R-E-FLEX

Renewable energy and **E**-mobility as a **FLEX**ibility service

D1.1. Report on primary research

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Version 1.1. (DRAFT)

26/11/2024

FPS Economy, S.M.E.s, Self-employed and Energy

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1. Introduction

Electrification is widely accepted as a sustainable solution to decrease global greenhouse gas emissions in the transport sector using electric vehicles (EVs). In this context, the REFLEX project aims to investigate new technical and business solutions to complete the demand for more renewable energy while supporting the grid. The main idea is to speed up the electrification of passenger cars in Belgium and provide flexible services to support the local grid. The charging station concept consists of a combination of photovoltaic solar panels, stationary batteries, and EVs operating together with the supply and demand of the local grid.

The present deliverable (D1.1) focuses on the preliminary research conducted within this project. Following this introductive part, **Section 2** of this deliverable presents the EV charging ecosystem in the Belgian market, where different stakeholders and popular EV models are illustrated.

Section 3 describes the key charging technologies: AC (on-board) and DC (off-board) charging systems. Different solutions widely adopted in the market are provided.

Section 4 analyses the Ecoob (project partner) charging station using realistic datasets from the power profiles of the station. It also gives insightful information on the 150 kW DC fast-charging system datasets collected during this project.

These collected datasets are then used to develop realistic electrical system modelling and simulation as described in **Section 5**. Different simulation scenarios use input parameters such as yearly PV profiles, local batteries, and EV charging systems. The simulation considers two main use cases, including residential and near highway areas. These use cases are the most interesting and possible for the charging station operators (project partners) involved in this project.

Conclusions and future works are summarised in **Section 6**.

2. EV charging ecosystem in Belgium

Figure 2.1 shows key stakeholders in the EV charging ecosystem in Belgium. This example illustrates how different stakeholders at different levels can directly or indirectly operate together. Each stakeholder's point of interest regarding charging impact might differ. For example, power quality and related impacts are the most important parts of a distribution system operator. For a charging point operator (CPO), optimal business cases and cost of charging technologies are key aspects to consider. At the same time, an EV owner focuses more on charging convenience, including reliable, fast, and cheaper charging energy. CPO is a pivotal player in the electric mobility industry, responsible for building, installing, and maintaining EV charging stations for drivers to charge their vehicles [1].

The EV growth in Belgium can be seen in Fig. 2.2. This impressive increase in EVs (BEV+PHEV) can be explained by the technological development in batteries and chargers and the aggressive policies and incentives for the electrification of the transport sector. The charging technologies (AC and DC) also follow the trend to enable the charging process. Tesla Model Y is the most popular model among Belgium's top ten widely adopted models [2].

Fig. 2. 1. EV ecosystem in Belgium [1]

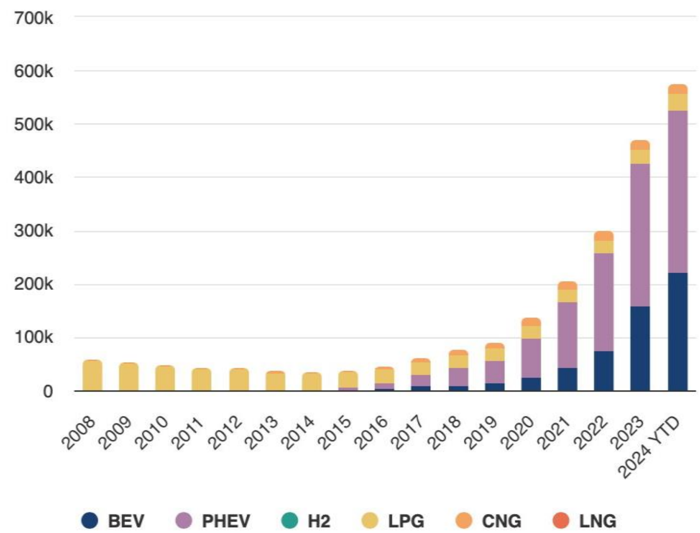


Fig. 2. 2. EV growth in Belgium [2]

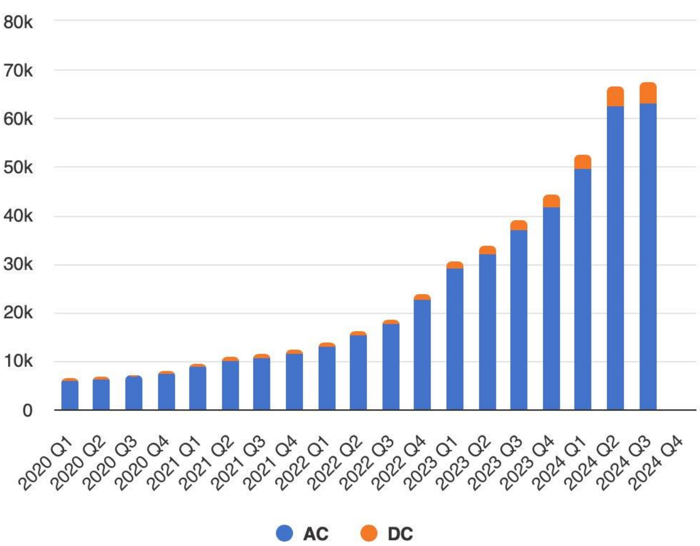


Fig. 2.3. Charging systems growth in Belgium [2]

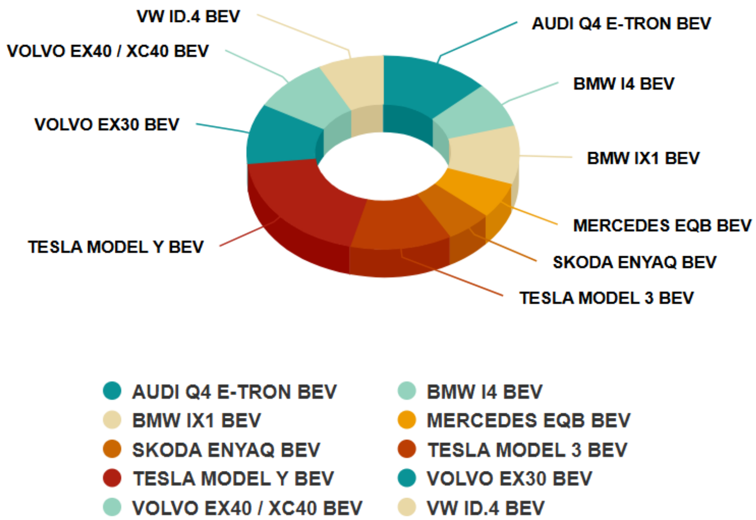
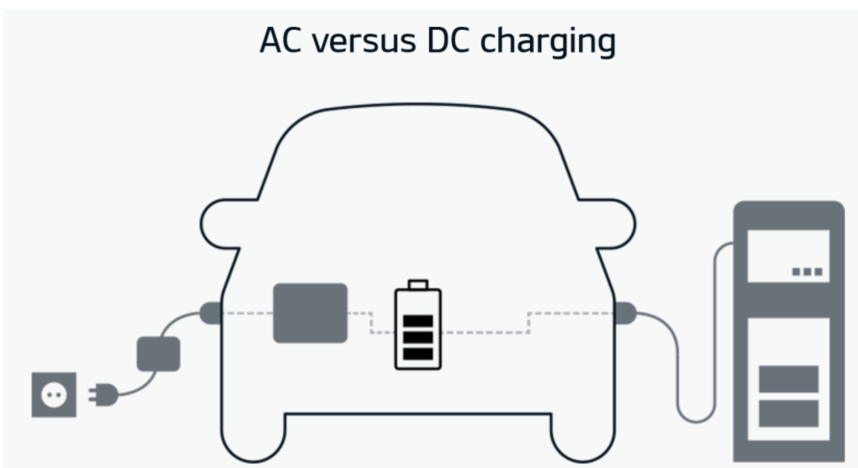


Fig. 2.4. Top EV models sold in Belgium [2]

3. EV charging technology

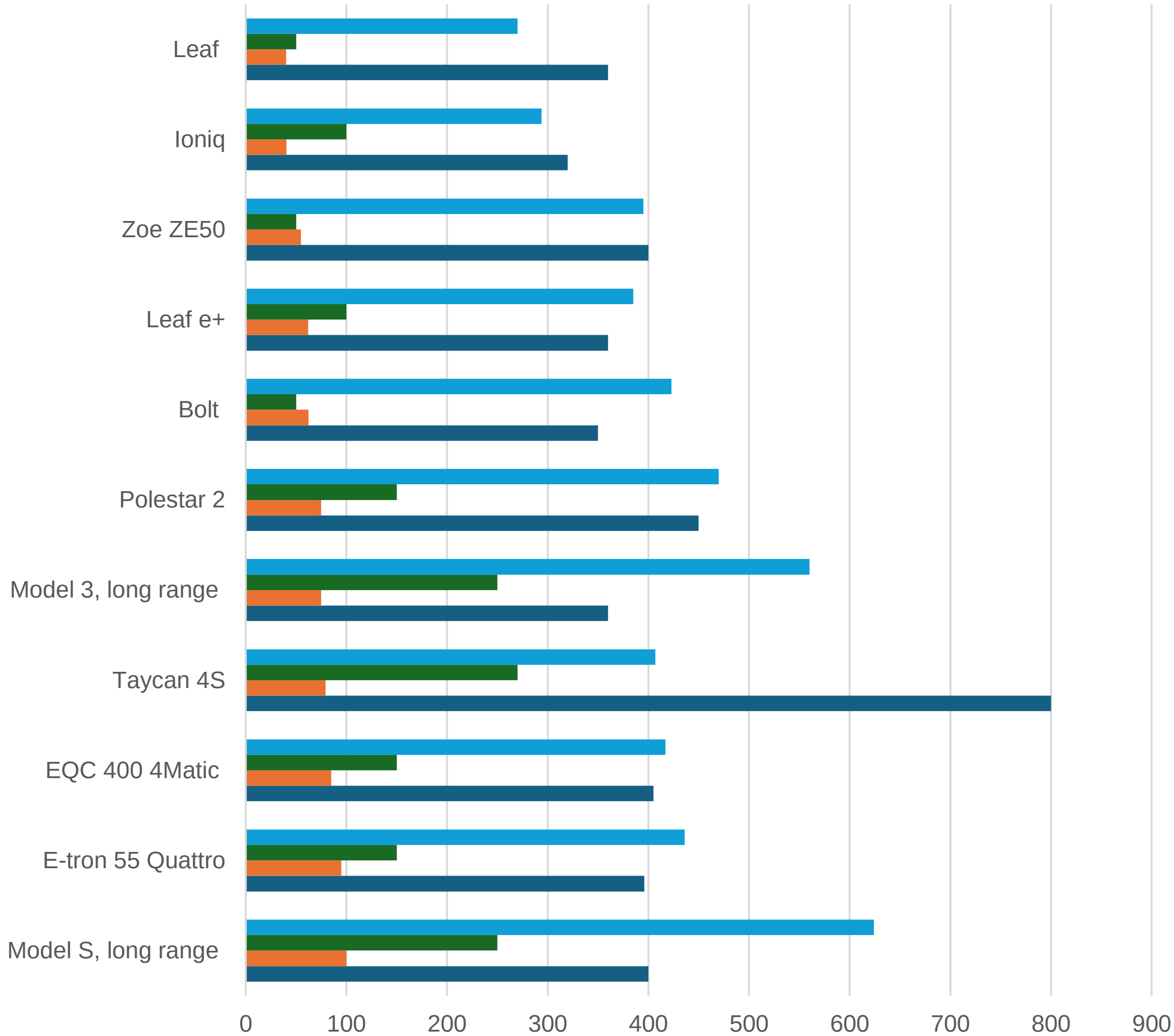
Typical EV charging systems, as illustrated in Fig 3.1 [3], consist of AC-type charging outlets delivering power into an on-board converter (typically from 2-22 kW), which supplies DC power to the EV battery. In a DC-type charging outlet, the AC power is converter outside the EV, which allows a higher power converter to increase the charging speed (typically 50-350 kW). More technical details on these on-board and off-board charging technologies and their operation can be found in research works [4-7] conducted at EnergyVille/KU Leuven team.

For a CPO, it is important to understand how these charging technologies operate. Additionally, the technical specifications of different EV models provide useful information on the limitations of the models and the charging technologies that could be connected to them. Fig. 3.2 and 3.3 show the specifications of the EV models and the DC charging technology market [8]. The energy requirement allows the CPO to plan better charging sessions, while the power capabilities indicate the power flexibility that could be available.



AC

Fig. 3.1. AC and DC charging technologies [3]



	Model S, long range	E-tron 55 Quattro	EQC 400 4Matic	Taycan 4S	Model 3, long range	Polestar 2	Bolt	Leaf e+	Zoe ZE50	Ioniq	Leaf
RANGE (km)	624	436	417	407	560	470	423	385	395	294	270
DC CHARGING POWER (kW)	250	150	150	270	250	150	50	100	50	100	50
RATED ENERGY (kWh)	100	95	85	79.2	75	75	62.2	62	54.7	40.4	40
BATTERY (V)	400	396	405	800	360	450	350	360	400	320	360

RANGE (km)   DC CHARGING POWER (kW)   RATED ENERGY (kWh)   BATTERY (V)

Fig 3.2: Charging specifications for different EV models.

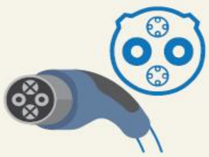
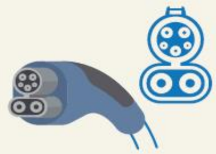
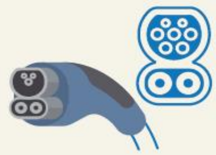
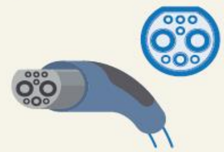
	CHAdeMO	CCS-1	CCS-2	GB/T	TESLA
Maximum power*	400 kW	350 kW	350 kW	237.5 kW	350 kW
Typical power†	50 kW	312 kW	350 kW	60 kW	250 kW
Output voltage	50–1,000 V	200–1,000 V	200–1,000 V	250–950 V	300–480 V
Maximum current	400 A	500 A	500 A	250–400 A	800 A
Communication	CAN	PLC	PLC	CAN	CAN
Region	Global	United States, South Korea	Europe, Australia	China, India	Global
Related standards	• IEC 61851-23/4 • IEC 62196-3 • JEVS G105-1993	• IEC 61851-23/24 • IEC 62196-3 • SAE J1772-2017	• IEC 61851-23/24 • IEC 62196-3	• GB/T 20234-3-2015 • IEC 62196-3	• IEC 62196-3
Vehicle to device	Yes	Under development	Under development	Under development	No
Plug type					
Time/100 km‡	13.73 min	4.4 min	1.96 min	11.44 min	2.74 min
Range/5 min§	36.4 km	113.54 km	254.73 km	43.67 km	181.95 km
Examples	 Delta Ultra Fast Charger: 50–550 V, 125 A (CHAdeMO); 170–1,000 V, 300 A (CCS); 150 kW maximum	 Charge Point Express Plus: 200–1,000 V, 390 A, 156 kW	 ABB Terra HP: 150–920 V, 500 A, 350 kW	 ABB Terra GB 184MVZ: 200–750 V, 300 A, 3 × 60 kW	 V3 Supercharger: 450 V, 250 kW

Fig 3.3: DC charging technology [8]

4. Ecoob use case analysis

Real datasets from a charging station operating AC and DC fast chargers are shared by Ecoob (project partner). Fig. 4.1. shows the power profiles throughout 15/08/23 to 15/05/24. The station has four 11 kW AC charging points and a dual port DC fast charger of 150 kW. This means that the maximum charging power of the station is around 194 kW. Different DC fast sessions using a 150 kW charger are illustrated in Fig. 4.2. This figure shows that even if a charger is designed to operate at 150 kW, it is most of the time working below that power level because of many reasons such as the EV model battery technology, the SoC at arrival, the battery temperature and the overall battery and charging management systems. The general charging pattern for the used EV model (Tesla model Y longue range) depends on the starting maximum charging power allowed. These charging curves are important elements that affect the charger usage time and efficiency. Therefore, they will impact the overall energy the CPO sells to the EV user.

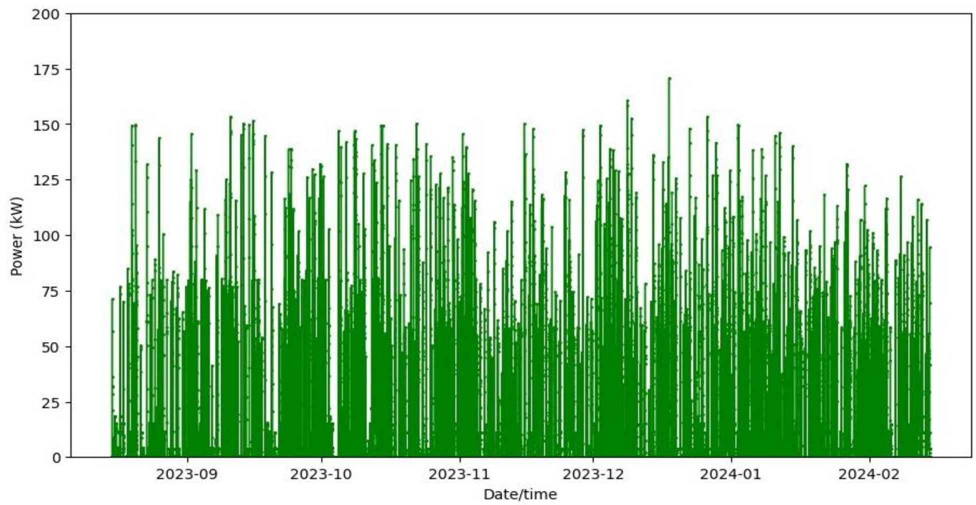


Fig 4.1. Ecoob charging station power profiles

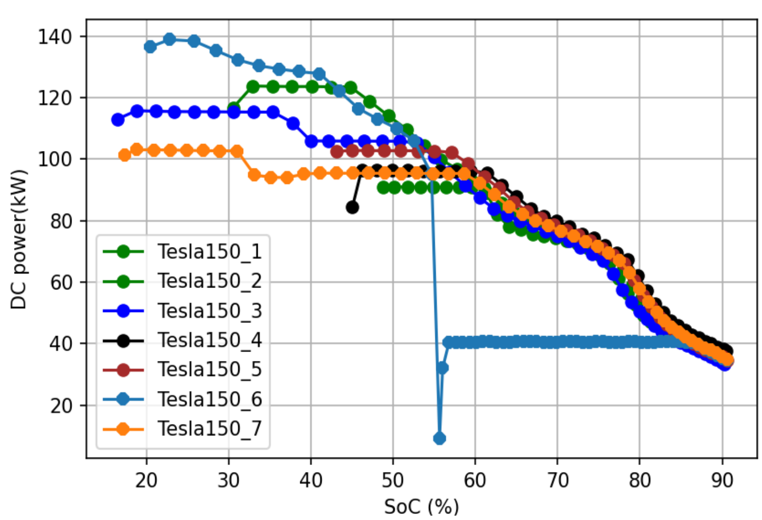


Fig 4.2: Different DC fast sessions using 150 kW charger

5. Modeling and simulation

5.1. Description

MATLAB/Simulink simulation tool is used in this study to model the electrical system and simulate the EV charging process. A controlled current source block driven by an input signal is considered an equivalent current source representing battery models. Lookup table blocks are also used to map these inputs to an output parameter by interpolating the table with a predefined simulation parameter. The phasor simulation method, which is a simplified fast solution to simulate power systems including large components, is used in this work. This method is also compatible with power/energy flow calculation using time series data like PV systems (irradiance profile), load (consumption), and battery (scheduling). The developed electrical system model screenshot is shown in Fig. 5.1.

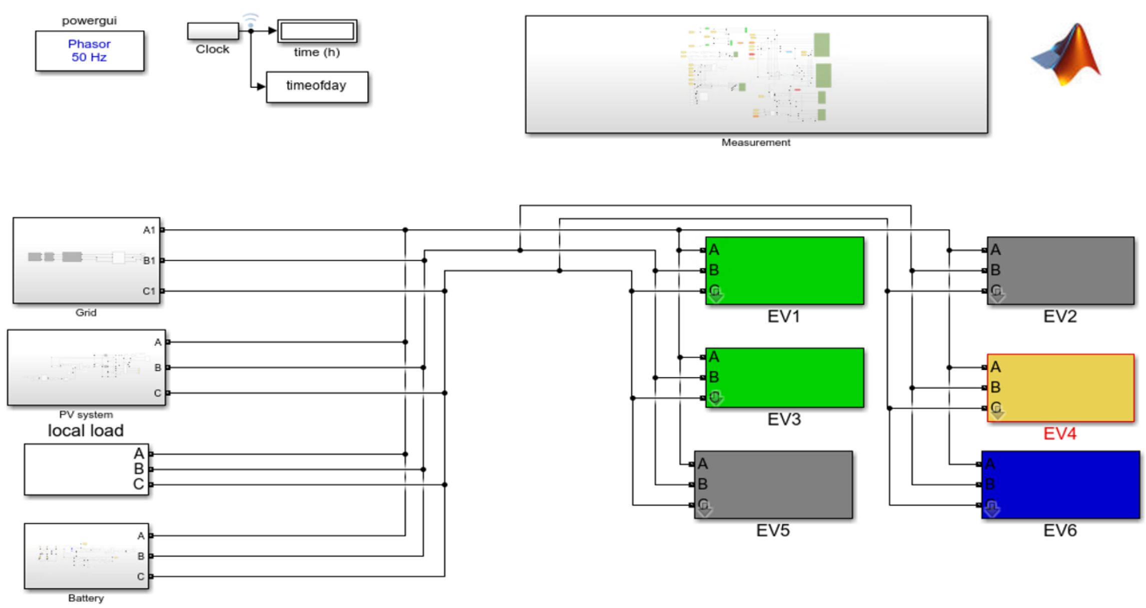


Fig: 5.1: Simulink blocks

5.2. Simulation parameters

As the project aims to look at the design and operation of an electrical system combining PV, battery, and EV charging systems, simulations using variable parameters of these systems are performed. These simulation variables (inputs and outputs) are shown in Table 5.1.

Table 5.1: Simulation parameters

Input parameters	Output parameters
Building consumption data	Daily/weekly charging scenarios
Irradiance profiles	PV power profiles
EV battery (scheduling time, battery size, charging power, SoC etc..)	Total generation/consumption
BESS (size, charging/discharging power, scheduling time, control with PV, EV station etc..)	Power/Energy consumption
Efficiency of charger	Dynamic efficiency curve
Battery charging curves	CC/CV curves

5.3. Simulation results

Case 1: Residential area

The residential use case is one of the interesting AC charging cases simulated in this work. The simulation parameters are shown in Table 5.2. Considering the time flexibility at home charging, it is assumed that most charging sessions will be during the evening (not at the same session start time). EV6 is a random car session that could happen in the daytime. The battery capacity of standard and long-range EV models, with the assumption that cars with larger battery sizes will have an SoC of around 40% at the beginning of the charging session, is considered.

Table 5.2: Simulation parameters for case 1

EVs	Session time	Charging type/ power	SoC (%)	Battery capacity (kWh)
EV 1	Evening	11 kW AC	30-100	60
EV 2	Evening	11 kW AC	30-100	80
EV 3	Evening	11 kW AC	30-100	60
EV 4	Evening	11 kW AC	40-100	80
EV 5	Evening	11 kW AC	40-100	80
EV 6	Day	11 kW AC	40-100	60

The residential case's yearly energy use and production are illustrated in Fig. 5.2. It can be seen that PV production is higher in April, May, and June while it is lower in October, December, and January (winter season). The energy profiles can provide a general idea of total energy consumption, but power profiles are required to show the energy used by the EV charging systems. Therefore, two different weekly power profiles are illustrated in Fig. 5.3. During the week with higher PV production, the local battery energy is used in the evening, resulting in less 40 kW peak power compared to the week with lower PV production where power can go higher than 40 kW. To further understand the usage of energy storage, the local battery SoC for the selected two weeks is illustrated in Fig. 5.4. The local battery SoC minimum and maximum levels are set between 10%-90%. The battery is full most of the week with higher PV production even though its energy is used to support the charging. On the other hand, the battery is at its lowest SoC level except when there was a random day on the weekend with higher PV production. It is worth noting that it is not assumed that cars will be charging at home during the daytime of a weekend.

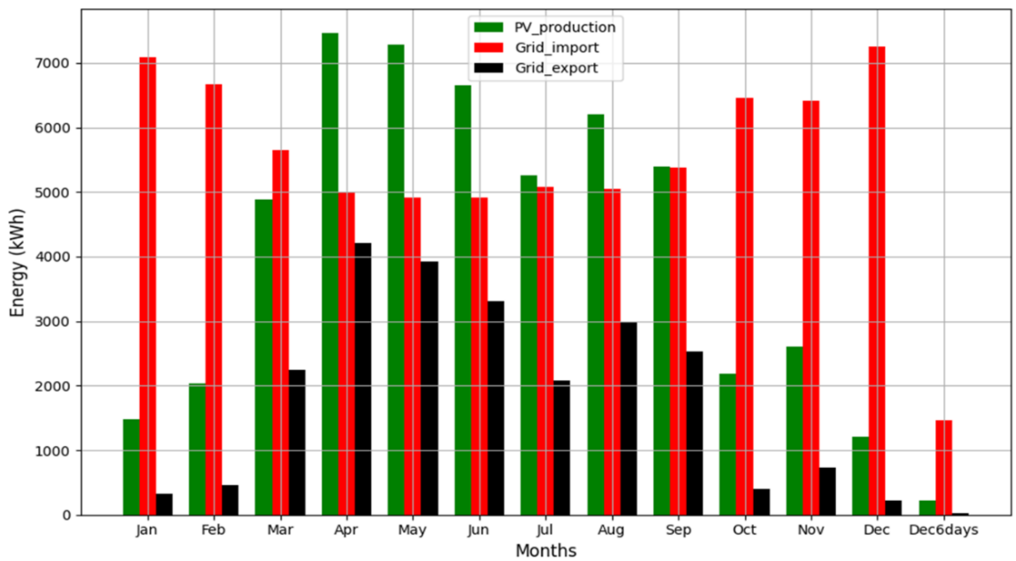


Fig: 5.2. Yearly energy use and production for the residential case

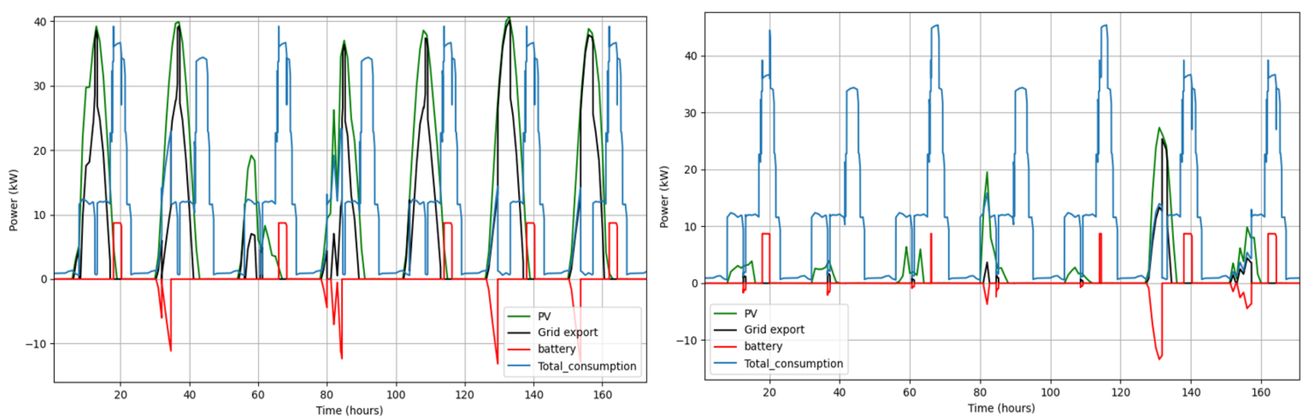


Fig: 5.3. Weekly power profiles in April (left) and January (right) for the residential case

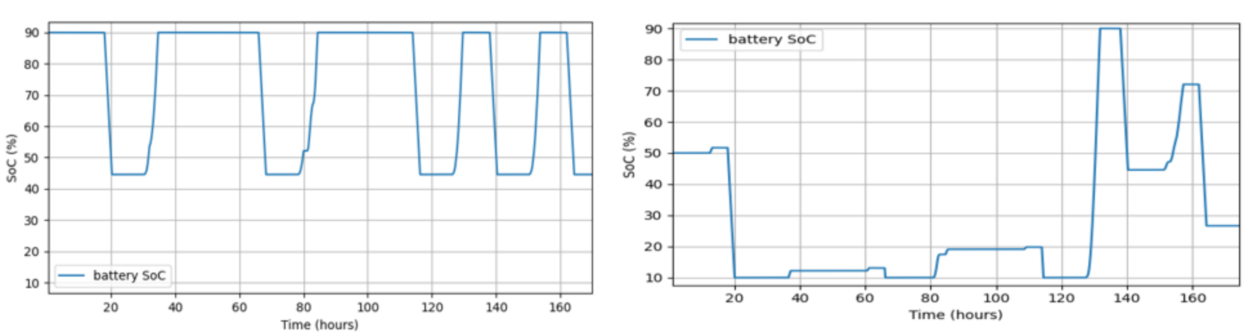


Fig: 5.4. Weekly SoC profiles of the local battery in April (left) and January (right) for the residential case

Case 2: Highway and visitors

Another interesting use case is the public charging stations located near highways. These are usually industrial sites or workplaces that visitors can use to charge their cars. The simulation parameters and assumptions are shown in Table 5.3. Considering the access flexibility for this kind of use case, it is assumed that a combination of charging technologies can be investigated. Therefore, the charging sessions can be during the day, afternoon, and evening (not at the same session start time). Similar battery capacities of EV models were assumed in the previous case. However, the DC charging session is considered to end around 90% of the SoC because the new LFP battery can go much higher before entering the constant voltage operation.

The yearly energy use and production for case 2 are illustrated in Fig. 5.5. It can be seen that PV production is similar to the previous case. The PV profiles are the same. From weekly power profiles, it is clear that the DC fast charging case has almost three times (120 kW) higher peak power than the residential case. April and January's weekly profiles are illustrated in Fig. 5.6. The local battery is used to support fast charging within a short time. The battery is almost full during the week with higher PV production. During the week with lower PV production, it can be seen that the battery is gradually used to support the fast charging until a random day with PV production happens to recharge the battery, as depicted in Fig. 5.7.

Table 5.3: Simulation parameters for case 2

EVs	Session time	Charging type/ power	SoC (%)	Battery capacity (kWh)
EV1	Day	11 kW AC	20-100	60
EV2	Day	150 kW DC	20-90	80
EV3	Day	11 kW AC	30-100	60
EV4	Afternoon	150 kW DC	30-90	80
EV5	Evening	150 kW DC	40-90	80
EV6	Evening	11 kW AC	50-100	60

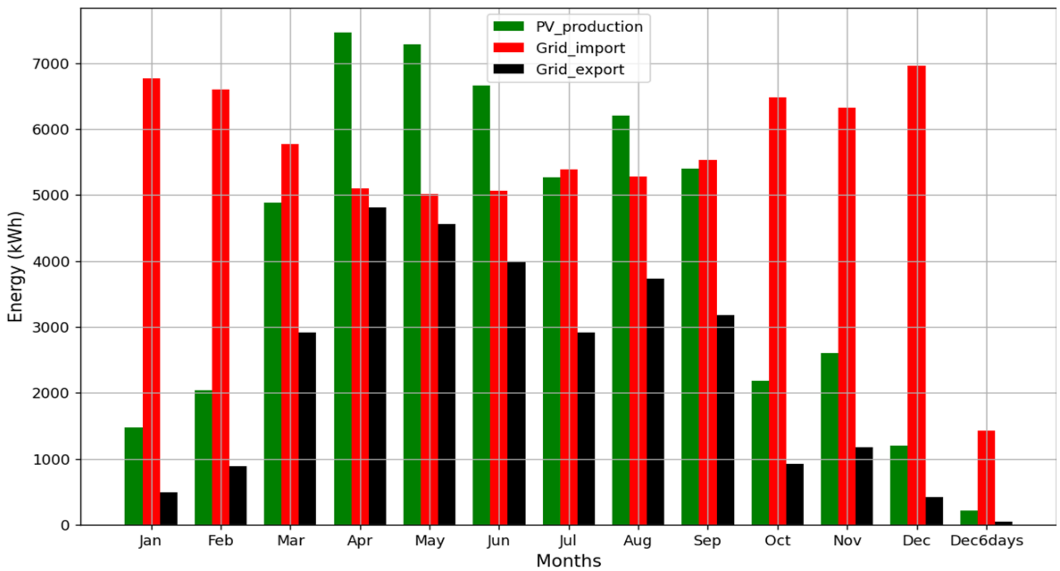


Fig: 5.5. Yearly energy use and production for the highway + visitors' case

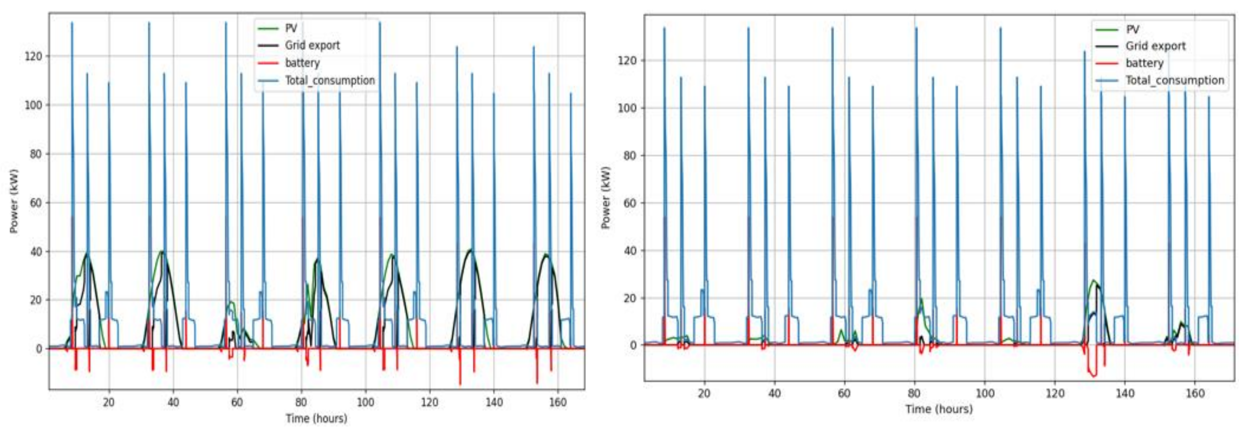


Fig: 5.6. Weekly power profiles in April (left) and January (right) for the highway + visitors' case

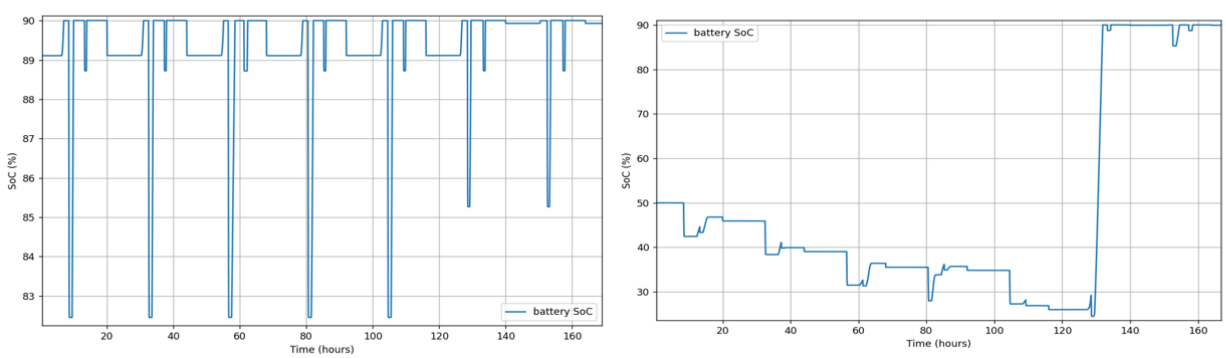


Fig: 5.7. Weekly SoC profiles of the local battery in April (left) and January (right) for the highway + visitors' case

6. Conclusions and future work

The EV charging ecosystem in the Belgian market is briefly discussed in this report, including information on the key charging technologies. This report summarises a comprehensive market review, while a more technical explanation of different technologies can be found in [4-6]. The Ecoob charging station power and battery SoC datasets revealed that the 150 kW DC fast is usually working below that power level, depending on the EV model charging curve. The charging curve is an important parameter that can affect **the charger usage time and energy efficiency,** reducing or increasing the overall energy the CPO sells to the EV user.

The electrical system model was developed using PV profiles, local battery parameters, and EV charging systems. Two interesting use cases were simulated under a full-year scenario. Monthly and two different (high and low PV production) weekly power profiles were illustrated for both use cases.

For residential cases, during the week with higher PV production, the local battery energy is used in the evening, resulting in less 40 kW peak power compared to the week with lower PV production, where power can go higher than 40 kW. The battery is full most of the week with higher PV production even though its energy is used to support the charging. On the other hand, the battery is at its lowest SoC level except when there was a random day on the weekend with higher PV production.

For the highway and visitors' case, it is clear that the DC fast charging case has almost three times (120 kW) higher peak power than the residential case in both April and January's weekly profiles. The local battery supports fast charging within a short time because of the DC charging session time. The battery is almost full during the week with higher PV production. During the week, with lower PV production, it can be seen that the battery is gradually used to support fast charging. The battery size is more optimal in this case than in previous scenarios.

These simulation results demonstrated that the local battery is oversized when the PV production is higher and undersized when it is lower. In the DC charging scenario, the battery power capacity is more important than the energy capacity, as the charging session should be supported as fast as possible to avoid peak power in the electrical systems. Therefore, the local battery provides a **higher flexibility level when the PV production is higher** (April, May and June).

These simulation results (power and energy) are used to calculate energy costs in the revenue model. **Future work** will identify and investigate more use cases and flexibility levels provided in the selected use cases. The battery size in terms of energy and power needs to be more optimal to support both AC and DC charging sessions. Therefore, more simulation scenarios will be performed in that sense. The battery control strategy for supporting charging systems or the grid needs to be optimised by using more realistic datasets.

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