UCLouvain

École polytechnique de Louvain

Assessment of low-power electric vehicle charging at UCLouvain

A techno-economic and behavioral analysis of a cost-effective and scalable alternative to conventional charging infrastructure

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Abstract

University campuses combine a growing demand for electric-vehicle charging with long and relatively predictable parking periods. These conditions may allow drivers to recover their daily mobility-related energy at powers well below those of conventional Mode 3 AC stations, typically rated from 7.4 kW to 22 kW. This thesis assesses reinforced low-power sockets as a cost-effective and scalable alternative for long-duration parking at UCLouvain. The case study combines a campus mobility survey, parking observations, a charging-demand simulation accounting for variability in vehicle use, a pilot experiment using two reinforced sockets near Hall Stévin, and a comparative techno-economic assessment. Across simulated fleets of 55 to 550 vehicles, reinforced sockets deliver about 97 % of the energy requested and fully satisfy more than 90 % of sessions, the residual shortfall being concentrated in stays shorter than about four hours rather than spread across the fleet. Diversity holds the aggregate peak of 550 vehicles near 1.1 MW, against 4.8 MW for the same spaces rated at 22 kW, and a reinforced point costs around EUR 900 against roughly EUR 10 000 per point in a 2024 campus design study at 11 kW. Pilot participants recovered more range than their commuting required and their ratings held after use. The study ultimately identifies the user profiles, site conditions and operating rules under which low-power charging can provide a useful and scalable campus service.

Keywords: electric vehicle charging; low-power charging; campus charging; charging demand; pilot experiment; user acceptance.

1. Introduction

1.1 Context and motivation

The rapid electrification of road transport is increasing the need for charging opportunities outside the home. On 1 August 2025, Belgium counted 395 188 battery-electric passenger cars, representing a 55.4% increase within one year; 81.8% of these vehicles were registered by companies [1]. This national market structure suggests that workplace charging will play an important role in Belgian electric mobility, although the vehicle population and charging needs at UCLouvain must be characterized separately.

Charging infrastructure should nevertheless be selected according to the service required at a given location rather than by systematically maximizing power. Conventional AC stations, commonly rated from approximately 7.4 kW to 22 kW, provide faster charging and can integrate metering, authentication and communication. These functions are valuable, but they also increase equipment cost, installation complexity and the electrical capacity required when many points operate simultaneously. DC fast charging serves a different use case: it is appropriate for short stops and rapid energy recovery, but its cost and power demand make it an unsuitable solution for vehicles parked throughout a working day.

At workplaces and university campuses, vehicles can remain parked for several hours. The relevant service is therefore the energy recovered during the available connection period:

$$E_{\mathrm{ch}} = P_{\mathrm{ch}}\, t_{\mathrm{ch}}\, \eta_{\mathrm{ch}}, \tag{1}$$

where E_{ch} is the energy transferred to the battery, P_{ch} the charging power, t_{ch} the effective charging duration and η_{ch} the charging efficiency. A lower-power connection may consequently provide a sufficient daily service when the parking duration is long relative to the energy request.

This principle is attractive for UCLouvain because a distributed low-power infrastructure could serve more parking spaces for a given investment and reduce the need for high coincident power. Its usefulness cannot, however, be inferred from nominal power alone. Commuting distances, vehicle consumption, parking duration, limited socket availability, local electrical capacity, safety requirements, user behaviour and operating rules all influence the service that can actually be delivered.

A campus-wide plan doesn't have to rely on only one charging technology. Reinforced sockets could form the main cost-effective layer for long-duration parking, with a smaller number of 22 kW AC stations and DC chargers reserved for shorter stays, larger energy requests, or rapid top-ups.

1.2 Problem statement and research questions

The central problem is to determine whether a distributed reinforced-socket infrastructure can use long campus parking periods to equip more spaces at lower cost than conventional Mode 3 stations. The assessment focuses on users whose daily energy needs and parking patterns are compatible with low-power charging.

The study addresses three research questions:

RQ1. To what extent can low-power charging meet the daily mobility-related energy needs of campus users under realistic parking durations, and how many charging points would a campus deployment require?

RQ2. Which behavioural and organizational factors influence user acceptance and the practical use of low-power charging on campus?

RQ3. Under which technical, operational and economic conditions could reinforced low-power charging be deployed and progressively scaled up at UCLouvain?

1.3 Scope and contribution

This thesis draws on four complementary strands of work within a single UCLouvain case study: characterizing campus mobility and parking needs, simulating charging demand, running a pilot installation with real users, and carrying out a comparative cost assessment. It combines survey responses, parking observations collected at UCLouvain, a small-scale pilot, and scenarios covering four fleet sizes and four rated powers. It therefore evaluates whether a reinforced socket can charge a vehicle, and more importantly, whether a shared low-power service can cover useful mobility, remain acceptable to users, and justify deployment under campus constraints.

The study does not provide the detailed electrical design of a campus-wide network, certify a permanent installation, or claim statistical representativeness for the pilot sample. Instead, it identifies the conditions that a limited deployment must satisfy before being extended, and distinguishes the user profiles that low power can serve from those that need faster or guaranteed charging.

2. Background and related work

2.1 Low-power charging and reinforced sockets

Reducing charging current increases the time required to deliver a given amount of energy. It may also increase the relative importance of the vehicle's auxiliary consumption and conversion losses. Brincourt et al. measured AC charging efficiency for an Opel e-Corsa, a Nissan Leaf e+ and a Renault Zoé at 8 A, 10 A, 16 A and 32 A [2]. For the three tested vehicles, operation at 16 A produced efficiencies close to those observed at 32 A. At 8 A, reported efficiencies were approximately 81%, 88% and 65%, respectively, demonstrating that losses at very low current can be substantial and vehicle-dependent.

These measurements support an important distinction within the broad category of slow charging. A 16 A, single-phase connection (approximately 3.7 kW at 230 V) can preserve much of the simplicity of socket-based charging without necessarily incurring the poor efficiencies observed at lower currents. The study involved only three vehicles and did not examine shared infrastructure. It therefore supports the selected power level but does not establish its ability to serve a heterogeneous campus population.

The term "socket-based charging" covers configurations with different safety and service levels. An ordinary domestic socket is not generally intended to supply its rated current continuously for several hours without prior assessment of the circuit and connection quality. A reinforced socket is intended for repeated vehicle charging and must be installed on a suitable dedicated circuit with the required overcurrent and residual-current protection. Charging takes place through the user's portable Mode 2 cable, which includes an in-cable control and protection device. For the Green'Up Access system used in the pilot, the manufacturer specifies a maximum of 3.7 kW at 230 V and 16 A when the cable and vehicle are compatible with the system [3]. A reinforced socket remains simpler than a wall-mounted Mode 3 station, which communicates with the vehicle and can integrate authentication, metering, supervision and load management.

This functional distinction is central to the comparison. A reinforced socket does not reproduce every feature of a conventional station at lower power. The potential advantage lies in installing less equipment at each parking space, since the user only needs a safe energy transfer during a long stay. It also lacks native identification, centralized communication, reservation and dynamic control, and any comparison based on rated power alone should treat that absence as part of the service design rather than ignore it.

2.2 Workplace and campus charging patterns

Workplace and university charging is generally treated as destination charging, for which parking duration and vehicle turnover are central design variables. The university-campus guidance by Giles et al. documents the use of both low- and medium-power charging and emphasizes that the choice of infrastructure depends on user needs, expected parking duration, site conditions and operating policy [4]. It does not, however, quantify the share of daily mobility needs that could be recovered from a reinforced 3.7 kW connection.

Bayram et al. analysed 166 weeks of data from 17 charging nodes on a university campus [5]. Demand was concentrated on weekdays and during daytime hours, and users frequently relied on campus charging to extend their available driving range rather than to restore a complete battery. This finding is directly relevant to low-power charging because a useful campus service need not reproduce the full-charge objective associated with long-distance travel. The authors also observed a temporal correspondence between campus charging demand and solar irradiation, suggesting potential for local photovoltaic self-consumption. The observed infrastructure was nevertheless based on higher-power Level 2 stations and provided functions that are not inherent to reinforced sockets.

Using a much larger German dataset, Hecht et al. similarly found that AC charging was concentrated on weekdays and daytime periods, while DC points served more vehicles and transferred more energy per session [6]. The dataset confirms the distinct roles of destination and rapid charging, but combines several AC use cases and does not isolate reinforced-socket operation. Existing campus studies therefore support the importance of long parking durations without determining the charging power or connection count required for UCLouvain.

Dimensioning at a destination site consequently differs from dimensioning a rapid-charging corridor. The useful quantity is not only the maximum energy that one point can deliver, but the relation between daily requests, parking-duration distributions, point availability and the number of users competing for access. Increasing charging power shortens the energy-transfer period, but does not necessarily increase the number of users served if vehicles remain connected after their request has been met. Additional throughput then requires vehicle relocation or another mechanism for reallocating the point. Conversely, a larger number of lower-power connections can reduce access conflicts but occupy each point for longer. The preferable configuration depends on whether energy-transfer time or access to a connection is the binding constraint.

2.3 Acceptance of a constrained shared service

Technical energy coverage is necessary but not sufficient for a shared charging service. Users need to be able to access the infrastructure, understand its rules and see the energy they receive as useful. Studies based on observed charging-station choices, often called "revealed preferences", find that location, accessibility and the number of available connections influence station choice, with substantial heterogeneity between users [7]. Public-charging research has also looked at tariffs and other mechanisms meant to free up high-demand points once charging is complete [8, 9].

The operating logic is different for low-power workplace charging. A vehicle is expected to remain connected during its normal parking period; a long occupation is therefore part of the service rather than necessarily an overstay. Acceptance depends more strongly on perceived usefulness, ease of use, facilitating conditions, reliability and fairness of access. These dimensions are consistent with the constructs commonly used in the Unified Theory of Acceptance and Use of Technology [10], although the present study uses them as a questionnaire framework rather than as a fully powered statistical validation of UTAUT.

The role of price must also be separated from acceptance of low power itself. Free electricity can make a limited service attractive even when its power, reliability or access rules would otherwise be judged insufficient. A before-and-after assessment is therefore required to distinguish anticipated interest from satisfaction after actual use.

2.4 Infrastructure costs and deployment constraints

The cost of a charging service extends beyond the purchase price of the visible device. It can include a dedicated distribution circuit, residual-current and overcurrent protection, cable routing, mounting and mechanical protection, civil works, inspection, metering, communication, access control, backend subscriptions, maintenance and reinforcement of the upstream installation. Published non-residential charging-cost data show wide installation-cost ranges because electrical work, trenching, labour, inspection and site configuration vary substantially [11]. Operating costs can additionally include electricity, maintenance and network fees [12]. Conventional Mode 3 stations can justify these costs when communication, billing, supervision or power-management functions are required. The same functions may be unnecessary for a workplace deployment with identified users and simple operating rules, independently of its size.

A reinforced-socket solution can reduce equipment cost per parking space, but the advantage is site-dependent. Long cable routes, excavation, new distribution boards or extensive mechanical protection may dominate project cost regardless of the outlet. Moreover, a low-cost point that is rarely available or delivers insufficient energy is not an economical service. Relevant indicators should therefore relate cost to useful capacity: simultaneously served vehicles, annual delivered energy, or users whose daily request is adequately covered.

Electrical constraints also become material at scale. One 3.68 kW point is a modest load on its own, but tens of points charging at the same time can require substantial feeder capacity and phase balancing. Because simple sockets cannot natively limit aggregate demand, the absence of embedded communication becomes more consequential as the number of points grows. Whether that matters in practice, and at what scale, is precisely what the economic comparison has to establish: a small manually managed pilot and a larger deployment do not necessarily call for the same supervision or load control.

2.5 Research gap

The literature establishes that 16 A charging can be reasonably efficient for several vehicle models, that campus vehicles often remain parked long enough for destination charging, and that infrastructure use depends on convenience and access conditions. It also shows why equipment cost alone cannot represent the cost of a functional charging service. These findings have mostly been produced separately and for conventional charging stations or public networks.

They do not determine whether reinforced 230 V, 16 A sockets can simultaneously provide adequate daily energy, acceptable shared access and an economic advantage in a specific university environment. This transfer to UCLouvain depends on local mobility profiles, parking durations, socket availability, electrical constraints and user behaviour. The present thesis addresses that gap by combining simulation, field operation and comparative cost assessment within one case study.

Table 1: Relationship between research questions and assessment methods.

RQ	Principal evidence	Assessment criteria
RQ1	Survey, parking observations, simulation and charging logs	Requested and delivered energy, fully satisfied users, connection duration, socket utilization and number of points required.
RQ2	Initial and final questionnaires, session observations and scheduling deviations	Usefulness, simplicity, satisfaction, reliability, fairness and influence of free charging.
RQ3	Site assessment, simulation, pilot and cost comparison	Electrical and safety conditions, number of points, investment, operating rules and suitable user profiles.

3. UCLouvain case study and assessment framework

3.1 Campus context and charging concept

This thesis uses a multi-method case study combining a campus survey, parking observations, a Monte Carlo charging-demand simulation, a field experiment and a comparative cost assessment. The concept targets users who remain on campus for several hours and can use that parking time to meet their daily energy needs through a distributed reinforced-socket infrastructure, potentially allowing more spaces to be equipped at lower cost than with conventional Mode 3 stations. The components address complementary questions: the survey and parking observations characterize potential users and their presence patterns; the simulation evaluates technical coverage at a larger scale; the pilot identifies practical and behavioural issues; and the cost assessment examines deployment conditions. Their respective roles are summarized in Table 1.

3.2 Study boundary

The reinforced socket was retained after comparing four configurations: a conventional Mode 3 AC station, taken as the reference; a fixed low-power Type 2 wallbox; an industrial socket used with portable equipment; and a reinforced domestic socket used with a portable Mode 2 cable. The last was selected because the research question concerns the minimum infrastructure able to deliver useful energy during a long stay, and it is also the least expensive of the four to install and the simplest to replace. Its limitations, a restricted power and a dependence on equipment the user brings, are therefore properties of the object under test rather than shortcomings of the experimental design.

The empirical study uses two Legrand Green'Up Access reinforced sockets at an outdoor location behind Hall Stévin. This small-scale pilot implements the architecture considered for wider deployment across suitable UCLouvain parking areas and evaluates its energy delivery, practical operation and user acceptance with two simultaneous users.

Underground parking facilities were excluded from the pilot. Fire-safety guidance for closed car parks calls for a risk-based assessment of the whole facility rather than of the charging equipment alone, covering compartmentation, detection and alarm, smoke and heat management, access for emergency services, emergency electrical disconnection and the removal of a damaged vehicle after an incident [13]. Meeting those conditions, together with the cable routing and civil-engineering work an underground installation would have required, exceeded the time and access available for the experimental phase. The thesis therefore focuses on suitable above-ground locations, without implying that reinforced-socket charging is impossible underground; Section 8.3 returns to the conditions such a site would have to satisfy.

Each participant was required to bring a compatible portable Mode 2 charging cable. The cable connects the reinforced 230 V socket to the vehicle and contains the in-cable control and protection device; the vehicle-side connector therefore depends on the vehicle and is not assumed to be Type 2 in every case. Access to a compatible cable was an eligibility condition and a practical limitation of the concept. At 230 V and 16 A, the maximum nominal power available at the socket is

$$P_{\mathrm{ch}} = UI = 230\,\mathrm{V} \times 16\,\mathrm{A} \simeq 3.68\,\mathrm{kW}. \tag{2}$$

The actual power absorbed may be lower because it depends on cable compatibility, recognition of the Green'Up system, the vehicle's onboard charger and charging losses. The selected architecture represents a potential configuration for suitable campus parking areas and allowed the pilot to test the technical, practical and behavioural propositions examined in this thesis. It does not reproduce the full functionality of a commercial station.

3.3 Electrical assessment boundary

Vehicle charging draws a nearly continuous electrical load for several hours at a time. A reinforced connection therefore still needs a properly sized circuit and conductors, overcurrent and residual-current protection, an acceptable voltage drop, mechanical protection, and equipment validated for the environmental conditions it will face. Any permanent UCLouvain installation must comply with the relevant provisions of the Belgian General Regulations for Electrical Installations and be approved by the competent technical services [14].

Aggregated across the installation, the coincident demand of N_{active} identical points is

$$P_{\mathrm{tot,max}} = N_{\mathrm{active}} \times 3.68\,\mathrm{kW}. \tag{3}$$

This expression is an upper bound: it assumes that every active vehicle draws the maximum nominal power at the same time. A single low-power connection is therefore no guarantee that the network impact stays negligible once many of them operate together. Each site still needs to check the number of simultaneous sessions, the distribution across phases, the existing building load and the available capacity of the local distribution board. Because detailed campus network data were not available, the present model evaluates charging demand and infrastructure utilization, rather than load flow, voltage quality or protection coordination.

Table 2: Data sources and roles in the assessment.

Source	Use in the study
Campus survey	Commuting, campus attendance, parking duration, access to other charging, interest and acceptance conditions.
Parking observations	Repeated observations across numerous parking areas over several days: number of unique electric vehicles, arrival and departure times, and parking durations. The observations did not cover the entire campus.
Pilot forms and logs	Vehicle type, expected need, connection times, session completion, driver-reported recovered range and operational incidents.
UCLouvain 2024 mobility survey	Modal split, commuting distance and campus attendance for the Louvain-la-Neuve site. Used to situate the present sample and to estimate the size of the campus car population [15].
Technical and cost information	Charging equipment, protection, cabling, installation, metering, maintenance and possible network-related costs.

3.4 Data sources and common assumptions

Table 2 summarizes the information used in the assessment. Three groups are kept distinct: respondents to the campus survey, users who expressed interest in the experiment, and participants who completed at least one charging session. Pilot participants were recruited among volunteers who were present on campus, had a compatible vehicle and cable, and were available during the experimental period. The selection is described in Section 6.2; it was not intended to represent statistically the full university population.

The campus survey was administered in person on the campus between 30 March and 5 August 2026 and yielded 50 usable responses. It collected commuting distance, frequency of campus attendance, typical parking duration, vehicle ownership, access to home or public charging and interest in campus charging. Because the questionnaire was administered face to face, respondents completed every item they were asked, and no response had to be excluded for incompleteness.

Names were entered in the source questionnaires, and registration plates were logged during parking observations to spot repeated sightings of the same vehicle, but neither is reproduced anywhere in this thesis. All questionnaire, parking and pilot results are reported in aggregate, never attributed to a named participant.

4. Campus mobility and charging needs

This section characterises the potential users of a campus charging service and assesses whether their declared mobility needs can be met by charging at 3.7 kW. Its results support the demand-side assumptions of Section 5 and the interpretation of the pilot in Section 6. Two sources are used: a campus questionnaire, which provides the mobility and acceptance data analysed below, and a non-exhaustive survey of several campus car parks, used only to document the observed presence of plug-in vehicles.

4.1 Respondent profile and mobility patterns

The questionnaire was administered in person on the campus between 30 March and 5 August 2026 and collected 50 responses, reported in Table 3. Students account for 36 of the 50 respondents and staff, researchers and professors for 14, a composition in which students predominate as they do in the campus population. The sample nevertheless remains a convenience sample: it is used to characterise mobility profiles and acceptance conditions, and no figure reported in this section should be read as an estimate of prevalence in the UCLouvain population.

The third block of Table 3 identifies the population that a daytime charging service would serve: the 18 respondents who use a vehicle to reach the campus on a regular basis. They are reported separately throughout. All 14 staff, researchers and professors of the sample belong to this subgroup, and 8 of the 18 already drive a battery electric or plug-in hybrid vehicle. A further 9 respondents intend to acquire one within four years.

The 18 regular drivers declare a home-to-campus distance with a mean of 24.8 km and a median of 23.8 km (5 km to 50 km), and a mean campus attendance of 4.61 days per week. Sixteen of the 18 park for at least 4 hours and 2 declare a 2–4 h stay. Long stays therefore dominate without being exclusive, and the parking profiles used in Section 5 follow this pattern by retaining a minority share of short stays.

The sample is small, but the two quantities that drive the energy request can be compared with the triennial UCLouvain mobility survey, whose 2024 edition retained 2 710 student and 1 520 staff responses for the Louvain-la-Neuve site after cleaning [15]. That survey gives a mean home-to- campus distance of about 23.8 km for staff, against 24.8 km declared here by the 18 regular drivers, and an average of 0.85 teleworking days per week, that is about 4.15 days of campus presence, against 4.61 days declared by the same subgroup. This attendance gap is expected: the subgroup was selected for its frequent attendance, so its members should show more campus presence than the reference population, not less. What the sample cannot reproduce is the modal split. The reference survey finds that 46% of staff and 20% of students reach Louvain-la-Neuve by car as their main mode, whereas this subgroup is made up entirely of vehicle users by definition. The declared distances and attendance figures used in the rest of this section therefore remain consistent with the site-wide reference, even though the composition of the sample is not.

The remaining 32 respondents do not use a vehicle for regular campus commuting: 19 use one only to leave the city at the end of the week, 12 own no car, and one owns a vehicle but does not use it for campus travel. They are therefore excluded from the daily parking-duration analysis, which concerns only the 18 regular drivers. Weekly travel represents a separate, periodic charging case that is noted here only as a possible extension.

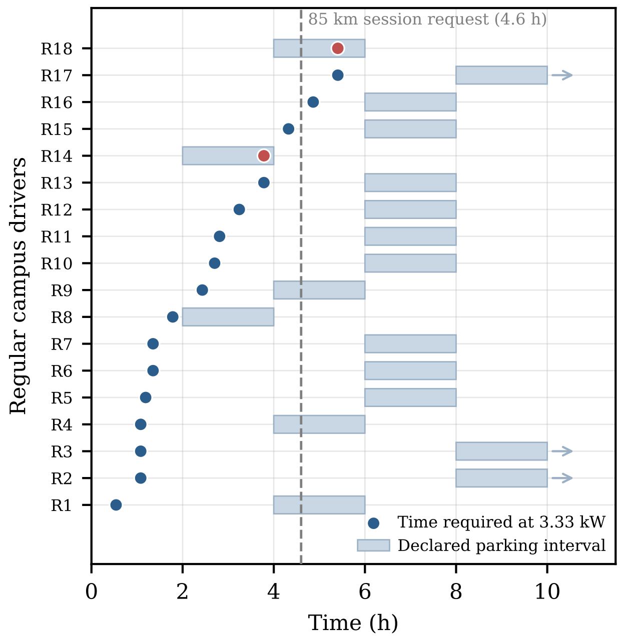

Figure 1: Daily energy need of the 18 regular campus drivers, expressed as the charging time required at the battery- side power of 3.33 kW, compared with their declared parking interval. The home-to-campus distance recorded in the questionnaire is treated as a one-way distance and doubled. Respondents are ordered by increasing requirement; the two red markers lie beyond the lower bound of their parking interval but within the interval itself. The dashed line is the time required by the 85 km session request used in Section 5.

4.2 Compatibility with low-power charging

Three quantities must be kept distinct: the minimum daily range a respondent would wish to recover on campus, the energy actually required by declared daily travel, and the energy transferred per charging session in the simulation.

The first is a service expectation. Thirty-five of 50 respondents request 60 km or less per day; assigning midpoints to the response classes gives an approximate mean of 48 km, about 2.6 h at the battery-side power of 3.33 kW. The top class being open-ended, this mean is indicative only, and it is not used to calibrate anything.

The home-to-campus distance recorded in the questionnaire is a one-way value and is therefore doubled to represent the daily return journey. The daily energy need of the 18 regular drivers then averages 8.9 kWh and reaches 18.0 kWh at most, requiring 2.7 h on average and 5.4 h at most at 3.33 kW. Figure 1 compares each respondent's requirement with the parking interval they selected. Sixteen of the 18 would recover their full daily need within the lower bound of that interval, and all 18 would do so within the interval itself. The two remaining cases therefore require the longer end of their declared stay. The declared daily needs of all 18 regular drivers remain within what a 3.7 kW connection delivers during their declared parking time.

The third quantity is the per-session request of the simulation. It is not a daily distance: a user charging two or three times a week accumulates several days of travel between two sessions. The questionnaire supports a plausibility check rather than a calibration. A mean daily round trip of 49.6 km over 4.61 campus days per week corresponds to about 229 km per week, that is 114 km per session at two campus sessions per week and 76 km at three. The value of 85 km retained in Section 5 lies inside this range. It requires $E_{\text{req}} = 85 \times 0.18 = 15.3$ kWh, delivered in 4.6 h at 3.33 kW, which is compatible with the multi-hour stays declared by the same respondents.

The charging frequency of 2.45 sessions per week is a modelling assumption of Section 5, and the questionnaire only records the total number of charging events per week across all locations, not the number performed on campus. What the survey supports is that a request of 85 km per session is plausible for this population and deliberately more demanding than the minimum daily service its members say they expect.

4.3 Acceptance and flexibility

Forty-four of 50 respondents would use a slow connection during a multi-hour stay, 2 would not and 4 answered maybe or unsure; among the 18 regular drivers, 16 would and 2 would not. Forty-seven accept that charging be temporarily reduced or interrupted, but 36 of them attach an explicit condition: that a minimum need be covered. Two respondents refuse any reduction and one is unsure.

Acceptance of flexibility is therefore mainly conditional on a guaranteed floor of delivered energy. Any control strategy applied to this infrastructure must protect such a floor; only 11 respondents out of 50 support temporary reduction or interruption without condition.

The priority attached to price is not uniform. Free charging is the leading factor overall (25 of 50), but it is selected by 22 of the 41 respondents who do not currently drive a plug-in vehicle and by only 3 of the 9 who do; among current users, a guaranteed charge leads instead (5 of 9). Since only current users have experienced the difference between an available connection and a reliable one, price and service reliability should be treated as distinct determinants of acceptance. Because the pilot supplies free electricity, the before/after questionnaires of Section 6 are the appropriate instrument for separating them.

Finally, campus charging would complement rather than replace existing access for current users: 8 of the 9 can charge at home, and 8 report at least three charging events per week across all locations. The three respondents who already charge at work do so for an electric bicycle or motorcycle with a removable battery, rather than for a car. Their situation therefore does not constitute an existing workplace car charging alternative. This is consistent with the modest daily range they request.

4.4 Parking observations

A non-exhaustive parking survey was carried out to obtain an order of magnitude for the number of plug-in vehicles present on campus, independently of any willingness to answer the questionnaire. After the observation files had been consolidated and repeated sightings removed, 55 distinct plug-in vehicles were identified: 41 battery electric, 11 plug-in hybrid and 3 undetermined. Since neither the spatial coverage nor the observation times were standardised, these records are interpreted only as evidence of an existing presence across several campus car parks, and not as estimates of parking occupancy, temporal distributions or relative demand between locations. The count is used as a descriptive lower bound consistent with the smallest fleet simulated in Section 5.

Table 3: Questionnaire results (n = 50), with the subgroup of regular campus drivers reported separately.

	All (n = 50)	Regular drivers (n = 18)
Status		
Students	36	4
Staff, researchers, professors	14	14
Vehicle		
Internal combustion	29	10
No car	12	0
Battery electric	7	6
Plug-in hybrid	2	2
Vehicle use for campus travel		
Regular campus driver (3–6 days/week)	18	18
End-of-week departure from the city only	19	0
No vehicle used	13	0
Declared parking duration (regular drivers, n = 18)		
2–4 h	2	2
4–6 h	4	4
6–8 h	9	9
More than 8 h	3	3
Minimum daily range requested on campus		
Below 20 km	4	2
20 km to 40 km	13	4
40 km to 60 km	18	6
Above 60 km	13	5
Unsure	2	1
Would use slow charging during a multi-hour stay		
Yes	44	16
Maybe or unsure	4	0
No	2	2
Accepts temporary reduction or interruption		
Yes, if the minimum need is covered	36	13
Yes, without condition	11	3
No	2	2
Unsure	1	0
Most important factor		
Free charging	25	11
Guaranteed charge	14	6
Other or not applicable	11	1

4.5 Limitations and use of these results

The questionnaire is exploratory rather than representative. Respondents were recruited both in person and through personal and professional contacts, mainly in the upper part of Louvain-la-Neuve; several neighbourhoods were not covered. The results therefore describe the sample and cannot be extrapolated as campus-wide prevalence. In particular, conclusions concerning the 18 regular drivers remain indicative.

The home-to-campus calculation represents direct return commuting only; it does not capture other daily travel such as shopping, school trips or personal journeys. The 85 km mean request used in Section 5 remains a scenario assumption rather than a parameter fitted to these responses: it represents accumulated mobility between charging sessions and is deliberately higher than the mean daily commute. Its dispersion and bounds are modelling choices. The parking survey is likewise non-exhaustive and non-standardised, so it provides a lower bound rather than a campus-wide occupancy estimate.

5. Simulation results

The pilot experiment evaluates the use of two reinforced sockets under real operating conditions, whereas the simulation extends the technical assessment to larger vehicle fleets and a

Table 4: Main simulation assumptions. Parking profiles and charging frequencies are derived from the campus survey and parking observations of Section 3.4; they are scenario assumptions rather than distributions fitted to UCLouvain data.

Parameter	Value
Period	Year 2025, hourly (8 760 steps)
Charging power	3.7 kW grid side, uncontrolled
Charging efficiency	90% (3.33 kW battery side)
Frequency	1, 2 or 3 days per week (p = 0.10, 0.35, 0.55; mean 2.45)
Day weighting	Mon–Thu 1.00, Fri 0.85, Sat 0.05, Sun 0
Parking profile	Short 0.10, medium 0.25, long 0.62, atypical 0.03 (weekdays)
Requested range	Truncated normal, 85 ± 25 km, [25, 150]
Consumption	Truncated normal, 18 ± 2.5, [14, 24] kWh/100 km
Campus load	Measured 2025 quarter-hourly data, hourly means
PV generation	TMY irradiance, performance ratio 0.85
PV capacity	$N \times 3.7$ kW, rounded up to the nearest 10 kWp

full year of campus operation. It quantifies the mobility service provided by a 3.7 kW connection, the aggregate charging power associated with increasing fleet sizes, and the resulting effects on UCLouvain's annual electricity imports and peak demand. Paired scenarios with additional photovoltaic capacity are then used to assess the temporal interaction between daytime solar generation and charging demand.

5.1 Simulation assumptions and energy request

The model represents one calendar year at hourly resolution. Each vehicle is assigned a weekly charging frequency and, on each charging day, a parking profile that determines its arrival and departure times. Charging is uncontrolled: it starts on arrival and continues until the requested energy has been delivered or the vehicle departs. No smart charging, reservation or power limitation is applied, which is the conservative reference case for a socket-based installation without communication.

Charging losses are represented by a constant efficiency $\eta = 90\%$, an order of magnitude consistent with the measurements at 16 A of Brincourt et al. [2], who also show that efficiency is vehicle-dependent. The socket draws $P_{\mathrm{ch}} = 3.7$ kW from the grid, and the battery receives $\eta P_{\mathrm{ch}} = 3.33$ kW. This distinction matters for two reasons: it lengthens each session, and it means that the grid energy attributed to charging exceeds the energy actually recovered by the vehicles by $1/\eta$. Unless stated otherwise, requested and delivered energies are reported on the battery side, whereas campus imports are reported on the grid side. The sensitivity of the results to this assumption is discussed in Section 5.6. The main assumptions are summarised in Table 4.

Each parking profile has its own triangular arrival and departure time distributions; a separate low-presence profile is used for Saturdays, and no sessions occur on Sundays. The battery energy requested during session i is calculated as

$$E_{i,\mathrm{req}} = \frac{d_{i,\mathrm{req}} c_i}{100}, \qquad (4)$$

where $d_{i,\mathrm{req}}$ is the driving range to be recovered and c_i is the vehicle consumption in kWh/100 km. To represent heterogeneous users more realistically than a single deterministic request, both variables are sampled from truncated normal distributions, with the parameters listed in Table 4. Fitting parametric distributions to charging-session variables is standard practice in charging-demand modelling and has been validated against large real-world session datasets [16]; truncation keeps the sampled values within a physically plausible interval.

Two conventions underlie these parameters. The requested range is not a single home-to-campus trip: because vehicles charge on average 2.45 days per week, one session covers several days of use. Individual daily driving distances are right-skewed and are better described by Weibull or log-normal laws [17], but the same study reports little autocorrelation between successive days, so the multi-day total behind one session behaves as a sum of nearly independent draws and is correspondingly more symmetric. Vehicle consumption, in turn, is expressed on the battery side, consistent with Eq. (4). Weiss et al. report a certified consumption of 19 ± 4 and a real-world consumption of 21 ± 4 kWh/100 km across 342 European battery-electric cars [18], without stating whether these values are taken at the socket or at the battery. The mean of 18 kWh/100 km retained here on the battery side, about 20 kWh/100 km at the socket, falls within one standard deviation of both, so the ambiguity does not affect the results.

The resulting mean battery-energy request is approximately 15.3 kWh, which requires about 4.6 h at the battery-side power of 3.33 kW. Over an eight-hour working day, the same connection draws at most 29.6 kWh from the grid and transfers 26.6 kWh to the battery, corresponding to about 148 km at the mean consumption. This is the maximum service available over eight hours, not the time required to recharge an empty battery; an individual session stops earlier once its requested energy has been delivered.[1]

The simulated fleet sizes are anchored on the campus car population rather than chosen arbitrarily. The 2024 UCLouvain mobility survey reports that 46% of staff and 20% of students reach the Louvain-la-Neuve site by car as their main mode [15]. Applied to the site populations implied by the corresponding response rates—about 4 370 staff and 19 400 students—these shares give approximately 5 900 car commuters, or about 5 550 present on a given day once the reported average of 0.85 teleworking days per week is taken into account. The four simulated fleets of 55, 110, 220 and 550 vehicles therefore represent plug-in shares of roughly 1%, 2%, 4% and 10% of the campus car population. For reference, battery electric cars represented 395 188 of the 6.14 million private cars registered in Belgium on 1 August 2025, or 6.4% [1]; transposed to the campus car population, that proportion corresponds to about 360 vehicles, between the third and fourth

[1]The simulated year does not begin or end on an ISO week boundary. The charging frequency assigned in the two incomplete weeks is scaled to the number of days actually simulated, so that the weekly frequency is preserved on average and no artificial concentration of sessions occurs at the year boundaries.

scenarios. These values give an order of magnitude, not a count: they combine a modal split measured on a partial sample with a national motorisation rate that need not apply to a university campus.

5.2 Charging adequacy and temporal margin

Table 5 reports fleet-wide service indicators as the simulated fleet grows from 55 to 550 vehicles, with each row aggregating all annual sessions for one fleet size. Energy coverage is the ratio of total energy delivered to total energy requested, while a session counts as fully satisfied when its complete request is delivered before departure. The two indicators are complementary: if two sessions each request 10 kWh and receive 10 and 9 kWh, energy coverage is 95%, even though only one of the two sessions is fully satisfied. Across the four fleet sizes, energy coverage remains between 97.0% and 97.5%, while the share of fully satisfied sessions stays between 90.6% and 91.3%. The mean recovered range stays close to the average requested range of 85 km. A larger fleet therefore delivers more total energy without significantly reducing the average service each connected vehicle receives. This stability makes sense in a model where vehicles do not compete for a limited number of sockets: the indicators describe the energy service achievable once a vehicle is connected, not the availability of a connection.

Table 6 decomposes the 220-EV scenario by parking profile to identify where incomplete charging occurs.

The short and Saturday profiles have the lowest energy coverage and the lowest shares of fully satisfied sessions, whereas medium and long stays are almost entirely served. Parking duration, rather than fleet size, is therefore the main determinant of charging adequacy in the model. Figure 2 makes this condition explicit. The dashed line $E_{i,\text{req}} = \eta P_{\text{ch}} t$ is the maximum battery energy a 3.7 kW connection can deliver during a parking period of duration t. Sessions below the line can be completed and those above it cannot, irrespective of the fleet size. Incomplete sessions are concentrated in the short-stay cluster, where the requested energy exceeds what the available connection time allows; a smaller number of high-demand medium stays fall on the same side of the line.

For a fully satisfied session, the temporal margin is defined as

$$M_i = t_{i,\text{departure}} - t_{i,\text{charge end}}, \quad (5)$$

that is, the time for which the vehicle remains parked after its requested energy has been delivered. Partially satisfied sessions are left out here, since their charging simply continues until departure. In the 220-EV scenario, the mean temporal margin is 4.2 h and the median 4.33 h, for a mean parking duration of 8.7 h among these sessions. This leftover parking time suggests that a substantial part of the charging demand could be delayed or temporarily reduced without hurting session satisfaction. That is a potential source of flexibility, though this study does not simulate controlled charging to test it.

5.3 Aggregate charging power and diversity

Figure 3(a) shows the aggregate charging power over a representative week. Demand rises after the morning arrival period and then decreases as individual requests are completed, and the pattern repeats from Monday to Friday with almost no weekend activity. Because vehicles arrive at different times, request different amounts of energy and stop charging once their needs are met, the full installed charging capacity is never

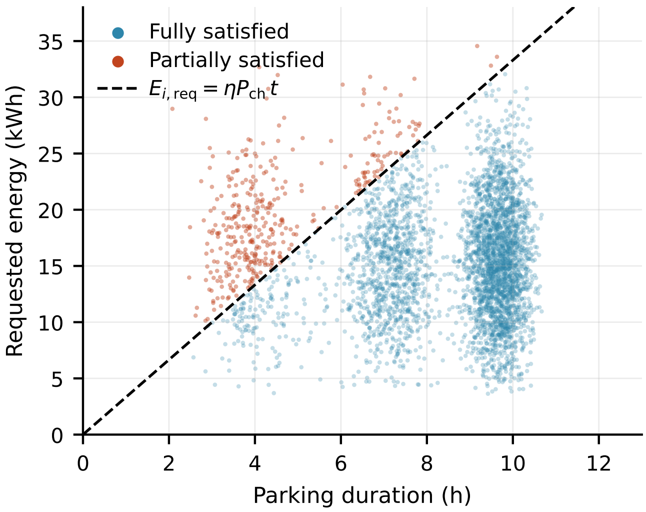

Figure 2: Requested energy against parking duration for a random sample of 4 000 sessions in the 220-EV scenario. The dashed line is the battery energy that a 3.7 kW connection delivers over the parking period at 90% efficiency. The three clusters correspond to the short, medium and long parking profiles.

used simultaneously.

The nominal maximum, defined as $N \times 3.7$ kW, therefore represents an upper bound rather than an expected operating condition. As shown in Table 7, the 550-EV scenario reaches a maximum aggregate charging power of 1074.7 kW, corresponding to 52.8% of its nominal capacity of 2035 kW. Aggregate power is a grid-side quantity and each connection therefore still draws 3.7 kW; the effect of charging losses is to lengthen sessions, which slightly increases the number of vehicles charging at the same time.

The annual maximum is an extremum statistic, so it is sensitive to the random draw, particularly for a small fleet. Repeating the 55-EV scenario with five random seeds produces peak factors ranging from 61.5% to 68.9%. The 99.9th-percentile factor, by contrast, varies within about four points, and energy coverage within half a point. This percentile-based factor also decreases more regularly with fleet size, from 60.5% for 55 EVs to 51.3% for 550 EVs. It therefore supports the same conclusion without relying on a single hour.

Figure 3(b) shows the corresponding duration curves. In the 220-EV scenario, charging power exceeds approximately 274 kW during 10% of annual hours, 356 kW during 5%, and 402 kW during 1%. These levels distinguish persistent demand from rare peaks and can inform the assessment of load management or local reinforcement. They do not, by themselves, authorise conductors or protection devices to be sized below applicable electrical requirements.

5.4 Campus energy and peak-import effects

Table 8 reports grid-side annual import and maximum hourly import for all scenarios. Percentage changes are calculated relative to the campus reference, which reproduces the measured 2025 campus load without simulated EV charging or additional PV generation. This reference imports 12.468 GWh per year and reaches a maximum hourly import of 4.844 MW.

At the present order of magnitude of 55 EVs, annual import increases by 0.92% and peak import by 1.42%. The intermediate 220-EV scenario raises the same indicators by

Table 5: Fleet-wide annual charging-service indicators under uncontrolled 3.7 kW charging at 90% efficiency. Requested and delivered energies are battery-side; grid energy is the corresponding consumption at the socket.

EVs	Sessions	Requested (MWh)	Delivered (MWh)	Grid (MWh)	Mean recovered range (km)	Energy coverage	Fully satisfied sessions
55	7 202	107.3	104.6	116.2	83.1	97.5%	91.3%
110	14 095	215.1	208.7	231.8	82.8	97.0%	90.6%
220	28 246	435.5	422.8	469.7	82.8	97.1%	90.6%
550	70 687	1 080.1	1 049.8	1 166.5	82.9	97.2%	91.0%

Table 6: Charging adequacy by parking profile in the 220-EV scenario. Profile shares refer to numbers of sessions; energy coverage is calculated from energy totals within each profile, and the temporal margin only for fully satisfied sessions.

Profile	Session share	Parking time (h)	Energy coverage	Fully satisfied sessions	Mean margin (h)
Short	9.9%	3.9	76.8%	33.6%	1.0
Medium	24.8%	7.2	99.0%	94.1%	2.8
Long	61.1%	9.7	100.0%	99.8%	5.0
Atypical	2.9%	6.2	96.4%	82.9%	2.1
Saturday low presence	1.4%	4.1	79.0%	38.8%	1.2
Total	100.0%	8.3	97.1%	90.6%	4.2

Table 7: Aggregate EV charging power. The 99.9th-percentile factor complements the annual maximum, which is sensitive to isolated extreme hours.

EVs	Nominal (kW)	Annual peak (kW)	Peak factor	P99.9 factor
55	203.5	140.2	68.9%	60.5%
110	407.0	241.3	59.3%	56.5%
220	814.0	448.2	55.1%	52.7%
550	2035.0	1074.7	52.8%	51.3%

Table 8: Annual campus grid import and maximum hourly import. Percentages are relative to the campus reference scenario.

Scenario	Import (GWh)	Change	Max. (MW)	Change
Campus reference	12.468	—	4.844	—
EV55	12.583	+0.92%	4.913	+1.42%
EV110	12.697	+1.84%	5.009	+3.41%
EV220	12.934	+3.74%	5.151	+6.35%
EV55–PV210	12.382	-0.69%	4.794	-1.04%
EV110–PV410	12.305	-1.31%	4.777	-1.39%
EV220–PV820	12.150	-2.55%	4.846	+0.04%
EV550, no PV	13.630	+9.32%	5.509	+13.73%
EV550–PV2040	11.725	-5.96%	5.287	+9.15%

3.74% and 6.35%, respectively. At 550 EVs without additional PV, annual import increases by 9.32% while maximum import increases by 13.73%. The larger relative increase in peak power reflects the concentration of workplace charging during daytime campus activity, whereas annual energy is accumulated over all hours of the year.

With 2040 kWp of additional PV, annual import falls to 11.725 GWh, 5.96% below the reference, while maximum import stays 9.15% above it at 5.287 MW. Figure 4(a) shows the same comparison across all hours of the year: adding vehicles pushes the import duration curve upward across the whole distribution, and additional PV pulls it back down over most of the year. At the extreme left of the curve, though, that reduction disappears: the highest campus imports occur exactly when solar generation is low, so PV can no longer offset the added charging demand there. Additional PV can therefore reduce the annual grid energy of a larger fleet, but it does not remove the maximum-power constraint.

5.5 PV self-consumption and temporal overlap

PV self-consumption is evaluated hour by hour. At each time step, on-site cogeneration is allocated first, and PV generation is then compared with the remaining campus and EV demand; the self-consumed share is the smaller of the two. The reported ratio therefore includes PV electricity absorbed by existing campus demand as well as by vehicle charging, and is not specific to the vehicles.

Across the four scenarios with additional PV capacity, the campus absorbs between 97.1% and 99.5% of the electricity generated locally. This consistently high self-consumption is mainly supported by the existing daytime demand of the campus buildings, whose magnitude remains an order of magnitude above the charging load; it does not indicate that vehicles are themselves predominantly PV-powered, since PV electricity is not attributed to a specific end use once injected into the campus network. A separate, EV-specific indicator is needed. The *EV–PV temporal coincidence ratio* is defined as

$$C_{\text{PV-EV}} = \frac{\sum_t \min(P_{\text{PV},t}, P_{\text{EV},t})}{\sum_t P_{\text{EV},t}}, \tag{6}$$

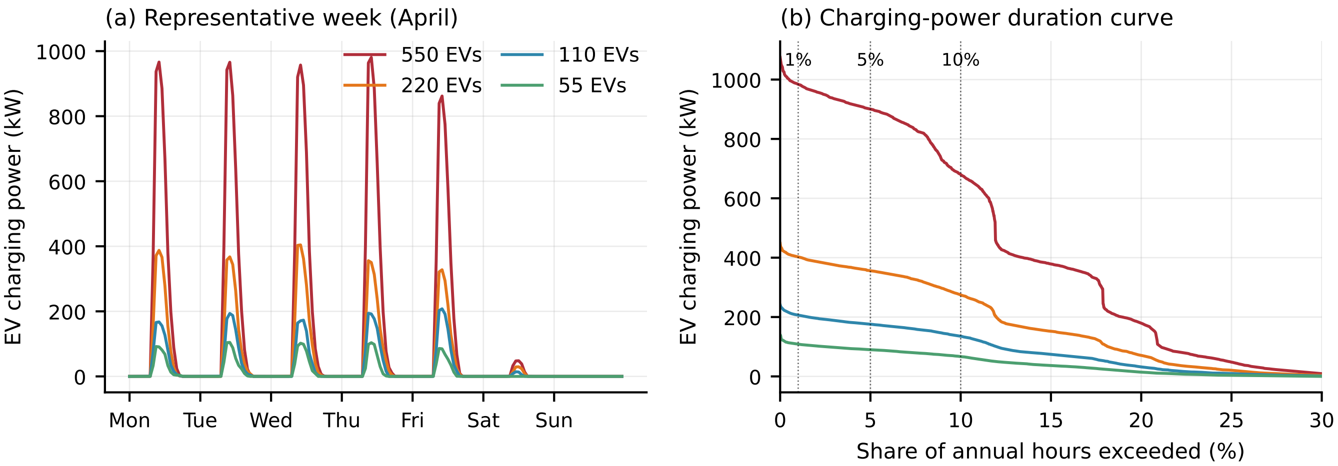

Figure 3: Aggregate EV charging power. (a) Representative April week for the four fleet sizes. (b) Annual duration curve of charging power; the dotted lines mark the 1%, 5% and 10% exceedance levels.

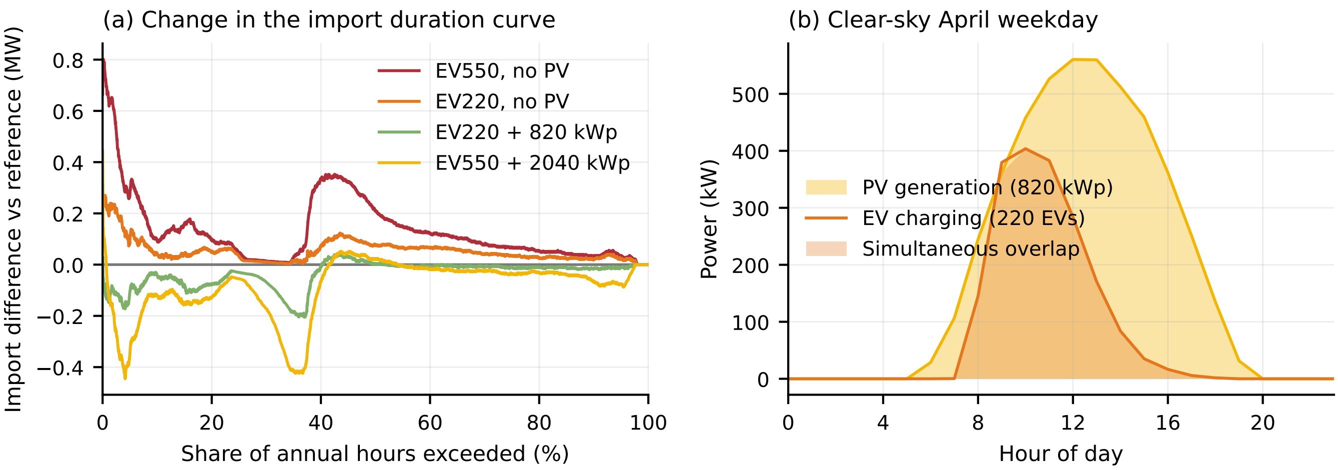

Figure 4: (a) Difference between the annual grid-import duration curve of each scenario and that of the campus reference. Positive values indicate a higher import at the same exceedance level. (b) PV generation and EV charging power on a clear-sky April weekday in the 220-EV and 820 kWp scenario; the shaded intersection is the temporal-coincidence term of Eq. (6).

taking at each hour the smaller of PV generation and EV charging power. It gives 62.4% to 63.2% of the grid energy drawn for charging, and represents the maximum share of charging that could temporally coincide with solar production, not the share physically supplied by it. Figure 4(b) illustrates this overlap on a representative day: charging demand peaks shortly after the morning arrivals, whereas PV generation peaks around midday, so the two profiles coincide only partially. The temporal margins identified in Section 5.2 indicate potential for shifting part of the demand towards midday, but this benefit is not quantified by the uncontrolled-charging model.

5.6 Interpretation and scope of the simulation

The simulation shows that 3.7 kW charging is best suited to vehicles connected for most of a working day. In the 220-EV scenario, medium and long stays achieve respectively 99.0% and 100% energy coverage, while incomplete service is concentrated among short stays and low-presence Saturday sessions. Increasing the fleet size raises annual energy use and aggregate power but leaves the service delivered per connected vehicle broadly unchanged under the same behavioural assumptions. Differences in arrival, departure and charging-completion times keep the simulated peak below the nominal sum of all connections. Additional PV reduces annual grid imports more effectively than maximum import because solar generation and peak campus demand do not always coincide.

Charging efficiency mainly affects the sessions with the least temporal flexibility. In the 220-EV scenario, the realistic 90%-efficiency case reduces energy coverage from 97.9% to 97.1% relative to the ideal loss-free case, while fully satisfied sessions decrease from 93.0% to 90.6%. For short stays, satisfaction decreases more markedly, from 44.5% to 33.6%. These results support the use of reinforced sockets for long-duration parking, while shorter stays or larger immediate energy needs may require higher-power alternatives, although this differentiated configuration is a design implication rather than a scenario directly tested here. However, the model assumes that every simulated vehicle can access a connection and represents the campus at hourly resolution, which smooths sub-hourly peaks; it therefore assesses charging adequacy after connection, rather than socket availability or compliance with local electrical-network constraints.

6. Pilot experiment and user acceptance

The campus survey indicates whether low-power charging is considered useful in principle, and the annual simulation quantifies the energy service that a 3.7 kW connection can deliver. The pilot contributes a third and different type of evidence. It tests whether the service can be absorbed into ordinary working days by real drivers, and it exposes practical constraints that neither a questionnaire nor a model can anticipate. It should therefore be read as a field test of use and acceptance rather than as an instrumented validation of the simulated energy flows.

6.1 Experimental setup and protocol

The pilot ran on working days from 6 July to 15 August 2026, using two Legrand Green'up Access reinforced outlets installed behind Hall Stévin. Two vehicles could be connected at the same time and could stay plugged in for the whole of their normal campus presence, so no relocation during the day was required. Seven volunteers were initially scheduled. They were selected on their expected presence during the study window, their access to a rechargeable vehicle and their willingness to use their own portable Mode 2 cable, and the intended group covered different battery sizes as well as both cars and an electric motorcycle.

The outlets are rated 16 A at 230 V, that is 3.7 kVA. In Mode 2 the current actually drawn is negotiated between the vehicle and the portable cable, and a cable supplied with a vehicle is often rated below the 16 A of the outlet. Participants used their own cables and no cable rating was recorded, so the power actually delivered cannot be assumed equal to the nominal rating of the outlet.

Each participant completed an initial questionnaire covering the vehicle, usual mobility and charging practices, expected usefulness and intention to use, and a final questionnaire covering the number of days of use, connection duration, driver-estimated recovered range, sufficiency for the immediate mobility need, difficulties encountered, satisfaction and preferred operating rules. Opinion statements were rated on a five-point scale, where 1 denotes strong disagreement and 5 strong agreement. A questionnaire after each charging day was designed but not deployed, in order to keep the effort asked of volunteers low over a six-week period. The items themselves are reproduced in Appendix 1, and their origin and intended role are documented in Appendix 2.

No dedicated meter was installed on the two circuits, so connection durations and recovered ranges are driver-reported quantities.

6.2 Participants and representativeness

Four of the seven scheduled volunteers used the outlets and returned both questionnaires; the others withdrew or could not take part during the study window. Table 9 summarises their profile and their observed use.

The four cases are few, but they are not interchangeable. Three are battery-electric cars whose usable capacities cluster between 51 and 58 kWh, so the sample covers the mid-size segment without testing the small electric-only batteries of plug-in hybrids or packs above 60 kWh. The fourth case, an electric motorcycle, extends the range downwards by an order of magnitude: with a 3.9 kWh battery and a consumption of about 6 kWh/100 km, a single low-power session covers well over a full round trip, but its onboard charger is limited to 0.9 kW [19]. The rider declared a recovered range of about 65 km, and that figure matches the battery and consumption values above, so the reference values used below can be trusted. Access to charging elsewhere also varied: two participants had a home wallbox, one had only a standard domestic socket and one declared no dedicated home charging point. The group combined staff members and one student. Home–campus distances were homogeneous and short, between 10 and 15 km one way. That is representative of a large part of the commuting population identified in the survey, though not of its longer-distance minority.

6.3 Use, recovered range and reconstructed energy

The four participants used the outlets on 10, 8.5, 5 and 5 days, 28.5 charging days in all. Two typically stayed connected for two to four hours, two for four to six. That is less than the presence times they had declared before the pilot, and less than the working day the simulation assumes. All four still answered that the range they recovered had always covered the return journey or whatever they needed that day.

The initial questionnaire recorded the vehicle model, so the range each driver estimated can be turned into energy with the relation $E_{\text{req}} = d\,c/100$ from the methodology, taking c as the published real-world consumption of that model [19, 20]. Those consumption values sit inside the range Weiss et al. report for the European electric car fleet [18]. Table 9 gives the result for the three participants who provided an estimate, with the average power it implies over their declared connection time.

The reconstructed energy runs from roughly 1 to 9 kWh per charging day, which places the whole pilot at 100 to 150 kWh over the 23.5 of the 28.5 charging days for which an estimate exists, or 4 to 6 kWh on an average day. No participant averaged more than 2.6 kW, well under the rating of the outlet. The three values belong to three different vehicles rather than to one distribution: the motorcycle cannot exceed its own 0.9 kW charger, while the two car values match portable Mode 2 cables limited to 10 to 14 A, possibly with sessions that stopped once the vehicle reached the charge level the driver had set. What limited the energy delivered was the vehicle and the size of the top-up needed, not the socket.

Set against actual use, that quantity is generous. The home–campus round trip of these participants requires 1.2 to 3.7 kWh, and they recovered between one and four times as much. At the nominal 3.7 kW, the connection times observed here would have made 7 to 22 kWh available. A reinforced outlet therefore delivers well beyond what an ordinary campus presence demands, and it still does at the reduced power the participants appear to have used.

The intervals in Table 9 are deliberately wide, since the values inside them come from driver estimates. What makes the reconstruction usable is that three separate self-reports, each converted with its own published consumption figure, all agree with the limits their own equipment imposes. That is an order-of-magnitude check and not a measurement, but it is not arbitrary.

One systematic effect is not captured by these intervals. A range converted into energy gives the energy that reached the battery, and reaching the battery costs more at the socket: during a session the on-board charger and the vehicle's own auxiliary consumption take a share of what is drawn, and that share grows as the charging current falls [2]. Applying the same charging efficiency of 0.90 as the simulation raises these values by about a tenth. No participant drew more than roughly 2.9 kW at the socket, and the pilot as a whole drew between about 110 and 170 kWh. Neither conclusion changes: the power stays below the rating of the outlet, and the margin

Table 9: Profile and observed use of the four pilot participants. Energy and power figures are reconstructed from the driver-estimated range and the reference consumption of each model; they are not measured values. "Home" is the one-way home–campus distance, "Connect." the typical daily connection time, "Range" the driver-estimated range recovered, "Energy" its conversion through $E = d\,c/100$ and "Power" the battery-side power this implies over the connection time.

	Model	Battery (kWh)	Cons. (kWh/100 km)	Home (km)	Charging at home	Days used	Connect. (h)	Range (km/day)	Energy (kWh/day)	Power (kW)
P1	BMW CE 02 (motorcycle)	3.9	6.0	10	Socket	10	2–4	20–40	1.2–2.4	0.3–1.2
P2	Cupra Born	58	14.4	11	Wallbox	5	2–4	n.r.	n.r.	n.r.
P3	Tesla Model 3	52.5	13.0	10	None	5	4–6	>60	7.8–10.4	1.3–2.6
P4	MG MG4	50.8	14.7	10–15	Wallbox	8.5	4–6	40–60	5.9–8.8	1.0–2.2

n.r.: not reported. Reference consumption: real-world combined values for mild weather [20] for the cars and the manufacturer WMTC figure [19] for the motorcycle. The commuting need implied by the home–campus round trip is 1.2, 3.2, 2.6 and 2.9–4.4 kWh per day for P1 to P4, so the energy recovered represents 1.0–2.0, –, 3.0–4.0 and 1.6–2.4 times that need.

Table 10: Ratings given by the four participants before and after the pilot, on a five-point scale from 1 (strong disagreement) to 5 (strong agreement). Values are the median of the four answers, with the lowest and highest answer in parentheses.

Statement	Before	After
Rated before and after the pilot		
Useful for daily mobility	5 (5–5)	5 (4–5)
Compatible with parking	5 (5–5)	5 (5–5)
Simple to plug in and use	5 (4–5)	5 (4–5)
Fits weekly organisation	4.5 (3–5)	5 (5–5)
Would use it permanently	5 (4–5)	5 (4–5)
Free or low cost matters	4 (3–5)	4 (3–5)
Accepts reduced charging	5 (5–5)	5 (5–5)
Rated after the pilot only		
Reduces reliance elsewhere	–	4 (3–5)
Overall satisfaction	–	4.5 (4–5)

over the commuting requirement stays wide.

All four said the campus outlet had taken over part of the charging they would otherwise have done elsewhere, and for most of them that meant charging less at home. One participant, who also used public charging points, reported using those less as well.

6.4 Perceived usefulness and acceptance

Table 10 compares the ratings given before and after the pilot. The participants were already favorable before any use, which left little room for an increase, and the ratings stayed at the same level once the service had been used. Compatibility with parking time was rated 5 by all four participants both before and after, and usefulness and ease of use kept a median of 5.

The one item that moved is organisational. Fitting a planned charging day into a normal week was the least consensual expectation before the pilot, with answers from 3 to 5, and all four participants rated it 5 afterwards. Within this small group, practical experience removed rather than confirmed the doubt about scheduling. Willingness to use a permanent service also stayed high: two participants would use it one or two days a week and two would use it four or five days a week.

Price was rated as a factor, with a median of 4, but below usefulness, compatibility and ease of use, so it does not appear to be the only reason for the reception the pilot received. The item on reduced reliance on other charging locations received the lowest median of the set, 4 with answers from 3 to 5, which is consistent with three of the four participants already having a charging point at home.

All four participants agreed without reservation with the principle of a temporary reduction or interruption of charging, provided that their minimum mobility need at departure is preserved. The conditions they attached to this agreement differ in an informative way: three linked it to a better use of renewable electricity, and three asked either for a guaranteed minimum energy or for the possibility of declaring a departure time or a minimum range. Low power charging on campus therefore appears compatible with a future renewable-following or controlled operation, and the design of such a scheme would benefit from making explicit to the user what remains guaranteed at departure.

6.5 Operational lessons and limitations

Two participants reported that access to the outlets or their location was inconvenient, one of whom added that this was the only drawback since the range was always secured, while another reported no difficulty at all. The motorcycle user noted that the exposed parking position left the removable battery in direct sunlight during the day. Preferences on how the outlets should be allocated were not unanimous: two participants preferred booking a time slot, one preferred fixed assigned days and one preferred giving priority to drivers without home charging. Availability of a compatible Mode 2 cable also proved to be a practical prerequisite that cannot simply be assumed. A technically simple outlet therefore still requires rules on eligibility, allocation and siting, and a sheltered position is preferable where bikes and motorcycles are concerned.

The pilot remains exploratory. Its four participants volunteered, charging cost them nothing, and their periods of use were uneven. The ratings of Section 6.4 therefore describe how a small, self-selected group experienced the service, and not what the campus population would report.

What the pilot adds is nonetheless specific. Four people used the service for several weeks before judging it: the range they recovered always covered what they needed, their doubts about scheduling faded with use, and satisfaction stayed high. Four users cannot establish that low-power charging is sufficient at campus scale. What they can do is remove two objections that would otherwise stand in the way: that a reinforced outlet cannot deliver enough energy within an ordinary parking duration, and that a scheduled charging day is too rigid to fit into a working week. Neither survived contact with real use, and that includes the participant whose vehicle cannot draw more than 0.9 kW.

The pilot also surfaced three implementation issues that neither the survey nor the simulation could reach: cable compatibility, where the outlets are placed, and how access to them is allocated. A larger follow-up should keep the questionnaires and add what this one lacked: metering at the socket, automatic connection timestamps, a record of cable and vehicle characteristics taken before the first session, and a window long enough to reach the winter, since the consumption values used here are mild-weather figures and a pilot run in July and August cannot say what the same journeys cost in January [20].

7. Economic assessment

7.1 Scope and method

The question addressed here is not what a campus-wide deployment would cost as a project budget, but whether low-power charging is a defensible use of university money compared with the conventional alternative. Three quantities are kept separate: the capital cost of equipping a parking space, the annual cost of the electricity consumed, and the service actually delivered to the user. All amounts exclude VAT.

One distinction governs the whole section. A vehicle keeps its space long after its battery is full, so two different counts matter: how many cars are plugged in at once, which fixes the number of points to build, and how many are drawing power at once, which fixes the size of the electrical connection. Neither is the size of the fleet, and Section 7.3 shows that the two behave very differently.

Capital and running costs are compared on a common annual basis. The capital recovery factor (CRF) converts a capital sum into the constant yearly payment that would repay it over the life of the equipment, in the same way as a loan annuity [21]:

$$\mathrm{CRF}(r, L) = \frac{r(1+r)^L}{(1+r)^L - 1}. \tag{7}$$

With a lifetime $L = 15$ years and a discount rate $r = 4\%$, CRF = 8.99%; adding maintenance at 1% of capital brings the annual charge to almost exactly 10% of the investment. Both are conventional values, used here because UCLouvain's own financial parameters were not available.

7.2 What the pilot installation actually costs

The pilot is treated as a cost measurement rather than as a price list. Its total of EUR 1 869 for two 3.7 kW reinforced outlets gives an apparent average of EUR 934 per point, but that average depends on having installed exactly two. Table 11 sorts the itemised quotation into the three ways its items behave.

The quotation gives a single price for each of its two lines, so the split shown for the second one is our own estimate rather than the installer's. It is nevertheless well constrained, since only the outlet and its type B residual-current device must be duplicated for each additional point, the residual-current device being the more expensive of the two. On that basis, about EUR 450 per point and EUR 450 for the cabinet, plus EUR 21 per metre of feeder, reproduce the invoiced total.

The shared part is visibly oversized. The cabinet, its isolator and its contactor are rated 25 A per phase, roughly 17 kW, enough for three or four 16 A single-phase points; only two were installed. A third and a fourth outlet on the same cabinet would cost no more than the per-point items, bringing the average down towards EUR 700. The apparent unit price of the pilot is therefore a consequence of its small size, and multiplying it by a number of parking spaces would repeat the shared items as many times as there are outlets.

Table 11: How the items of the pilot quotation scale (SC04 building, two 16 A reinforced outlets). EUR excluding VAT.

Item	Scales with	Amount
XGB 5G4 mm^2 feeder, 25 m, supplied, laid and connected	length of route	517
Enclosure, 25 A 4P isolator, 25 A 4P contactor, 4 A control breaker, external on/off switch	number of cabinets	≈ 450
16 A 2P breaker with 30 mA type B residual-current device; Legrand EV outlet	number of points	≈ 900
Total		1 869

Equation (8) formalises this behaviour. Its purpose is to separate what is paid once per site from what is paid once per point, which is what determines how cost evolves with the size of a project:

$$\begin{aligned} C_{\mathrm{CAPEX}} = C_{\mathrm{study}} + \sum_{j=1}^{J} \left(\ell_j\, c_{\mathrm{feed}} + C_{\mathrm{cabinet},j}\right) \\ + N\, C_{\mathrm{point}} + \ell_{\mathrm{civil}}\, c_{\mathrm{civil}} + C_{\mathrm{reinforcement}}, \end{aligned} \tag{8}$$

where J is the number of electrical clusters, ℓ_j the feeder length of cluster j and N the number of points. Of all these terms, only $N\, C_{\mathrm{point}}$ is proportional to the number of equipped spaces.

7.3 How many points, and does 3.7 kW suffice?

The simulation of Section 5 produces, for every charging session, an arrival time, a departure time and an energy requirement. These sessions were replayed at 3.7, 7.4, 11 and 22 kW. The sessions themselves are unchanged from one case to the next — same vehicles, same arrivals and departures, same energy to recover — so the only thing that varies is how quickly a point can supply that energy.

In the 550-vehicle scenario the fleet generates 70 687 sessions a year. A car stays 8.3 hours on average, with a median of 9.3 hours, and asks for 15.3 kWh; these are properties of the parking event and of the driver, and they are identical in all four cases. What the rated power changes is the time needed to deliver those 15.3 kWh: 4.5 hours at 3.7 kW, 1.5 hours at 11 kW and 0.8 hour at 22 kW.

Figure 5 shows the consequence. The number of occupied points follows arrivals and departures, not charging speed, so the grey envelope is the same in all four cases. Sizing on the 95th percentile of weekday daytime occupancy gives 279 points for 550 vehicles, one point for two cars, and that figure is the same at every power tested. What differs is what happens inside the envelope: a point is electrically active 53%

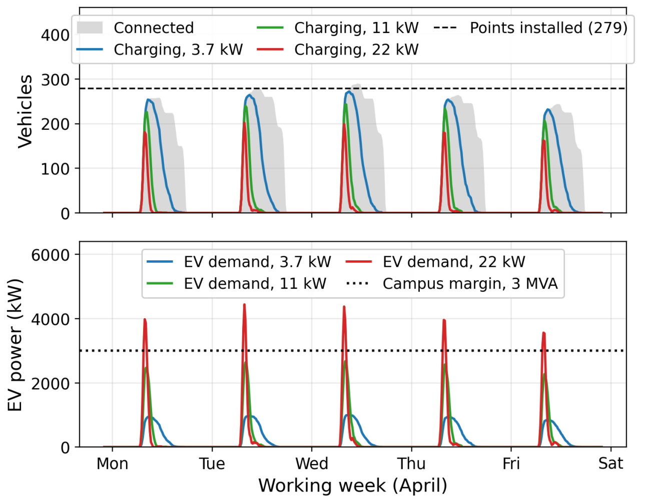

Figure 5: One working week of the 550-vehicle scenario. Upper panel: vehicles connected, and vehicles actually charging at each rated power. The occupancy envelope, and hence the number of points to install, does not depend on the rated power. Lower panel: the resulting demand, compared with the margin presently available at the campus connection.

Table 12: Effect of the rated power on service and on demand, 550-vehicle scenario. The sessions are identical in all four columns.

	3.7 kW	7.4 kW	11 kW	22 kW
Energy not delivered (%)	2.80	0.11	0.00	0.00
Sessions completed (%)	91.0	99.4	100.0	100.0
Shortfall per session (km)	2.3	0.1	0.0	0.0
Charging time (h)	4.5	2.3	1.5	0.8
Points required	279	279	279	279
Point in use (%)	53.5	28.2	19.4	10.5
Peak EV demand (MW)	1.1	2.1	3.0	4.8

of the time it is occupied at 3.7 kW, 19% at 11 kW and 10% at 22 kW.

Table 12 measures what the service actually loses. At 3.7 kW, 2.8% of the requested energy is not delivered before departure and 91% of sessions are completed in full, the mean shortfall over all sessions being 2.3 km of range. Low-power charging is therefore not entirely free of consequences, but the shortfall is small and, more importantly, it is not spread evenly. Sessions lasting a full working day, which are 62% of the total, are completed in 99.9% of cases. The 10% of sessions shorter than about four hours account for 79% of all the energy not delivered.

The difficulty is thus not the power of the outlets but their unsuitability for brief stops. Raising every point to 7.4 kW would indeed remove almost all of the shortfall, but it would double the peak demand of the entire installation in order to serve a small minority of visits. Equipping a limited number of spaces with higher-power chargers, and leaving the remainder at 3.7 kW, reaches the same users without inflating the connection. It is this mixed configuration, rather than a uniform increase in power, that the present results support.

The cost of the extra power, by contrast, is substantial. A higher-power charger exists precisely to deliver the energy in 1.5 hours at 11 kW, or 0.8 hour at 22 kW, instead of 4.5, and since almost every car arrives within the same morning window, the same annual energy is compressed into a much shorter and much higher peak: 3.0 MW at 11 kW and 4.8 MW at 22 kW, against 1.1 MW for the same fleet (Fig. 5, lower panel). It is that peak, not the annual consumption, which sizes cables, transformers and the connection itself.

The campus is supplied at 11.25 kV under a contractual capacity of 8.125 MVA, with a margin of approximately 3 MVA presently available at the head substation [22]. The comparison is most telling at 11 kW, the power for which these car parks have actually been costed (Section 7.4). Over the year, these 279 spaces peak at 3.0 MW at 11 kW and absorb essentially the whole of that margin; at 22 kW they exceed it; equipped with reinforced outlets they call on about a third of it. This says nothing about the loops and boards close to each car park, whose capacity would have to be checked individually. But the gap is wide enough that the options do not pose the same problem: one fits inside the existing margin, the others take all of it.

Table 13: Points required and cost by fleet size. Equipment only, at the invoiced pilot unit cost and the ACEA benchmark respectively; civil works excluded. kEUR excluding VAT. The 3.7 kW row uses EUR 934 per point, an upper bound at scale (Section 7.2); the 11 and 22 kW rows apply the ACEA average of EUR 125 per installed kW linearly, which understates a managed AC station at the lower power.

EV fleet size	55	110	220	550
Points required	31	59	114	279
Energy delivered (MWh/yr)	105	209	423	1 050
Per point (MWh/yr)	3.4	3.5	3.7	3.8
Electricity (kEUR/yr)	9.6	19.2	38.8	96.3
Equipment, 3.7 kW	29	55	106	261
Equipment, 11 kW	43	81	157	384
Equipment, 22 kW	85	162	314	767

7.4 Comparison with conventional AC charging

The pilot cost EUR 934 per outlet, equipment and connection included, on a site where a distribution board stood 25 m away and no excavation was needed. The European EV Charging Infrastructure Masterplan reports about EUR 125 per installed kW across the 4–22 kW range, excluding grid investment [23], which places an 11 kW point near EUR 1 375 and a 22 kW point near EUR 2 750. That average is applied per kW, and an AC station carries an enclosure, a meter, communication, user identification and load management whose cost barely changes with the rated power, so EUR 1 375 is a floor rather than a price. A firm comparison would need quotations for both technologies on the same site, which this work does not have; Table 13 therefore reports the benchmark for what it is, and the argument below does not rest on the ratio.

A local figure shows how small a share of a real project that equipment represents. A design study prepared for UCLouvain in 2024 costed an installation of 52 charging points at 11 kW across seven campus car parks at an estimated EUR 500 000 to 650 000 [24]. The estimate covers earthworks and trenching, ducts and a draw pit, metering, cabling from the main low-voltage board, distribution boards and protection, interlocking with fire detection where the car park is enclosed, the chargers, load balancing, protective bollards, signage and maintenance. That is of the order of EUR 10 000 per point, against roughly EUR 1 400 for the charger itself [24]. The study has not been executed, and the reasons are not documented here, but its bill of quantities remains the most detailed description available of what equipping these particular car parks involves. It is consistent with published cost breakdowns of charging sites, in which trenching, reinstatement and the grid connection routinely exceed the price of the equipment [25].

This bounds what can be claimed for the reinforced outlet. Most of that figure does not depend on the charging power. A trench costs what it costs to open and reinstate, and the study's bill of quantities itemises 162 m of trenching across five surface types, from pedestrian paving to asphalt [24]. Substituting a reinforced socket for a charger at the end of the same trench saves the equipment and a conductor size, not the trench. The advantage of low power is therefore not a proportional reduction of the project cost. It is that the outlet can be placed where no trench is needed: on facades, on existing walls, close to boards that are already there, exactly as the pilot was.

Two differences hold whatever the size of the project. The first is the electrical envelope: the same study specifies load balancing at all seven sites, because 52 points at 11 kW represent 572 kW that the boards cannot supply at once, whereas the same 52 spaces at 3.7 kW represent 192 kW and need no such system. The second is what can be taken from the installation that already exists. The study connects to the moulded-case circuit breaker already present at three of the seven car parks, and has to add one at the other four [24]. Spare capacity is therefore scattered: some boards have room and others have none. A single large load must find one board with enough room for all of it, whereas a set of small ones can take a little from each.

Several costs escape every figure quoted so far. The distance to the nearest suitable board is decisive, and the pilot, with a board a few tens of meters away, is a favorable rather than a representative case. Ownership is not uniform either: part of the parking capacity is connected to the ORES distribution network or operated under private concession, so a single arrangement would not apply everywhere [22]. And operation, from supervision to any obligation arising from the closed professional network regime, is recurring. Against all this, an 11 kW charger provides metering, communication, user identification and dynamic load management that a reinforced outlet does not, functions whose operational value is not credited anywhere in this comparison.

7.5 Annual energy cost and cost recovery

The electricity attributable to charging is obtained by difference. The campus is simulated twice, with and without EV charging, the load and the photovoltaic capacity being otherwise identical, and the two import and export profiles are subtracted from one another:

$$C_{\mathrm{EV}} = \sum_{t} \left[p_t \left(I_{s,t} - I_{0,t} \right) + p_t \left(X_{0,t} - X_{s,t} \right) \right] \Delta t, \quad (9)$$

where I and X are campus import and export and p_t the Belgian day-ahead price, for which Elia publishes the reference series [26] and whose 2025 annual mean was EUR 82.6/MWh [27]. Working by difference rather than from the charging energy alone matters, because part of the charging is met by local generation and never appears as an additional purchase.

For the 550-vehicle scenario the calculation gives EUR 96 thousand a year, or EUR 175 per vehicle. That is easier to judge against the fuel it replaces. Each vehicle receives about 1.9 MWh at the battery over the year, which at the battery-side consumption of 18 kWh/100 km assumed in the simulation (Table 4) corresponds to some 10 600 km. A petrol car covering the same distance would burn roughly 760 liters at 7.2 L/100 km, the on-road average measured for European passenger cars [28], worth EUR 1 260 at the 2025 Belgian average of EUR 1.65 per liter [29]. The electricity the university would pay for is therefore of the order of one seventh of the fuel expenditure that the same mobility would otherwise require.

Whether that cost is recovered depends on what users are charged. The break-even tariff has two components: the annual charge on the infrastructure, about a tenth of its capital cost spread over the 3.8 MWh a point delivers each year, and the electricity itself, close to EUR 0.09 per kWh delivered at the day-ahead price used above. Applied to the equipment references of Section 7.4, this gives about EUR 0.12 per kWh for reinforced outlets, EUR 0.13 for 11 kW and EUR 0.17 for 22 kW charging, all below the EUR 0.35 per kWh that a Belgian household paid for electricity in 2025 [30].

Those figures cover equipment alone. Applying the same convention to the 2024 design study and treating its whole estimate as capital pushes the break-even up to between EUR 0.36 and 0.42 per kWh. Two assumptions inflate that range: the estimate bundles a maintenance contract with the works, and the energy per point is transferred from the simulation rather than measured. The order of magnitude is nevertheless the useful result. What it separates is the two options from each other, not the campus from the home. Civil works, not equipment, are what carry a tariff from the comfortable range into the uncomfortable one. They also weigh twice on the higher-power option, which needs both the trench and the larger conductor inside it. This is where the low-power solution earns its case: it stays near EUR 0.12 per kWh before any works are avoided at all, and it can be placed on the sites where they are not needed.

7.6 Limitations

Several limits apply. The unit costs rest on a single quotation for one favourable site, and the split between shared and per-point items within it is an estimate rather than an invoice. The AC reference, meanwhile, is a published European average applied linearly to a power at which it is unreliable.

Civil works are quantified through one local study only, itself a pre tender estimate that bundles the works with a maintenance contract, and they vary considerably from one car park to another. The number of points is a sizing choice, the 95th percentile of weekday daytime occupancy. The model also assumes that every arriving vehicle finds a free point, so queuing is not represented.

Charging is simulated as uncontrolled, so every peak reported here would be lowered by any form of load management. The day-ahead price is a wholesale reference from which network tariffs, levies and supplier margin are absent. Beyond the head substation, the capacity actually available on the campus network cannot be established either.

8. Regulatory context and deployment perspectives

What the service delivers and what it costs has now been established. Four things still stand between the pilot and a campus installation: the legal status of the outlets, the capacity of the campus network, the condition of the car parks themselves, and the rules under which the service would run. This section takes each of them as far as the available evidence allows. The aim is to show that these routes are credible, not to design a future installation.

8.1 Regulatory status of the installation

The RGIE, the Belgian general regulation for electrical installations, devotes its Chapter 7.22 to charging stations, meaning fixed equipment wired specifically to supply a vehicle. A reinforced socket is not that. Charging through a socket outlet falls back on Book 1, the part of the RGIE that sets the general rules for every low-voltage installation in the country [14]. The socket is regulated, then, but by rules written for sockets rather than for vehicle charging.

Chapter 7.22 remains the right reference for design. It requires a dedicated circuit for each connection point, its own overcurrent protection, a 30 mA residual-current device, protection against DC residual currents, and outdoor equipment able to take weather and impact. None of this applies automatically to a socket, so it has to appear in the specification instead. The pilot circuit was built this way. The same specification should also cover phase allocation, mechanical protection, cable routing and inspection intervals.

The installation is also divided differently from a conventional station. The control and protection electronics sit in the driver's Mode 2 cable rather than in fixed equipment. That is what allows the fixed part to stay as simple and as inexpensive as Section 7.2 describes. The counterpart is that one link in the charging chain belongs to the user, so the specification has to state which cables are accepted and in what condition they must be kept.

Whether such an outlet counts as a charging point is not a formality, because Wallonia now imposes a minimum number of them. Under the regional energy performance of buildings framework, known as the PEB, any existing and mainly non-residential building attached to more than twenty parking spaces has had to provide at least one charging point, together with empty cable ducts serving one space in five, since 1 January 2025. The obligation applies automatically: it waits neither for building works nor for a PEB procedure [31]. The Walloon text defines a charging point by what it does, an interface that allows a vehicle to be recharged, and sets no minimum power [31]. European law is narrower but points the same way: it excludes devices of 3.7 kW or less only when charging vehicles is not their main purpose [32]. A socket installed for that purpose is therefore counted. That is also how the campus network operator reads it [22].

Two things follow. UCLouvain can meet this obligation with reinforced sockets rather than with charging stations, at a lower equipment cost and without the connection capacity that the same number of stations would demand. And the ducts it has to lay for one space in five are the ducts any later extension would use.

Which buildings are concerned is less obvious. A car park only counts as attached to a building when it is physically connected to it, used mainly by its occupants, and owned by the same party [31]. Part of the campus parking sits on the ORES network or under private concession [22], so the obligation does not fall evenly across the site and the perimeter has to be established building by building.

That ratio will rise. Where the requirement today is one charging point and ducts for one space in five, the recast European directive on the energy performance of buildings asks, for new and heavily renovated non-residential buildings with more than five spaces, for one charging point per five spaces, one per two in office buildings, and pre-cabling for at least half the spaces; existing buildings above twenty spaces move to one point per ten by January 2027 [33]. Wallonia had not published its implementing text at the time of writing, and these are minima it may tighten. Whatever the final timetable, it is the density that constrains the choice of power. Section 7.3 showed that 279 spaces at 22 kW would on their own exceed the margin available at the campus connection, and that 11 kW would absorb essentially all of it. One point for every two spaces is reachable at low power, and not much else.

Access rules matter too. A service open only to identified staff and students is not public infrastructure, so it escapes the European requirements on ad hoc payment, price display and connectivity that a publicly accessible car park would trigger [32]. That keeps the service simple. It does not remove the need to name someone responsible for it, to record incidents, and to justify whatever is metered under data-protection rules.

8.2 Integration into the campus network

Section 7.3 measured a deployment against the margin at the head substation. The network operator points to a tighter constraint further down. The medium-voltage loops that distribute power around the site are already well loaded, and charging is not the only project queuing for what is left, since new buildings will also need to connect [22]. Where the power is drawn therefore matters as much as how much of it is drawn.

A low-power deployment can be broken up; a high-power one cannot. Twenty reinforced outlets come to about 74 kW, and that total can be split between several boards on different loops. Twenty spaces at 22 kW form a single 440 kW block, drawn at one point of one loop, which usually calls for a connection of its own.

The design study prepared for the campus in 2024 illustrates the difference. Spread over seven car parks, it keeps the moulded-case circuit breaker already installed at three of them, adds a new one at the other four, and specifies load balancing at every site [24]. Even at 11 kW, then, the installed power cannot simply be drawn: it has to be actively managed to fit what the boards can supply. A 3.7 kW deployment reaches a comparable number of spaces without that equipment, because the diversity measured in the simulation already holds the aggregate to about half the installed total.

This turns a capacity question into a siting question, and the survey it calls for is a modest one. For each candidate car park, it is enough to establish how much room remains at the nearest board and on the loop that feeds it. Points can then be placed where headroom already exists. The same survey identifies the car parks that have none, and those belong to a later phase rather than to an immediate reinforcement of the network.

8.3 Site conditions and car park types

Surface car parks come first, though not because the others are impossible. Two things separate them. The dominant expense of any deployment is not the outlet, it is reaching it: trenching and reinstatement routinely cost more than the equipment [25]. And the campus car parks are not equally ready. Several are old, with aging distribution that would have to be renewed before carrying a new continuous load, so the work involved is a renovation rather than an addition.

Section 7.4 puts a local figure on that work: the 2024 design study for seven campus car parks comes to about EUR 10 000 per point at 11 kW once earthworks, cabling, boards and protection are counted, against approximately EUR 1 400 for the charger [24]. What matters for siting is that most of that difference does not depend on the charging power.

If reaching the space is the expensive part, one option removes much of it and answers a second problem at the same time. A solar canopy spans a row of spaces and can carry cable trays to each of them, which avoids most of the excavation; it also generates directly above the vehicles that consume, so that energy never crosses the loaded loops. The timing suits workplace charging: the coincidence ratio of Eq. (6) puts the upper bound on the overlap between charging and solar output at just above 60%, because the cars are there during the day. A canopy is also a building, with a permit and a structure to pay for, and whether it beats a trench in a given car park is a calculation this work has not made. It remains the only option identified here that answers the cost, the network and the renewable question together.

Covered and underground car parks bring further requirements, electrical as well as regulatory. Fire detection has to cut the supply, an emergency stop has to be within reach, ventilation and evacuation conditions have to be agreed with the fire service, and the supply itself has to be routed and protected inside a structure never designed to carry it. These are the reasons the pilot stayed outdoors.

They are not reasons to leave underground parking out of the plan. The 2024 study already covered two enclosed car parks, and the additional work appears there as identifiable items rather than as an open risk: fire-detection interlocking, emergency stops and wall-mounted equipment [24]. Waiting for new construction is not an option either, since the Louvain-la-Neuve car parks lie beneath the center of the city and cannot be relocated. The realistic route is to fold these provisions into the renovation each of these structures will need in any case, and to prefer low power there for the same reason it works above ground: it demands the fewest changes to a structure where every change is expensive.

8.4 Operating the service

Three questions remain whatever is built, and none of them needs new hardware.

Access comes first. A free service still needs rules: who may use it, who answers for the cable, what happens when equipment breaks, and how points are allocated when demand exceeds their number. One rule should not be borrowed from public charging. The purpose of low-power charging is to use the hours a car is already parked, so asking a driver to move a full vehicle in the middle of the day would remove the reason for it. Fairness is better served by adding outlets, which are inexpensive, and by stating clearly who is eligible.

Someone then has to own the service. Inspection, faults, signage and user communication need a named operator. A research project cannot fill that role at campus scale, and the work keeps costing money even when the electricity is free.

Finally, the university has to decide what it measures. Everything needed to plan the network and to judge whether a further stage is warranted can be read from aggregates: energy delivered, occupancy, local peak, fault rate and user satisfaction. Individual records become necessary only where a specific function requires them, such as access control, billing, or attributing an incident to a session. Each of those uses carries a data-protection obligation, so which of them the service actually needs is worth settling before any metering is specified.

One development lies outside this study but will change its context. The planned biomass plant is expected to cover almost all of the campus heat and electricity needs [34], which would lower the carbon intensity of charging and improve the annual balance. It would not relieve the constraint described above. Generation added at one point of a network supplies energy; it does not increase what the loops running to the car parks are able to carry. Establishing what the plant does change for charging would require its connection point and its output profile, neither of which is available here.

One boundary should be stated plainly. Charging infrastructure serves journeys that are already made by car, and does nothing about congestion, land use or the space those vehicles occupy. The argument made here is that if the university is going to equip parking spaces, low power equips more of them for less, not that equipping them constitutes a mobility policy.

9. Conclusion

This thesis asked whether reinforced 230 V, 16 A sockets can form the base layer of a campus charging service at UCLouvain, and under which conditions. The answer given by the survey, the simulation, the pilot and the cost comparison is that the binding variable is parking duration, not charging power. A 3.7 kW connection transfers about 26.6 kWh to a battery over an 8 hour working day, some 148 km at the consumption assumed here, whereas the 18 regular campus drivers of the survey declare a daily need of at most 18.0 kWh and all of them could recover it within the parking interval they report. In the simulation, energy coverage stays between 97.0 % and 97.5 % and fully satisfied sessions between 90.6 % and 91.3 % as the fleet grows from 55 to 550 vehicles, for a mean recovered range close to 83 km. What a connected vehicle receives is therefore set by how long it stays, not by how many vehicles are equipped.

The shortfall that remains is concentrated rather than diffuse. Long stays reach full energy coverage, whereas sessions shorter than about four hours receive 76.8 % of what they request and account for 79 % of all the energy not delivered. Raising every point to 7.4 kW would remove almost all of that gap, but equipping an entire installation at 11 or 22 kW to serve a minority of brief visits multiplies the peak demand of the fleet by three to four. The results therefore support a mixed configuration, a majority of 3.7 kW points and a limited number of faster ones where short stays concentrate, rather than a uniform increase in rated power.

Acceptance was measured before and after real use, rather than asked about hypothetically. Four drivers used the outlets over several weeks. The range they recovered always covered what they needed that day, and their ratings of usefulness, ease of use and compatibility with parking time stayed at the top of the scale. The one expectation that had divided them beforehand, fitting a planned charging day into an ordinary week, was settled by use. All four accepted that charging be temporarily reduced or interrupted, provided a minimum energy is secured at departure. That is the condition any renewable following or load managed operation would have to make explicit to the user. Price ranked below usefulness in these ratings, but the pilot supplied free electricity, so that ranking cannot be carried over to a tariffed service.

The economic case rests on what a socket avoids rather than on what it costs. The pilot invoice gives EUR 934 per outlet and about EUR 700 per additional point on the same board, against roughly EUR 1 375 and EUR 2 750 for 11 and 22 kW stations at the European benchmark. The decisive figure lies elsewhere: the 2024 design study prepared for the campus reaches about EUR 10 000 per point at 11 kW, of which some EUR 1 400 is the charger and the rest is trenching, boards, protection and load balancing. Low power earns its case by needing none of that where a board is already close, and by fitting inside the capacity that exists: 550 vehicles peak at 1.1 MW, about a third of the margin presently available at the campus connection, against 4.8 MW at 22 kW, which would take all of it. On that basis a reinforced point recovers its cost at about EUR 0.12 per kWh delivered.

The photovoltaic pairing tested here changes the annual balance more than the peak: additional capacity lowers annual campus import below the reference, while the maximum hourly import stays above it, because the highest campus imports occur when solar generation is low. At most 62 to 63% of the charging energy could coincide with local production, which sets an upper bound on what a solar canopy could supply directly.

The recommendation of this article for UCLouvain follows. Equip suitable above-ground car parks with reinforced sockets wherever a distribution board is already within reach, using the ducts that the Walloon performance-of-buildings obligation requires in any case. Keep a small number of higher-power stations for short stays and exceptional needs. Extend the deployment only once delivered energy, occupancy, local peak, fault rate and user satisfaction have been recorded over a longer period.

What transfers to another site is the method and the diagnosis, not the numbers. The cost per point, the margin available at the connection and the regulatory framing are specific to this campus and to Wallonia / Belgium.

The evidence behind this remains exploratory, in line with the scope set out from the start. Fifty questionnaire responses were collected through personal and professional contacts, four pilot participants charged free of charge, the parking count was non-exhaustive, and the simulation ran uncontrolled at hourly resolution. Together, these sources describe the conditions under which the service works; they were never meant to establish its prevalence across the university. A follow-up should meter energy at the socket, timestamp connections automatically, and extend through the winter, since the consumption values used throughout are mild-weather figures.

Bibliography

[1] Statbel, "Parc de véhicules," 2025. Annual vehicle fleet statistics, reference date 1 August 2025; breakdown by fuel type and by holder (natural person / legal entity). https://statbel.fgov.be/fr/themes/mobilite/circulation/parc-de-vehicules; accessed 15 August 2026.

[2] T. Brincourt, D. Leroy, F. Giraud, R. Payen, and A. Séguret, "Electric vehicle AC charging efficiency at low charging power and consequences on local charging strategies," in *Proceedings of the 38th International Electric Vehicle Symposium and Exhibition (EVS38)*, (Gothenburg, Sweden), Electric Vehicle Symposium, June 2025. Conference paper. https://evs38-program.org/images/Proceedings/D%20Charging%20Infrastructure%20and%20grid%20integration/432_Paper%20Electric%20Vehicle%20AC%20Charging%20Efficiency%20at%20Low%20Charging%20Power%20and%20Consequences%20on%20Local%20Charging%20Strategies%20final.pdf.

[3] Legrand, "Prise en saillie VE 3,7 kva mode 2 — IP66, IK08, réf. 090471 (Green'up Access)," 2024. Legrand Belgium catalogue; 3.7 kVA, 16 A, single-phase, Mode 2. https://www.legrand.be/fr/catalogue/prise-saillie-ve-37kva-mode-2-ip66-ik08-090471; accessed 15 August 2026.

[4] C. Giles, C. Ryder, and S. Lommele, "Workplace charging: Charging up university campuses," Tech. Rep. DOE/GO-102016-4856, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Washington, DC, USA, Mar. 2016. https://docs.nrel.gov/docs/fy16osti/66003.pdf.

[5] I. S. Bayram, V. Zamani, R. Hanna, and J. Kleissl, "On the evaluation of plug-in electric vehicle data of a campus charging network," in *2016 IEEE International Energy Conference (ENERGYCON)*, 2016. Preprint available as arXiv:1602.02943. https://arxiv.org/abs/1602.02943.

[6] C. Hecht, J. Figgener, and D. U. Sauer, "Analysis of electric vehicle charging station usage and profitability in Germany based on empirical data," *iScience*, vol. 25, no. 12, p. 105634, 2022. doi: 10.1016/j.isci.2022.105634.

[7] S. Lamontagne, M. Carvalho, E. Frejinger, and R. Atallah, "What makes a good public EV charging station? a revealed preference study." arXiv preprint arXiv:2504.17722, 2025. https://arxiv.org/abs/2504.17722.

[8] T. Zeng, H. Zhang, and S. Moura, "Solving overstay in PEV charging station planning via chance-constrained optimization." arXiv preprint arXiv:1901.07110, 2019. https://arxiv.org/abs/1901.07110.

[9] S. Bae, T. Zeng, B. Travacca, and S. Moura, "Inducing human behavior to alleviate overstay at PEV charging station." arXiv preprint arXiv:1912.02341, 2019. https://arxiv.org/abs/1912.02341.

[10] V. Venkatesh, M. G. Morris, G. B. Davis, and F. D. Davis, "User acceptance of information technology: Toward a unified view," *MIS Quarterly*, vol. 27, no. 3, pp. 425–478, 2003. doi: 10.2307/30036540.

[11] M. Smith and J. Castellano, "Costs associated with non-residential electric vehicle supply equipment: Factors to consider in the implementation of electric vehicle charging stations," tech. rep., U.S. Department of Energy, Vehicle Technologies Office, Washington, DC, USA, Nov. 2015. Prepared by New West Technologies, LLC. https://afdc.energy.gov/files/u/publication/evse_cost_report_2015.pdf.

[12] Alternative Fuels Data Center, "Operation and maintenance for electric vehicle charging infrastructure," 2025. https://afdc.energy.gov/fuels/electricity-infrastructure-maintenance-and-operation; accessed 15 August 2026.

[13] Fireforum, "Code de bonne pratique : véhicules électriques dans les parkings." Fireforum asbl, 2nd ed., Oct. 2023. https://www.fireforum.be/fr/reglementation/cbp-vhicules-electriques-dans-les-parkings; accessed 15 August 2026.

[14] SPF Économie, P.M.E., Classes moyennes et Énergie, "Règlement général sur les installations électriques : Livre 1 — Installations à basse tension et à très basse tension," 2025. See in particular Chapter 7.22 on the supply of electric vehicles. https://economie.fgov.be/sites/default/files/Files/Publications/files/RGIE-Annexe-Livre-1-Installations-a-basse-tenstion-et-a-tres-basse-tension-2025.pdf; accessed 9 August 2026.

[15] UCLouvain, "Enquête mobilité 2024 : tableaux croisés, site de Louvain-la-Neuve." Unpublished cross-tabulations from the triennial company travel plan survey, provided by the UCLouvain mobility unit, 2024. Personal communication, 6 August 2026.

[16] M. Lahariya, D. Benoit, and C. Develder, "Synthetic data generator for electric vehicle charging sessions: Modeling and evaluation using real-world data," *Energies*, vol. 13, no. 16, p. 4211, 2020. doi: 10.3390/en13164211.

[17] P. Plötz, N. Jakobsson, and F. Sprei, "On the distribution of individual daily driving distances," *Transportation Research Part B: Methodological*, vol. 101, pp. 213–227, 2017. doi: 10.1016/j.trb.2017.04.008.

[18] M. Weiss, T. Winbush, A. Newman, and E. Helmers, "Energy consumption of electric vehicles in Europe," *Sustainability*, vol. 16, no. 17, p. 7529, 2024. doi: 10.3390/su16177529.

[19] BMW Motorrad, "BMW CE 02 — technical data," 2024. 3.92 kWh battery, 0.9 kW standard charger, 1.5 kW optional charger, 6.0 kWh/100 km (WMTC). https://www.bmw-motorrad.com; accessed 15 August 2026.

[20] EV Database, "Real-world range and consumption data: Tesla Model 3, CUPRA Born and MG MG4," 2026. Combined mild-weather figures. https://ev-database.org; accessed 15 August 2026.

[21] W. Short, D. J. Packey, and T. Holt, "A manual for the economic evaluation of energy efficiency and renewable energy technologies," Tech. Rep. NREL/TP-462-5173, National Renewable Energy Laboratory, Golden, CO, USA, Mar. 1995. https://docs.nrel.gov/docs/legosti/old/5173.pdf.

[22] UCLouvain, "Capacity and constraints of the Louvain-la-Neuve campus electrical network." Personal communication from the campus network operator, 2026.

[23] ACEA, "A European EV charging infrastructure masterplan," research whitepaper, European Automobile Manufacturers' Association (ACEA), Mar. 2022. https://www.acea.auto/files/Research-Whitepaper-A-European-EV-Charging-Infrastructure-Masterplan.pdf; accessed 7 August 2026.

[24] UCLouvain, "Planned 11 kW charging installation at the Louvain-la-Neuve campus: scope, bill of quantities and cost estimate." Personal communication from the project manager, with the bill of quantities established by WaLK Engineering, lot "Électricité", 2026. 24 dual 2×11 kW and 4 single 11 kW charging stations over seven car parks; estimate EUR 500 000 to 650 000 covering earthworks, ducts, cabling, distribution boards, protection, fire-detection interlocking, chargers, load balancing, bollards, signage and maintenance.

[25] Transport & Environment, "Roll-out of public EV charging infrastructure in the EU: Is the chicken and egg dilemma resolved?," tech. rep., Transport & Environment, Brussels, Belgium, Sept. 2018. Standard L2 charger, 11–22 kW: EUR 6 400 in total, of which EUR 1 400 equipment and EUR 5 000 installation and grid connection. https://www.transportenvironment.org/uploads/files/Charging-Infrastructure-Report_September-2018_FINAL-1.pdf; accessed 15 August 2026.

[26] Elia, "Belgian bidding zone day-ahead reference price." Elia Open Data Portal, 2025. https://www.elia.be/en/grid-data/transmission/day-ahead-reference-price; accessed 7 August 2026.

[27] CREG, "Study on the functioning and price evolution of the Belgian wholesale electricity market — monitoring report 2025," tech. rep., Commission de Régulation de l'Électricité et du Gaz (CREG), 2025. Reports an average Belgian day-ahead price of 82.6 EUR/MWh in 2025. https://www.creg.be/fr/publications/etude-f3197; accessed 7 August 2026.

[28] U. Tietge, N. Zacharof, P. Mock, V. Franco, J. German, A. Bandivadekar, N. Ligterink, and U. Lambrecht, "From laboratory to road: A 2015 update of official and real-world fuel consumption and CO_2 values for passenger cars in Europe," white paper, International Council on Clean Transportation, Dec. 2015. Average real-world consumption of new EU cars estimated at 7.2 L/100 km petrol-equivalent in 2014. https://theicct.org/publication/from-laboratory-to-road-a-2015-update/; accessed 15 August 2026.

[29] Statbel, "Tarif officiel moyen des produits pétroliers," 2025. Annual average price of Euro 95, VAT included. https://bestat.statbel.fgov.be/bestat/crosstable.xhtml?view=74d181b1-7074-4c9f-9a71-85303980d41f; accessed 8 August 2026.

[30] Eurostat, "Electricity price statistics: Household consumers," 2025. Consumption band 2 500–4 999 kWh, all taxes included. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_price_statistics; accessed 8 August 2026.

[31] Service public de Wallonie, "Exigences d'électromobilité : bâtiments non résidentiels existants," 2025. Since 1 January 2025: at least one recharging point and ducting for one space in five, with no condition of building works or EPB procedure. https://energie.wallonie.be/home/performance-energetuique-des-batiments/batiments-non-residentiels/renovation/obligations/exigences-electromobilites.html; accessed 15 August 2026.

[32] European Parliament and Council of the European Union, "Regulation (EU) 2023/1804 of 13 September 2023 on the deployment of alternative fuels infrastructure." Official Journal of the European Union, L 234, pp. 1–47, 2023. See Article 2 for the definition of a recharging point. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32023R1804; accessed 9 August 2026.

[33] European Parliament and Council of the European Union, "Directive (EU) 2024/1275 of 24 April 2024 on the energy performance of buildings." Official Journal of the European Union, 2024. See Article 14 on recharging infrastructure. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32024L1275; accessed 9 August 2026.

[34] UCLouvain, "Une centrale biomasse d'envergure pour alimenter l'UCLouvain en chaleur et électricité vertes," Nov. 2024. Page updated 21 May 2026.

https://uclouvain.be/fr/news/une-centrale-biomasse-d-envergure-pour-alimenter-l-uclouvain-en-chaleur-et-electricite-vertes; accessed 9 August 2026.

[35] F. D. Davis, “Perceived usefulness, perceived ease of use, and user acceptance of information technology,” *MIS Quarterly*, vol. 13, no. 3, pp. 319–340, 1989. doi: 10.2307/249008.

[36] B. C. Bektaş and G. Akyıldız Alçura, “Understanding electric vehicle adoption in Türkiye: Analyzing user motivations through the technology acceptance model,” *Sustainability*, vol. 16, no. 21, p. 9439, 2024. doi: 10.3390/su16219439.

[37] Enedis, “Utilisation et recharge : enquête comportementale auprès des utilisateurs de véhicules électriques,” tech. rep., Enedis, Sept. 2024. Private-customer edition, version 2. https://www.enedis.fr/sites/default/files/documents/pdf/utilisation-et-recharge-enquete-comportementale-aupres-des-utilisateurs-de-vehicules-electriques-septembre-2024-particuliers-v2.pdf; accessed 15 August 2026.

[38] S. Hovet, B. Farley, J. Perry, K. Kirsche, M. Jerue, and Z. T. H. Tse, “Introduction of electric vehicle charging stations to university campuses: A case study for the university of Georgia from 2014 to 2017,” *Batteries*, vol. 4, no. 2, p. 27, 2018. doi: 10.3390/batteries4020027.

[39] M. Kubli, “EV drivers’ willingness to accept smart charging: Measuring preferences of potential adopters,” *Transportation Research Part D: Transport and Environment*, vol. 109, p. 103396, 2022. doi: 10.1016/j.trd.2022.103396.

1. Pilot questionnaire items as administered

Both instruments were administered in French through an online form. The items are reproduced below in English translation, with the response format of each one; the rationale for including them is given in Appendix 2. Statements of opinion used a five-point agreement scale from 1 (strong disagreement) to 5 (strong agreement). Where a closed question offered predefined intervals, the intervals are reproduced as they appeared in the form.

Table 1.1: Initial questionnaire, completed before the first charging session.

	Item	Response format
I1	Your vehicle is	Fully electric / plug-in hybrid
I2	Vehicle model	Open
I3	Approximate battery capacity of the vehicle	Open; "?" accepted, in which case the base-model capacity was used
I4	Approximate distance between your home and the campus	Open
I5	How many days per week do you generally use your vehicle?	Single choice, in days
I6	How many days per week are you usually on campus with your vehicle?	Single choice, in days
I7	On a typical day, how long does your vehicle stay parked on campus?	2–4 h / 4–6 h / 6–8 h / more than 8 h
I8	Where do you mainly charge your vehicle?	At home / at the workplace / public charging point
I9	Do you have a home charging option?	No / yes, standard socket / yes, wallbox
I10	How often do you usually charge your vehicle?	Every day / about once a week / other
I11	At what battery level do you generally plug in?	20–40% / 40–60% / 60–80% / other
I12	What is your main reason for charging at your workplace?	Single choice
I13	"Low-power charging on campus would be useful to cover my daily mobility needs."	Five-point scale
I14	"Low-power charging is compatible with the time my vehicle stays parked on campus."	Five-point scale
I15	"I think it would be simple to plug in, unplug and regularly use a charging socket on campus."	Five-point scale
I16	"I think I could fit a planned charging day into my usual organisation."	Five-point scale
I17	"The fact that charging is free or inexpensive would strongly influence my use of the service."	Five-point scale
I18	"I would be willing to regularly use low-power charging on campus if the installation became permanent."	Five-point scale
I19	"In the future, I would accept charging being temporarily reduced or interrupted in order to follow local renewable generation, provided my minimum mobility need is secured at departure."	Five-point scale
I20	What additional range would you ideally like to recover during a day on campus?	20–40 km / 40–60 km / more than 60 km
I21	What are your expectations and concerns regarding this experiment?	Open

Table 1.2: Final questionnaire, completed at the end of the participation period.

	Item	Response format
F1	How many days did you actually use the charging point during the experiment?	Open, in days
F2	On a typical day, how long did your vehicle stay plugged in?	2–4 h / 4–6 h / 6–8 h / more than 8 h
F3	On average, what electric range do you estimate you recovered during a charging day?	20–40 km / 40–60 km / more than 60 km
F4	Was the recovered range sufficient to cover your return trip or immediate mobility need?	Always / usually / rarely / never
F5	Did campus charging reduce your use of other charging options?	Multiple choice: home, public charging points, another location, no reduction

Continued on the next page.

Table 1.2 continued from the previous page.

	Item	Response format
F6	Did you encounter any difficulties during the experiment?	No difficulty / inconvenient access or location / technical problem / other
F7	"Low-power charging on campus would be useful to cover my daily mobility needs."	Five-point scale
F8	"Low-power charging is compatible with the time my vehicle stays parked on campus."	Five-point scale
F9	"I think it would be simple to plug in, unplug and regularly use a charging socket on campus."	Five-point scale
F10	"I think I could fit a planned charging day into my usual organisation."	Five-point scale
F11	"The availability of charging on campus would reduce my reliance on home charging or public charging points."	Five-point scale
F12	"The fact that charging is free or inexpensive would strongly influence my use of the service."	Five-point scale
F13	"I would be willing to regularly use low-power charging on campus if the installation became permanent."	Five-point scale
F14	"In the future, I would accept charging being temporarily reduced or interrupted in order to follow local renewable generation, provided my minimum mobility need is secured at departure."	Verbal agreement scale†
F15	Overall level of satisfaction with the experiment	Five-point scale
F16	If the installation became permanent, how often would you like to use it?	Once or twice a week / three times a week / four to five times a week
F17	Which access arrangement would seem most appropriate to you?	Time-slot booking / fixed assigned days / priority for drivers without home charging
F18	Under what conditions would you accept charging being temporarily reduced or interrupted?	Multiple choice: greater use of renewable electricity, guaranteed minimum energy, ability to state a minimum range, ability to state a departure time, no particular condition
F19	Main feedback on the experiment: principal benefit, main difficulty encountered, or priority improvement	Open

† Item F14 was presented with verbal labels rather than with the numeric scale used for the other statements. All four answers were "strongly agree" and were coded as 5 in Table 10.

2. Origin and justification of the questionnaire items

The pilot questionnaires were not written from scratch. Most items adapt constructs that are established in the technology-acceptance literature, or reproduce variables tracked in comparable charging studies; the wording was adjusted to the campus context rather than reproduced verbatim. Three instruments were designed: an initial questionnaire, a questionnaire after each charging day and a final questionnaire. The intermediate instrument was ultimately not deployed, so that the effort asked of volunteers stayed compatible with a six-week participation; its items are listed here for completeness, since they define the session-level variables that an instrumented follow-up should collect. Opinion statements use a five-point scale from 1 (strong disagreement) to 5 (strong agreement).

Two families of sources are used. The first is the technology acceptance model [35] and the unified theory of acceptance and use of technology [10], in the adaptation to electric vehicles proposed by Bektaş and Akyıldız Alçura [36], from which the perceived usefulness, perceived ease of use, compatibility, facilitating conditions and behavioural intention constructs are taken. The second is empirical: the Enedis behavioural survey of electric vehicle owners [37] for mobility and charging habits, the campus charging case study of Hovet et al. [38] for session-level variables, and Kubli [39] for the acceptability of smart charging.

Table 2.1: Initial questionnaire: origin and role of each item.

Item	Origin	Role in the study
Vehicle type (battery-electric or plug-in hybrid)	[37]	Separates two groups whose charging habits and energy needs differ.

Continued on the next page.

Table 2.1 continued from the previous page.

Item	Origin	Role in the study
Model and approximate battery capacity	Specific to this study	Required to interpret the recovered range as energy (Section 6.3).
Home–campus distance and weekly presence	[37]	Gives the daily energy requirement and the potential frequency of use.
Typical parking duration on campus	[38]	The variable on which the central hypothesis of this work depends.
Home charging availability, main charging location, usual charging frequency	[37]	Distinguishes a real need from an additional convenience.
Usual state of charge at plug-in	[37]	Separates necessity charging from convenience charging.
"Low-power charging on campus would be useful for my daily mobility"	Perceived usefulness [35,36]	Whether a concrete benefit is perceived.
"I could fit a planned charging day into my usual organisation"	Ease of use and compatibility [36]; facilitating conditions [10]	The protocol relies on a weekly schedule rather than on free access.
"If the service became permanent I would use it regularly"	Behavioural intention [10, 36]	Potential interest in a permanent deployment.
"Free or low-cost charging would strongly influence my use"	[37]	Separates interest in the service from interest in its price.
"I would accept reduced or interrupted charging if my minimum need at departure is covered"	[39]	Prepares the transition towards renewable-following operation.

Table 2.2: Per-session questionnaire: items designed but not deployed.

Item	Origin	Role in the study
Use or non-use of the reserved slot, and reason for non-use	Specific to the protocol	Separates unused slots from absences, access problems and schedule conflicts.
Plug-in and unplug times, parking duration, energy recovered	[38]	Actual utilisation of the outlets and energy effectively delivered.
State of charge before and after charging (optional)	Plug-in level from [37]; final level added here	Gain obtained during a session.
"The charging duration was compatible with my parking time today"	Compatibility [36]	Tests the central hypothesis at session level.
"Using the outlet was simple today"	Perceived ease of use [35, 36]	Measures simplicity after use rather than as an expectation.
"The energy recovered was sufficient for my need today"	Perceived usefulness [35,36]	Sufficiency of low-power charging from the user's point of view.
Problem or inconvenience encountered	Facilitating conditions [10]	Identifies concrete constraints: access, parking, cable, outlet, organisation.

Table 2.3: Final questionnaire: origin and role of each item.

Item	Origin	Role in the study
Days of use, connection duration, recovered range, sufficiency for the immediate need	[38]	The use variables analysed in Section 6.3.
Perceived usefulness, simplicity, compatibility with the weekly schedule, intention to use	[35, 36]	Compared item by item with the initial ratings (Table 10).
Practicality of the location and of access to the outlets	Facilitating conditions [10]; workplace charging [37]	Separates problems caused by the device from problems caused by its siting.
Importance of price or of free access	[37]	Needed to read the acceptability of a pilot offered free of charge.
Acceptance of flexible charging following renewable availability, and conditions attached to it	[39]	Links the grid-supplied pilot to a possible photovoltaic-driven operation.
Reduced reliance on other charging locations	[37]	Indicates whether the service substitutes for existing charging or adds to it.
Overall satisfaction, preferred access rule and priority improvement	Specific to this study	Synthetic assessment and operational feedback for a permanent deployment.

3. Simulation assumptions and implementation

This appendix documents the charging-demand model used in Section 5 in enough detail for the results to be reproduced. It states the sampling laws, the time base, the treatment of the campus load and of photovoltaic generation, and the conventions that govern charging efficiency. Table 4 summarises the same parameters; what follows gives the distributions, the bounds and the order in which quantities are drawn.

3.1 Time base and scope

The model represents the calendar year 2025 at hourly resolution in the Europe/Brussels time zone, that is 8 760 steps. Every random draw uses a single pseudo-random generator seeded at 42, so a given scenario reproduces exactly from one run to the next.

Three quantities are simulated at each step: the campus electrical load, the photovoltaic generation where the scenario includes it, and the aggregate electric-vehicle charging power. Their combination gives the grid import and export reported in Section 5.4.

3.2 Campus load

The campus load is not synthetic. It is reconstructed from the 2025 metered data of the Louvain-la-Neuve site, recorded at fifteen-minute resolution, as

$$P_{\text{campus}} = \max\left(P_{\text{import}} + P_{\text{cogen}} - P_{\text{export}},\ 0\right), \tag{10}$$

then averaged to hourly means. Clipping at zero removes the few steps where the metering signs produce a negative residual. This reconstruction is what the scenario labelled “campus reference” in Table 8 represents: the site as measured, without simulated vehicles and without additional generation.

3.3 Photovoltaic generation

Photovoltaic output is derived from the global horizontal irradiance of a typical meteorological year for the site:

$$P_{\text{PV}} = P_{\text{peak}} \times \frac{G_{\text{GHI}}}{1000} \times \text{PR}, \qquad \text{PR} = 0.85, \tag{11}$$

with G_{GHI} in W m^{-2} and P_{peak} in kWp. The performance ratio of 0.85 is a single constant: temperature derating, soiling, inverter efficiency and orientation losses are not modelled separately. Over the year this yields 961.6 equivalent full-load hours.

Installed capacity is not a free parameter. It follows the rule $P_{\text{peak}} = N \times 3.7\,\text{kW}$ rounded up to the nearest 10 kWp, so that each paired scenario carries a photovoltaic capacity equal to the theoretical simultaneous peak of its fleet. This makes the scenarios comparable rather than optimally sized; no optimisation of the capacity was performed.

Self-consumption is settled hour by hour. On-site cogeneration, which is part of the measured campus data, is allocated first; photovoltaic generation is then compared with the remaining load. Import and export follow $P_{\text{import}} = \max(P_{\text{load}} - P_{\text{gen}}, 0)$ and $P_{\text{export}} = \max(P_{\text{gen}} - P_{\text{load}}, 0)$.

3.4 Fleet generation

Two attributes are drawn once per vehicle and held for the whole year.

Weekly charging frequency is categorical: one charging day per week with probability 0.10, two with probability 0.35, three with probability 0.55, giving a fleet mean of 2.45.

Energy consumption is drawn from a normal distribution of mean 18 kWh/100 km and standard deviation 2.5, truncated to $[14, 24]$. Drawing it once per vehicle rather than once per session is deliberate: a given car does not change its consumption between two campus days, and this preserves the between-vehicle heterogeneity that a per-session draw would average away.

3.5 Choice of charging days

Charging days are selected week by week, on ISO weeks, with day weights of 1.00 from Monday to Thursday, 0.85 on Friday, 0.05 on Saturday and 0 on Sunday. For each vehicle and each week, the required number of days is drawn without replacement among the weighted candidates.

The simulated year does not begin or end on an ISO week boundary, so the first and last week groups contain fewer candidate days than a full week. Applied naively, the rule $n_{\text{select}} = \min(n_{\text{days}}, |\text{candidates}|)$ would force every vehicle to fit its full weekly frequency into those few days, collapsing the between-vehicle diversity and plugging the whole fleet in on the same dates. This produced an artificial peak of roughly 1.6 to 1.7 times the median number of weekday sessions, always located on 1–5 January and 29–31 December, which dominated the annual maximum of simultaneous power and distorted the diversity factor.

The frequency is therefore scaled to the fraction of the week actually available:

$$n_{\text{target}} = n_{\text{days}} \times \frac{w_{\text{available}}}{w_{\text{full week}}}, \tag{12}$$

and the fractional part is resolved by a Bernoulli draw, so that the weekly frequency, and hence the total annual energy requested, is preserved in expectation. Every figure reported in Section 5 uses the corrected model.

3.6 Parking profiles

On each charging day, one parking profile is drawn: short with probability 0.10, medium 0.25, long 0.62 and atypical 0.03 on weekdays; Saturdays use a separate low-presence profile. Arrival and departure times follow triangular distributions, specified in Table 3.1 as (minimum, mode, maximum) in decimal hours. A minimum connection time of one hour is enforced when a draw would otherwise produce a shorter stay.

Table 3.1: Triangular arrival and departure distributions by parking profile, in decimal hours (minimum, mode, maximum).

Profile	Share	Arrival	Departure
Short	0.10	(8.0, 8.8, 10.3)	(12.2, 12.8, 13.7)
Medium	0.25	(8.0, 8.6, 9.8)	(15.2, 16.0, 16.8)
Long	0.62	(7.8, 8.5, 9.3)	(17.6, 18.3, 18.7)
Atypical	0.03	(9.5, 11.0, 13.0)	(16.0, 17.5, 18.7)
Saturday low presence	—	(9.0, 10.0, 11.5)	(12.5, 14.0, 16.5)

These profiles are scenario assumptions informed by the declared parking durations of Section 4, not distributions fitted to UCLouvain data. The share of long stays reflects the dominance of multi-hour presence in the survey while retaining a minority of short stays, which is where the residual shortfall concentrates.

3.7 Energy request and charging

The range to be recovered is drawn afresh at each session from a normal distribution of mean 85 km and standard deviation 25 km, truncated to $[25, 150]$. Combined with the vehicle's own consumption through Eq. (4), this gives a mean battery-side request of 15.28 kW h over the 550-vehicle scenario.

Charging is uncontrolled: it starts on arrival and continues at constant power until the requested energy has been delivered or the vehicle departs. There is no reservation, no deferral and no power modulation, which is the conservative reference case for a socket-based installation without communication.

The efficiency convention governs the whole model and is worth restating. The rated power $P_{\text{ch}} = 3.7$ kW is the power drawn *from the grid* at the socket. With $\eta = 0.90$, an order of magnitude consistent with the 16 A measurements of Brincourt et al. [2], the battery receives $\eta P_{\text{ch}} = 3.33$ kW. Within each hourly step the model transfers $\min(\eta P_{\text{ch}} \Delta t,\ E_{\text{remaining}})$ to the battery and charges E_{battery}/η to the grid. Requested, delivered and unserved energies are therefore battery-side quantities, while the series added to the campus load is grid-side. This is why, in Table 5, the grid column exceeds the delivered column by a factor $1/\eta$.

3.8 Scenarios

Seven scenarios were run. Phase 1 covers 55 and 110 vehicles without additional photovoltaic capacity; phase 2 pairs the same two fleets with 210 and 410 kWp; phase 3 covers 220 vehicles with and without 820 kWp, and 550 vehicles with 2040 kWp. There is no 550-vehicle scenario without photovoltaic generation in the paired series; the "EV550, no PV" row of Table 8 is obtained by removing the photovoltaic contribution from the same charging profile, since the vehicle-side results do not depend on it.

Vehicle-side results are identical with and without photovoltaic capacity for a given fleet size, because generation does not alter the charging decision in an uncontrolled model. The comparison across rated powers reported in Table 12 replays the same sessions—same vehicles, same arrivals and departures, same energy to recover—at 3.7, 7.4, 11 and 22 kW, so that only the time needed to deliver the energy varies.

The diversity factor reported in Table 7 is the ratio of the simulated aggregate peak to the theoretical maximum $N \times 3.7$ kW. Because an annual maximum is an extremum statistic and therefore sensitive to a single hour, the 99.9th percentile of the hourly charging power is reported alongside it.

3.9 What the model does not represent

Four limits bound the interpretation of these results.

Access is not modelled. Every vehicle that arrives is assumed to find a free connection. The model describes the energy service achievable once a vehicle is connected, not the availability of a point; queuing, contention and reallocation are absent. The number of points a deployment would require is addressed separately, in Section 7.3, by sizing on observed occupancy rather than by simulating competition.

Battery behaviour is simplified. Charging is constant-power until the request is met. The taper at high state of charge, the dependence of the onboard charger's efficiency on current and temperature, and cold-weather consumption are not represented. The consumption figures used throughout are mild-weather values.

The electrical network is not modelled. The model evaluates charging demand and infrastructure utilisation, not load flow, voltage quality, phase balance or protection coordination. Detailed campus network data were not available. Nothing in Section 5 authorises conductors or protective devices to be sized.

Resolution smooths sub-hourly peaks. An hourly time step averages within each hour, so brief coincidences of arrivals are not visible. This matters for the aggregate peak more than for the annual energy.

3.10 Reproducibility

The model is written in Python and organised as follows: `config.py` holds the scenario parameters; `ev.py` the fleet, the session generation and the charging model; `generation.py` the photovoltaic model; `data_io.py` the reading of the metered campus data and of the meteorological year; `dispatch.py` the hourly settlement of self-consumption, import and export; and one `run_simulation_phase*.py` script per phase. Each run writes a `summary.json` containing every aggregate quoted in Section 5, together with the hourly series and the full session table, so that any figure in that section can be traced back to the run that produced it.

4. Declaration on the use of generative AI

This appendix states the extent and manner in which generative artificial intelligence tools were used in the preparation of this thesis, in accordance with the EPL guidelines on the responsible use of generative artificial intelligence. The author remains responsible for the content and the form of the whole document.

Tools and period. Two general-purpose conversational tools were used in the course of this work: ChatGPT (OpenAI), from September 2025 onwards, and Claude (Anthropic), during the preparation of the manuscript in 2026. No other generative tool was used.

Language assistance. Both tools were used to correct spelling, grammar and syntax, to find synonyms and to improve the readability of text first written by the author. Under §III.A of the guidelines this use does not require indication; it is reported here for completeness.

Exploratory search and source identification. The tools were used to identify lines of enquiry and candidate references, in the way a search engine would be used. Every source cited in this thesis was obtained by the author in its original form and consulted directly: the sections relevant to the claim being made were read, and each figure attributed to a source was located and checked in that source. No bibliographic reference and no numerical value was taken from a tool without this verification. The bibliography was also not restricted to sources surfaced this way: the ICCT, ACEA, Transport & Environment, NREL, Statbel, Eurostat, Elia, CREG, Fireforum and RGIE documents were retrieved from their publishers, and the peer-reviewed articles from their journals.

Drafting assistance. Drafting assistance took different forms across the manuscript. For most sections, the author wrote an initial text, which the tools were then asked to improve: proposing additions, alternative formulations, shorter passages and the relocation of material within a section; each suggestion was reviewed and retained only where the author agreed with it. The abstract and the conclusion were drafted by the tools from results, figures and arguments supplied by the author, and were revised by the author before inclusion. Section 3 was generated by the tools from detailed prompts written by the author that specified the content, the arguments and the structure to be covered; the resulting text was then substantially revised by the author in wording and form, incorporating further suggestions made by the tools during that revision. In every case the substance the research questions, the modelling choices, the interpretation of the results and the recommendations formulated for UCLouvain—originates with the author.

Formatting. The tools were used to write LaTeX and BibTeX code: table environments, equation formatting and bibliography entries. The content of those entries was verified against the corresponding publications.

Source code. The simulation was written by the author. Generative AI was used in a supporting role: to interpret error messages and locate defects, to suggest general improvements to the structure and efficiency of the code, and to advise on which avenues were worth pursuing and which were not. Part of the plotting code that produces the figures of Section 5 was revised with this assistance.

Work not performed with AI. The campus mobility survey, the parking observations, the pilot experiment with its participants, the collection of the questionnaire responses, the quotation and cost data, and the design and execution of the simulation are the author's own work. No result, measurement, figure or quotation reported in this thesis was produced by a generative AI tool.

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