAdeMO and CCS connections.

In addition, Tesla deployed in September 2021 the first superchargers (up to 150 kW) in the African continent in two Moroccan cities: Casablanca and Tangier (4 chargers per city) [31]. As the law has not yet allowed the selling of electricity by third parties, operators charge indirectly for electricity by billing the use of charging-related services (parking time for instance) [32].

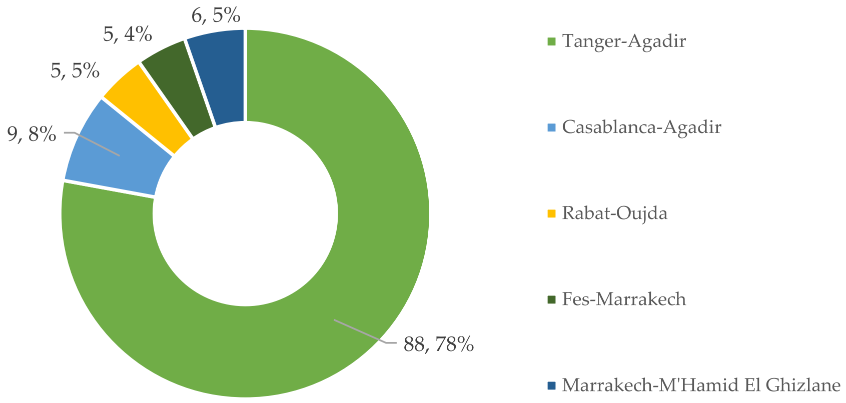


Fig. 5. Division of charging stations along national routes in Morocco.

Fig. 6. Charging network on highways.

4.2.2. Green miles: charging infrastructure on highways

Green Miles (Fig. 6) is a project initiated by the Research Institute for Solar Energy and New Energies (IRESEN) in partnership with Schneider Electric, service stations (Afriquia, Shell, Winxo, Vivo Energy), and Autoroutes Du Maroc (ADM) in 2017 [33]. The project aimed to install charging stations for EVs along the highways. A total of 37 charging stations (7 kW–22 kW) have been installed, covering 800 km of the highway from Tangier to Agadir. To increase the reliability of EVs, a station was installed every 60 km [33].

In addition, the charging stations are equipped with smart meters and communication modules to centralize the data and control the charging process. The monitored data is being processed for research and business purposes, such as charging patterns analysis, opportunity studies, investigation of the impact of initial investments on electric mobility, traffic modeling, etc. To make the project more sustainable, IRESEN aims to introduce solar shades to charging stations, which will improve the decarbonization of electric mobility in Morocco [33].

4.2.3. Planned infrastructure and upcoming projects

IRESEN, Green Energy Park, and the Mohammed VI Polytechnic University, under the auspices of the Ministry of Industry, launched the iSmart charging station plant in 2020. This charging station is the first of its kind produced in Morocco, in the city of Benguerir. The project aims at starting the manufacturing process in 2022 with a capacity of 5000 terminals annually [34].

AFRIMOBILITY, a new CPO and player in the e-mobility sector in Morocco, has deployed on Moroccan highways and cities a charging network branded as FASTVOLT, composed of 22 fast chargers with a rated power of 50 kW for each, as well as 28 AC chargers. By the end of 2024, this CPO is planning to deploy about 220 chargers (80 DC, 140 AC). In addition, some local partners are conducting R&D activities to develop an in-house fast charger (60 kW to 100 kW) for AFRIMOBILITY. Large-scale manufacturing and commercialization are planned for next following years to meet the increasing need present in the national market [35].

On the other hand, IRESEN and AMEE are currently launching a Call for Expressions of Interest for the "Green Miles - Cities" program. This new project is seen as a continuation of the "Green Miles - Highway" program and aims to set up a national network of more than 100 charging stations for EVs in the cities of the Kingdom to strengthen the necessary infrastructure for the transition to low carbon mobility [36].

The EV manufacturer Porsche, as part of the "Destination Charging" program, has announced that it aims to deploy a network of 33 charging stations by the end of 2021, and 100 e-chargers by 2022 in strategic locations and tourist sites across the country [37].

In 2023, the intersectoral professional association for electric mobility (APIME) has announced the deployment planning of 2500 new charging stations for electric vehicles in Morocco by 2026. This infrastructure, which will be distributed in the main Moroccan cities including Casablanca, Tangier and Rabat, will encourage the massive importation of electric cars [38].

5. Charging activities analysis

5.1. Web-based monitoring platform

To ensure a daily monitoring of charging activities and associated KPIs, a web-based dashboard has been implemented by Green Energy Park (Fig. 7). This dashboard displays real-time, historical, and statistical data such as: energy delivery, charging duration, the number of charging events, corresponding mileage, and saved emissions, etc. Such data could be helpful not only from the technical point of view but also for economic opportunities assessment, as well as for decision-making & policy strategies.

5.2. Time-based analysis

Fig. 8 shows that two years of continuous data gathering yielded a total of 2835 charging events, with "Year 2" accounting for 56.11% of all charging sessions. From "Year 1" to "Year 2", there is a clear progression in terms of charging events occurrence corresponding to a 28% increase.

On the other hand, the monthly comparison, given in Fig. 9, shows that the studied time range is marked by three main periods in terms of charging events evolution:

- **Summer–Autumn Transition:** the period July–Sept. 2019 represented the higher number of charging sessions (more than 60% of Year's 1 total sessions). As this period corresponds to the summer season, some possible interpretations could be (i) the presence of more Moroccan residing abroad owning EVs during their stays, and (ii) the higher free time of EV drivers residing in Morocco during the summer holidays. With the start of the Autumn season, a sudden fall of 71% in terms of charging events is observed in the period Sept.–Oct. 2019.
- **Quarantine Period:** March–May 2020 corresponded to the quarantine period due to the Covid-19 crisis. Thus, charging events have recorded the lowest number in May 2020 with a significant decrease of approximately 85%, compared to March 2020.
- **Post-quarantine Period:** the month of June 2020 coincided with the lifting of the quarantine. Consequently, the period May–July 2020 has marked a significant evolution in terms of charging sessions quantified at approximately 90% and remained stagnant in the following months.

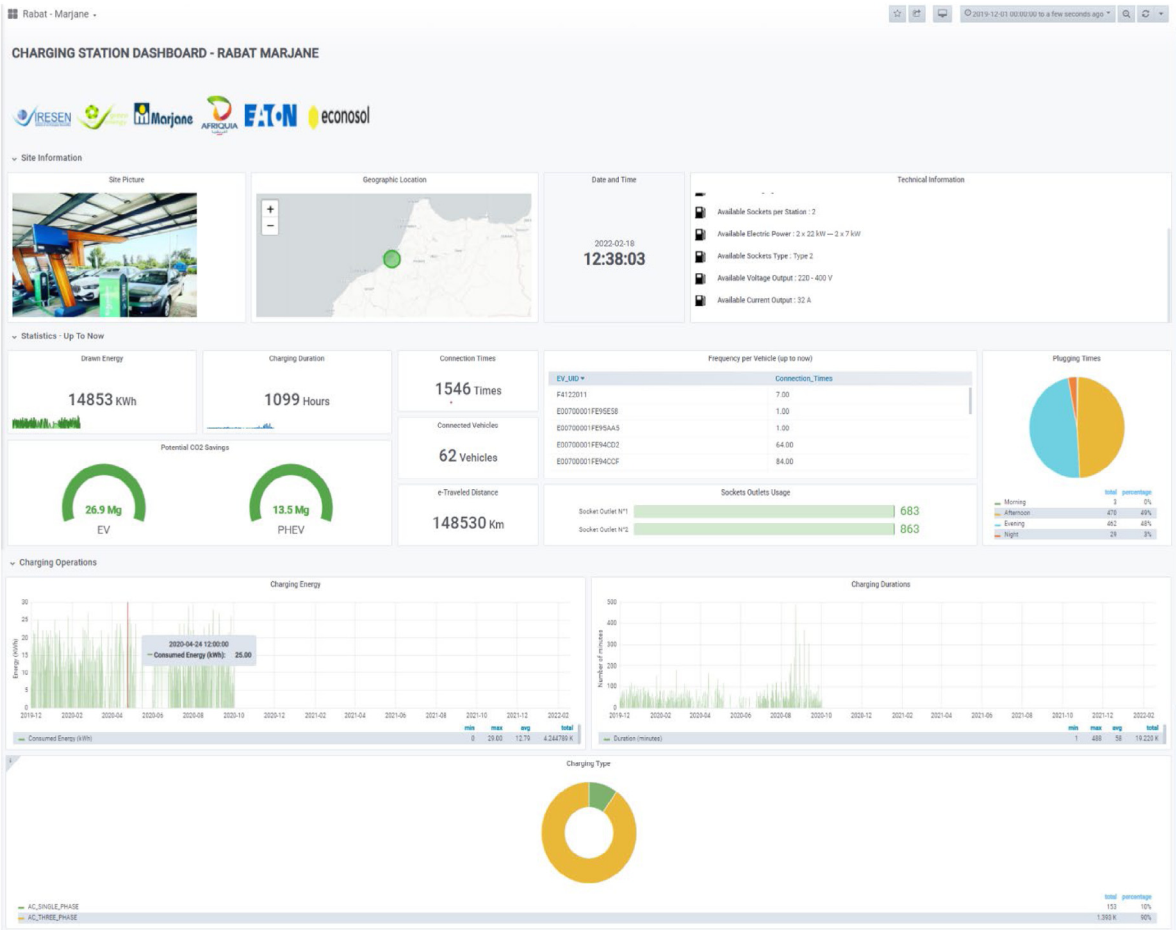


Fig. 7. Charging activities monitoring platform of Rabat Marjane's EVSE.

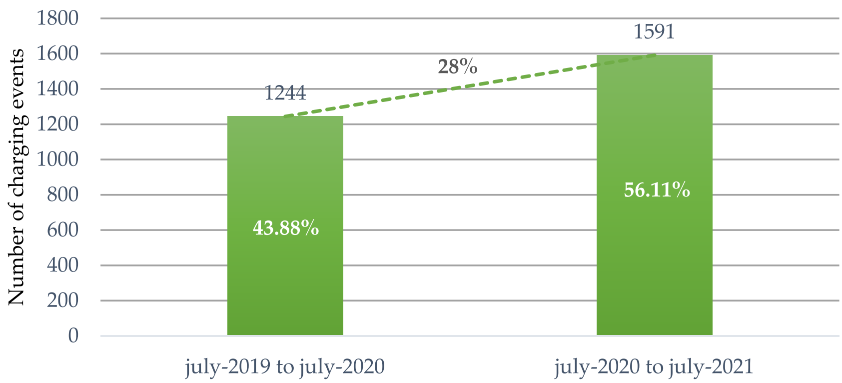


Fig. 8. Total events by year.

5.3. Energy-based analysis

Fig. 10 represents the total energy delivered per year. The amount of energy delivered during the second year reaches 58.84% of the global energy consumed within the two years. This number shows a sort of adequation

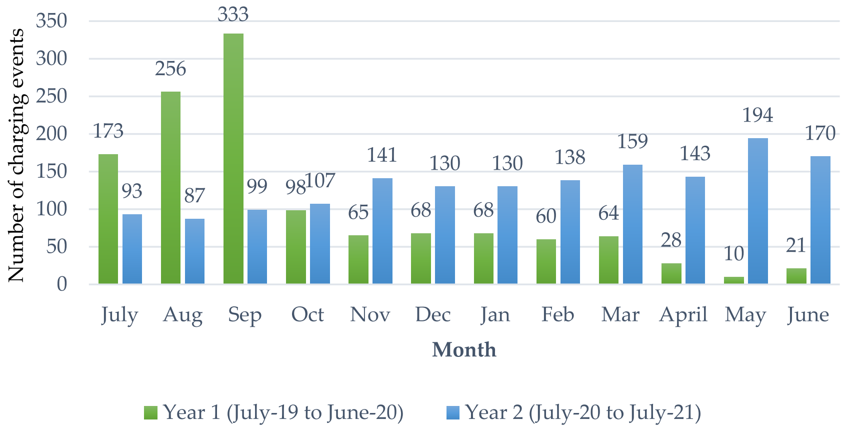


Fig. 9. Monthly comparison of charging events (Year 1 + Year 2).

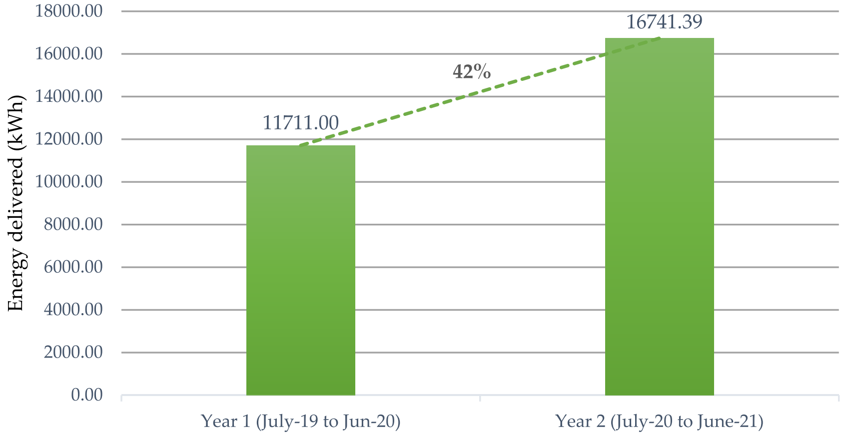


Fig. 10. Total of transferred energy per year.

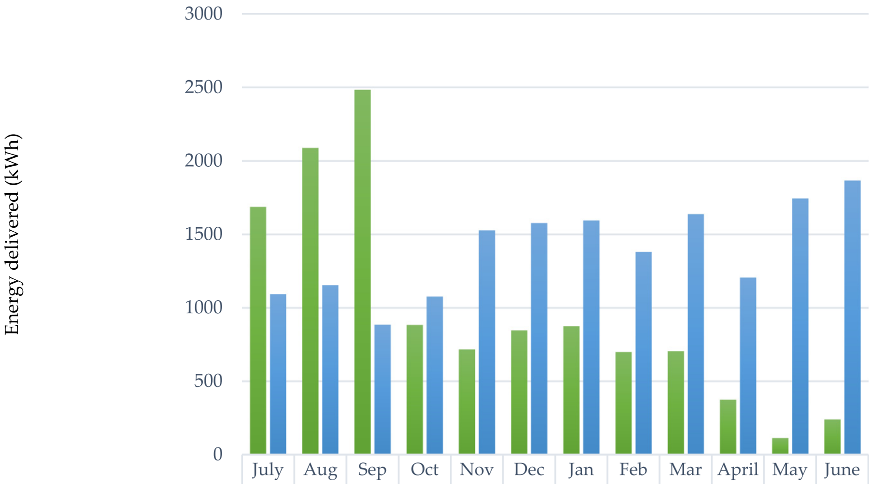
with the percentage of total charging events that occurred in year 2 (56.11%), meaning that charging sessions were done in a regular manner. Meanwhile, a total of 28 452.39 kWh corresponds to 142 261.95 km according to 0.2 kWh/km [39].

Regarding the finding that yearly charging events and energy delivery shares are slightly similar, the monthly comparison chart in Fig. 11 confirms the assumption of uniformity of "charging energy/session" since there is a notable similitude in monthly evolution as well.

The scatter graph in Fig. 12 plots a point cloud representing total charging sessions by their energy delivery. It is observed that almost 96.24% of the charging events consumed less than 25 kWh with an average energy delivery of 12 kWh. A standard deviation of 7.31 corresponds to an energy interval between 5 and 19 kWh, meaning that most charging events consumed energy within this interval. Moreover, the average energy delivery (12 kWh) allows for covering a distance of up to 60 km for a personal car, which exceeds the daily mileage needs, estimated at 25 km per day [40].

Fig. 13 gives a chart corresponding to the energy delivery versus charging duration. As pictured in Fig. 11, it is obvious that charging events data are mostly aggregated in the 25-kWh area. Otherwise, the two straight lines represent the charging power output limits (22 kW as the upper limit and 3 kW as the lower limit). Also, it should be mentioned that the EVSE comprises 220 V sockets. Therefore, the data under the lower power output limit may correspond to two/three-wheelers vehicles.

According to ONEE (the national electricity operator in Morocco) [41], the MV electricity system corresponds to a three-hourly pricing scheme: peak hours, full hours, and off-peak hours. Fig. 14 shows the corresponding tariffs



	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June
Year 1 (July-19 to June-20)	1687	2088	2483	883	717	846	876	699	706	375	114	241
Year 2 (July-20 to July-21)	1093	1155	885	1076	1526	1577	1595	1380	1638	1206	1744	1866

Month

Fig. 11. Monthly comparison of energy delivery.

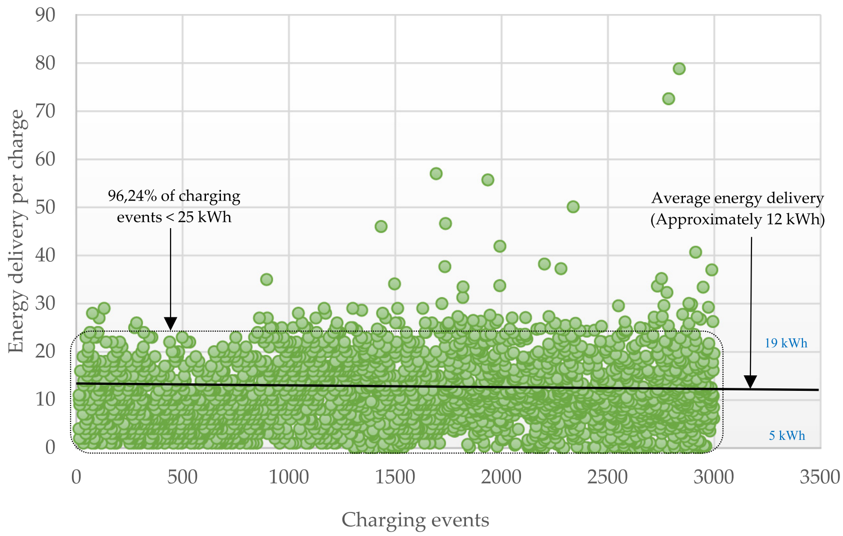


Fig. 12. Energy delivery by charging event.

and time intervals, as well as the hourly distribution of charging energy delivery for the studied period. As can be noticed in Fig. 15, the full hours corresponded to the highest charging energy delivery (57%), followed by peak hours (37%), and finally off-peak hours (6%).

Fig. 16 sums up the previous findings and develops a relationship between three main KPIs: number of charging events, energy delivery, and charging duration. Thus, some other relevant metrics could be extracted: the average energy delivery and the power output range for various charging duration intervals.

It is observed that most of the charging sessions lasted for a duration between 0 and 2 h, while the sessions between 30 min and 1 h have recorded maximum values in terms of energy and number of charging events. It can also be noted that some charging sessions exceeded standard charging durations and reached 6–8 h. By analyzing the associated energy delivery, it turns out that most of these vehicles correspond to low power levels and may probably be electric three/two-wheelers.

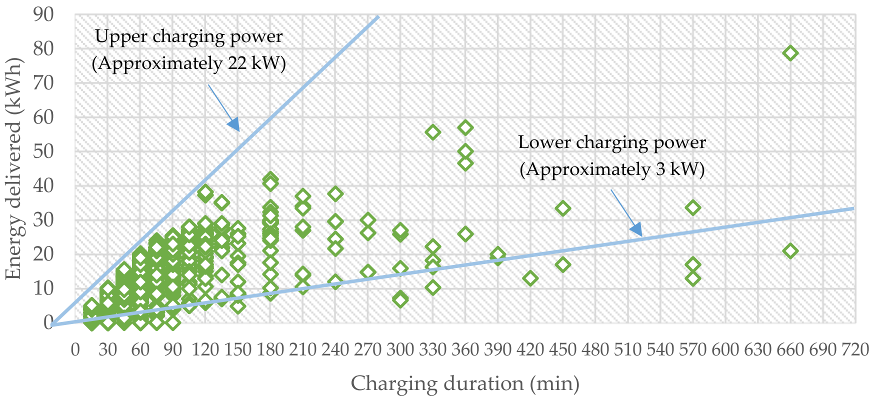


Fig. 13. Energy delivery by charging duration.

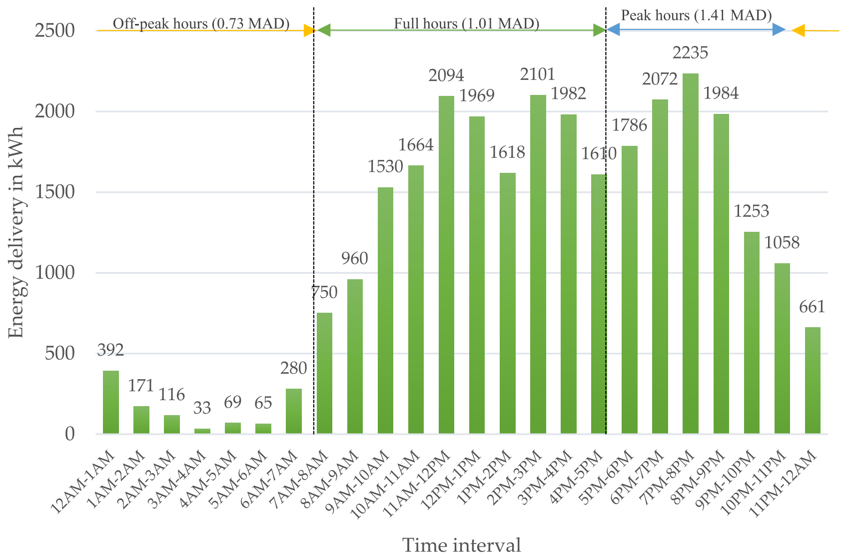


Fig. 14. Energy delivery per time interval.

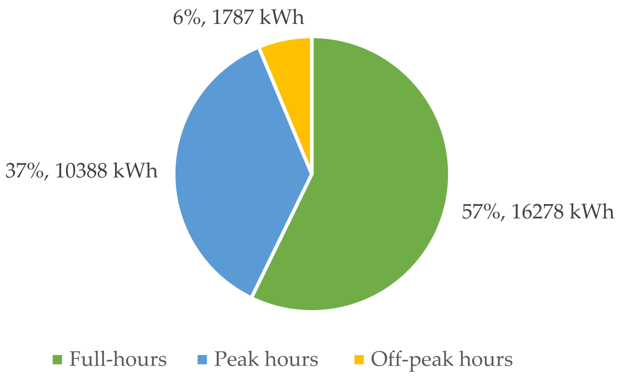


Fig. 15. Energy delivery per tariff time intervals.

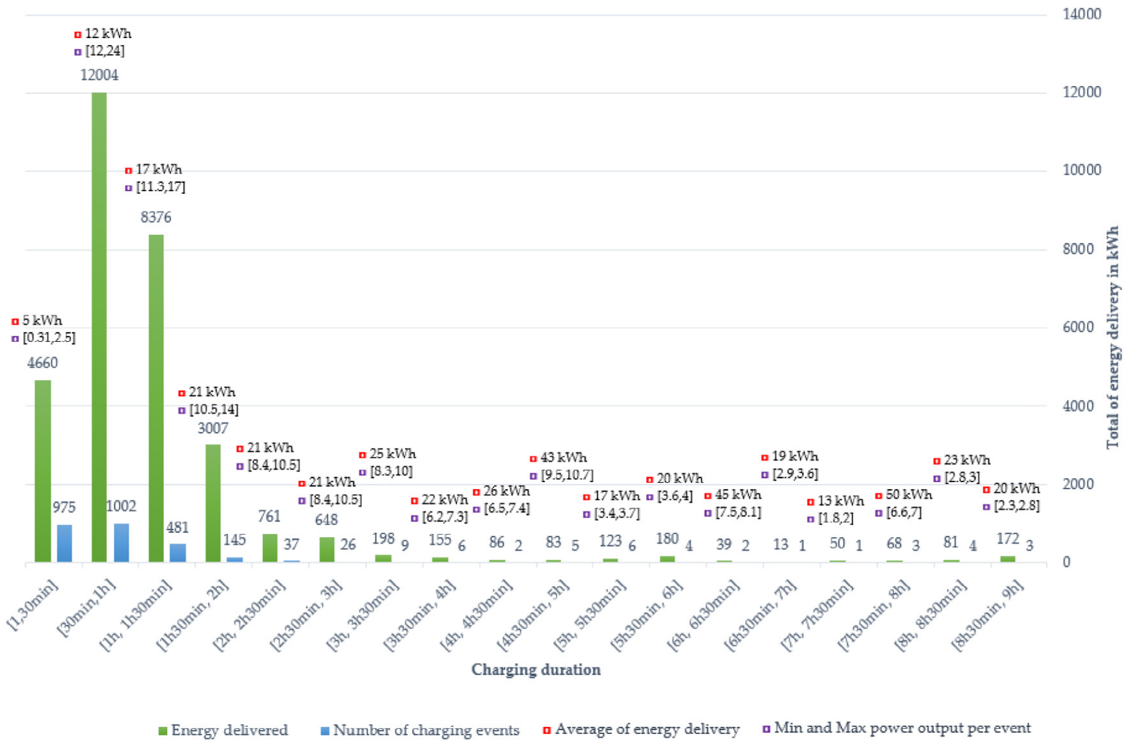


Fig. 16. Energy delivery vs. charging duration.

5.4. Behavior-based analysis

In addition to the average energy need and charging duration parameters, some other metrics such as occupancy may also be useful in understanding and orienting the users' behavior. Such data could be exploited at the service of grid load and parking pressure alleviation by the means of energy management and charging sessions scheduling [42].

The bar chart in Fig. 17 indicates the number of charging events by day of the week. According to the chart, the charging events' distribution over weekdays is slightly uniform, ranging from 378 to 454. Accordingly, more than 70% of charging events happened during weekdays, and approximately 30% during weekends.

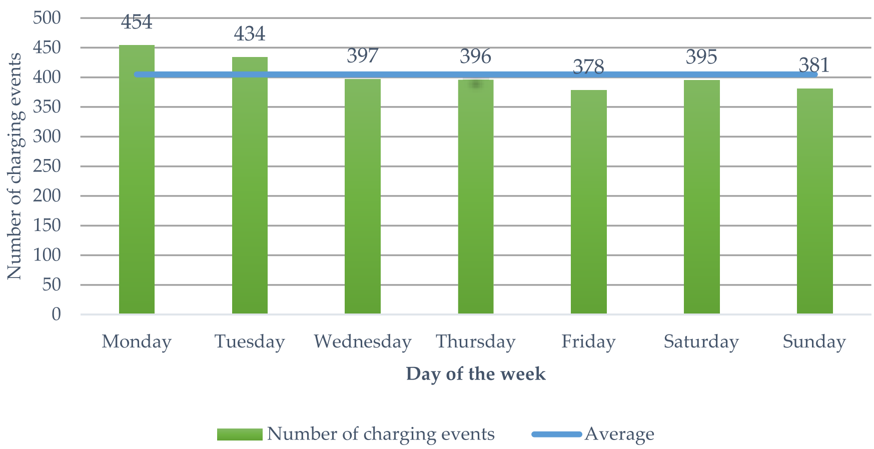


Fig. 17. Number of charging events by weekdays.

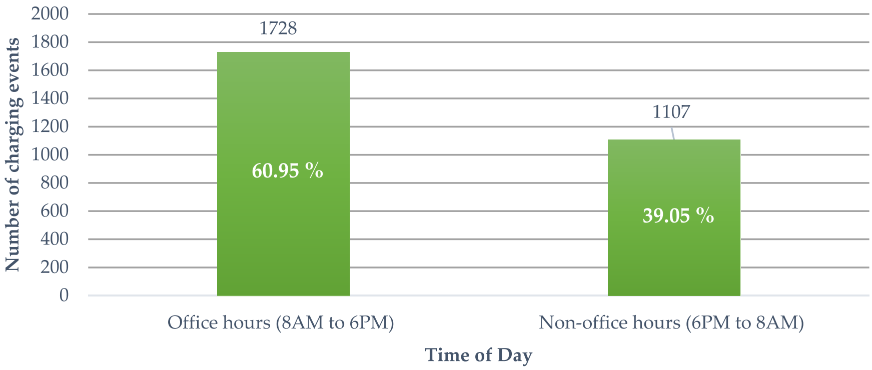


Fig. 18. Number of charging events at office and non-office hours.

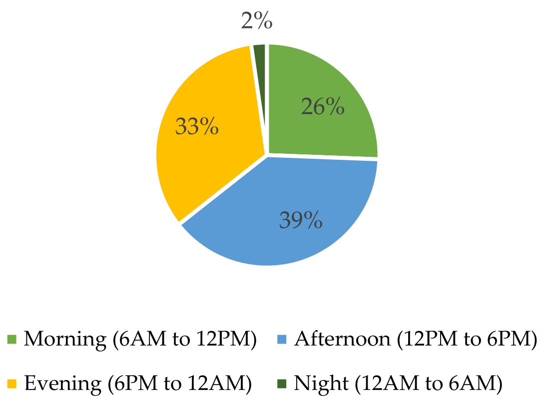


Fig. 19. Shares of charging events per the period of the day.

In terms of users' occupancy, Figs. 18 and 19 show respectively that about 60% of charging events were recorded during office hours, and more precisely the afternoon (39%). Note that these charts considered the whole studied period.

5.5. Discussion

The previous parts of this section allowed us to assess Rabat Marjane's EVSE use regarding various criteria: time, energy, and behavior. The three conducted analyses resulted in numerous findings, including the domination of Year 2 in terms of charging events number, showing the increasing yearly evolution. Also, the studied data showed the impact of the Covid-19 crisis where the use of EVSE dropped significantly during the quarantine period. Additionally, a high similarity was observed between charging events and energy delivery in terms of profile, distribution, and evolution. This finding proved that the EVSE's use was done in a regular manner during weekdays, including weekend days.

When it comes to energy needs, it turned out that 96% of charging events consumed less than 25 kWh with an average value of 12 kWh per event. This energy amount corresponds to a distance range of up to 60 km.

In addition, it turned out that there is a considerable potential to shift on-peak consumption to avoid the highest electricity tariffs and harness the on-site solar PV generation during the day. However, charging sessions' shifting will depend on a set of constraints to be considered, including EVSEs' and users' availabilities. By aggregating occupancy data, charging habits information, and electricity prices, it will be possible to design efficient energy management strategies and charging activities schedules, allowing to alleviate the grid load and parking pressure.

Charging occupancy and duration need to be examined considering the location of the charging station. Thus, it is important to contemplate the impact of locating the charging station in a shopping center where people spend upwards of an hour. Thus, long shops mean long charging times.

Table 5. Summary of the analyses' findings.

				Min		Max		Average	
	Total	Year 1	Year 2	Per day	Per month	Per day	Per month	Per day	Per month
Charging events	2835	1244	1591	1	10	19	333	5	118
Energy delivery (kWh)	28 452	11 711	16 741	0.001	114	78.7	2483	38	1186
Average energy delivery per event (kWh)								12	
Average duration per event (min)								48	
Average power output per event (kW)								7.09	

This paper intended to analyze the performance of an EVSE located in a shopping market. Nevertheless, its findings are expected to help in decision-making regarding the future charging infrastructure implementation in Morocco, mainly by hypermarket chains. The followed methodology is also reproducible and can be used to analyze EVSE usage in other locations. However, this paper investigates a single EVSE, whereas most of the other papers worldwide focus on a large number of charging stations, making their findings difficult to be compared to those of this paper. In addition, the necessity to take local specificities into account (e.g. location, EV uptake, policies, incentives, socio-economic parameters, existing infrastructure, etc.), implies that the findings of this study could not be completely generalized to other shopping centers or workplaces. Therefore, readers and decision-makers should consider the correlation between such parameters and the findings.

Table 5 sums up the main technical findings of the previous analyses.

6. Recommendations

Regarding the analyses' findings, it is possible to retrieve some general recommendations such as:

• According to the analyzed data, the average energy delivery absorbed by EV users (12 kWh) can take from 1 to 1, 5 h, and corresponds nearly to 60 km. This distance range can be acceptable for urban circulation but is insufficient for inter-urban travels. Therefore, it is recommended to reinforce the charging park with fast chargers (50–100 kW) which can charge fully some EVs in less than 30 min.

• According to AFID (Alternative Fuel Infrastructure Directive), the key policy regulating the deployment of public EVSE in Europe, it is recommended to have 1 public charger per 10 EVs, corresponding to a ratio of 0.1 in 2020 [9]. By 2030, the optimistic scenario predicts an uptake of 425,000 EVs in Morocco, while the intermediate scenario predicts 258,000 EVs [30]. Applying the above-mentioned rule, the EVSE number should range from 25,800 to 42,500, depending on the uptake scenario, to meet the growing demand by 2030.

• EVs are usually seen as an intense load by the grid and may imply sometimes some negative consequences such as power outages and frequency instability. Therefore, it is recommended to implement Load Management Systems (LMS) and perform necessary grid reinforcement measures to ensure a stable and reliable power supply. The large-scale implementation of LMS, smart meters, and communication modems in EVSE will help considerably pave the way to smart charging under the Smart Grids paradigm.

• EV users' behavior regarding charging and driving habits can influence considerably the energy efficiency of both their vehicles and the power supply system. The sensibilization of EV users to schedule their charging sessions during off-peak hours, when possible, may help alleviate the grid load during peak hours. Additionally, sensitizing EV users to eco-driving practices seems to save energy and emissions as well.

• It is common that electric vehicles, especially battery EVs, are eco-friendly and correspond to zero direct emissions. However, when they are charged with a non-decarbonized grid, GHG emissions and air pollution are only shifted from cities to power plants. Consequently, it is highly recommended to supply EVSE with renewable and clean energy sources, ideally through solar shades, to ensure greener mobility.

7. Conclusion

Promoting the adoption of EVs and the corresponding charging infrastructure is a key contribution to sustainable development in Morocco. The shift to electric mobility improves air quality and reduces the level of CO2 emissions, especially when combined with the growing share of renewable energy in Morocco's energy mix [43]. The shift away from fossil fuels also limits energy dependence on oil-exporting countries. As a leading car manufacturer in

Africa, the evolution of an EV ecosystem presents valuable opportunities for Moroccan companies and possibilities for international cooperation.

This paper, which is the first document reporting the EVSE usage at a public charging infrastructure in Morocco, proposed a methodology to analyze an EVSE usage regarding time evolution, energy delivery, and user behavior. By collecting and analyzing a 2-years historical dataset, corresponding to 2835 events that occurred from July 2019 to July 2021, the study resulted in various findings and recommendations which are expected to support decision-making regarding the future charging infrastructure in Morocco. Additionally, considering the reproducible aspect of the followed methodology, it could be possible to use it as a reference for EVSE usage analysis in other urban environments.

Following the analyses performed in this study, some future works may address (i) the on-site PV generation data analysis to assess the self-sufficiency and self-consumption metrics in the studied EVSE; (ii) the simulation of EV demand and its impact on the electricity grid; (iii) the simulation and feasibility analysis of bi-directionality (V2G); (iv) the evaluation of the techno-economic benefits of energy management and EV charging scheduling; and (v) technology adoption and acceptance evaluation through the analysis of socio-economic and socio-technical aspects of electric mobility technologies.

Declaration of competing interest

Abdelilah ROCHD reports administrative support, article publishing charges, and statistical analysis were provided by Green Energy Park. Abdelilah ROCHD reports a relationship with Green Energy Park that includes: employment.

Data availability

Data will be made available on request.

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