

Towards Net Zero Buildings

The Investment Case for Smart EV Integration

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Executive Summary

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Dear Reader,

This report comes as a new brick in the Building Series of the Schneider Electric Sustainability Research Institute™, providing in-depth exploration of decarbonized buildings through the deployment of digital and low-carbon technologies such as heat pumps, rooftop solar photovoltaic (PV), stationary batteries, building energy management systems, across a variety of building types and geographical contexts.

Our analysis focuses on three aspects: energy bill reduction and associated CO2 emissions reduction, investment paybacks, peak load implications.

We look here at the benefits of a combined EV smart charging system and a microgrid system (i.e., rooftop solar combined with a battery energy storage system), each digitally managed, into non-residential efficient, heat electrified buildings. We provide a first of its kind broad study analyzing 65 use cases (5 building sectors x 13 geographies with electricity dynamic tariffs) looking at different EV penetration rates and associated charging scenarios depending on the building type and associated EV user behavior. Building owners and investment decision makers are today facing a dual challenge.

On one side they need to move the needle on their asset decarbonization journey, on the other side they also need to welcome people on-site with more EV cars.

Key to addressing this challenge is the need to better understand where to start, what return on investment (ROI) is to be expected, and whether these transitions will imply grid upgrades.

We answer these questions in the report by exploring:

1. How to cope with the grid peak issue with EVs?
2. Is it economically sound to leverage these new technologies for EV integration?

We use a powerful modelling approach using data as close as possible to reality from a technical and cost perspective (for buildings, assets, geographies, and financial data) and leveraging advanced optimization methods for both smart charging (rule-based) and microgrid (model predictive control) allowing to consider more than one hundred EVs.

Our research shows that (Exhibit 1):

1. With respect to peak issues:
 - a. Uncontrolled charging leads to peak issues in around 80% of the cases while Smart Charging helps to avoid them without compromising EV satisfaction, in all modeled cases,
 - b. The addition of well-designed microgrids further enables peak reduction, and headroom recovery up to 50% (allowing for other electricity demand expansion),
 - c. Peak issues are contained when increasing EV penetration rates with a microgrid invested today.
2. When it comes to economics:
 - a. Smart charging investment is attractive at noticeable EV penetration rates, adapting timely to the electricity rate and contributes to avoid grid connection costs,
 - b. The investment case of adding a microgrid is viable in most cases, thanks the combined use of rooftop PV and stationary battery contributing to significant self-consumption, self-dispatched PV use and export to the grid,
 - c. Microgrid investment remains economically sound when the EV penetration rate increases. It is thus future-proof.
3. When it comes to the EV users:
 - a. EV user satisfaction does not deteriorate when deploying smart charging,
 - b. EV user satisfaction is excellent when adding a Microgrid and remains very good with higher future EV penetration rate, except in a few extreme cases.

¹ We selected an already partly decarbonized building equipped with an electrified heating system and a Building Management System.

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Exhibit 1. Overall benefits of adding a microgrid, to an electrified and efficient building equipped with smart charging. Peak issue containment in % of the grid power limit(top), Profitability with the Internal rate of return in % (middle), EV user satisfaction, as the share of EV users leave the building site with state of charge or at least 90%, at future higher penetration rate (bottom).

	Legend													
	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W	
Hospital	100,0	62,4	100,0	100,0	66,2	86,9	100,0	96,8	72,8	100,0	63,2	100,0	64,8	
Large office	99,1	57,3	100,0	100,0	92,9	98,9	95,3	100,0	80,8	100,0	96,8	84,1	73,9	
Secondary school	82,4	62,8	87,5	99,8	41,8	66,2	87,7	99,8	44,7	100,0	47,2	75,5	55,0	
Small hotel	100,0	54,4	100,0	100,0	49,2	69,1	96,9	100,0	51,9	100,0	59,7	68,8	55,6	
Strip mall	88,0	64,9	100,0	100,0	71,1	57,1	96,3	100,0	70,9	92,2	71,8	100,0	53,3	

	Legend									= 0	> 0 & < HR*	>= HR*	
	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W
Hospital	9,9	14,5	7,0	5,1	5,0	4,6	5,7	13,1	5,4	18,7	4,7	4,8	29,9
Large office	9,9	11,8	10,3	8,8	8,6	30,1	13,3	13,1	9,9	12,9	11,7	10,7	30,5
Secondary school	17,9	22,6	9,9	8,5	9,9	15,2	13,8	9,4	10,2	23,7	8,9	8,8	38,5
Small hotel	18,3	20,6	10,6	7,8	8,5	9,3	11,9	13,1	19,8	28,5	7,8	8,7	30,3
Strip mall	15,0	21,9	9,0	8,9	9,0	17,4	13,5	9,1	16,5	20,9	8,6	5,6	37,9

*HR: hurdle rate. 3,2% for Hospital, 6,8% for Large office, 7,1% for Secondary school, 6,4% for Small Hotel and 6,9% for Strip mall

										Legend		<= 50	> 50 & < 80	>= 80
	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W	
Hospital	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	
Large office	92,7	100,0	89,3	69,3	86,2	100,0	99,8	100,0	96,6	80,0	98,1	97,9	98,7	
Secondary school	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	
Small hotel	100,0	100,0	99,8	99,5	99,8	100,0	100,0	100,0	100,0	99,8	100,0	99,7	99,7	
Strip mall	100,0	100,0	99,9	99,7	99,9	100,0	100,0	100,0	100,0	99,9	99,9	97,3	97,6	

This large diversity of results is rooted in the combination of several highly influencing parameters, including:

- The temporal alignment of time varying characteristics, namely the solar irradiance and temperature variations, dynamic tariffs, timing nature of the building process and presence of occupants, EV usage and presence of the EV regulated by site policies,
- The attributes of the dynamic tariffs and in particular the existence and level of demand charges/subscribed power fee or penalties, of sellback mechanisms to the grid, and the large variations of EV presence scenarios,
- The relative weight of the EV load to the building load typically,
- The building characteristics, and particularly the roof to floor ratio, conditioning the performance of the microgrid both for direct PV use and self-dispatch through the stationary battery,
- The photovoltaic production potential of the building, which depends on the prevailing climatic conditions and the available surface for Photovoltaic (PV) panel installation,

We hope this work will bring confidence in building sector decarbonization investments and stimulate further research and discussion in this converging area of Building, Grid and Mobility.



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Part I: Problem Statement

This report comes as a natural extension of our on-going “Decarbonizing Buildings” paper series (Minier, 2024) (Minier, 2025), now seeking to incorporate electrical vehicles and in particular smart charging in non-residential buildings.

Making the right investment decision

Building owners and investment decision makers are today facing a dual challenge. On one side they need to move the needle on their asset decarbonization journey, on the other side they also need to welcome people on-site with more EV cars.

So, the questions they are asking themselves are typically: *“Where should I start? Is it profitable, what is my ROI? Is that a sustainable investment, shall I do it now or wait when there are more EVs? Do I need to upgrade my grid connection? What are my savings and CO2 reduction with smart charging and rooftop solar eventually with complementary batteries?”*

Academic research related to smart charging has been extensive over the last years (Sadhegian, 2022), (Deb, 2022)). Most of the research has been focused on the residential sector (Transport & Environment, 2024)), smart charging, and bill reduction implications. Less research has focused on commercial building sectors (Seger, 2025), or the integration of smart charging with rooftop solar and batteries ((Kassab, 2025) (ERM, 2023)).

This is what this gap in research which this report intends to bridge, extending an original work published in 2021 (Minier, 2021).

We conduct here an extensive “market study” covering services building sectors (5) and geographic coverage (13 regions).

We consider buildings which are already benefiting from electrified heating and efficient building management systems.

We retrieve for each geography weather data and illustrative commercial retail tariffs, and for each building sector occupancy levels, EV user presence and EV charging behaviors.

Also, we look at two horizons i.e., 2025 (low penetration) and 2035 (higher penetration) when it comes to EV deployment rate, without (uncontrolled charging) and with smart charging and with and without the presence of a microgrid (rooftop PV and battery storage).

We describe a comprehensive microgrid sizing approach based on a multi-criteria assessment (profitability, bill).

We propose a tool allowing to visualize what microgrid solutions (PV sizing, Battery sizing) deliver for the variables of interest (e.g., profitability, bill reduction) on top of deploying smart charging. It reveals whether a solution provides adequate value for all the variables of interest and, if not, enables the investor to identify concessions.

Report organization

Following this introductory Part I, the report is organized as follows.

In Part II we describe the methodological approach of this research, outlining notably the EV charging scenario build up per building type and the EV smart charging management in the overall optimization approach.

In Part III, IV and V, we describe the three key findings of the research, focusing sequentially on peak load management, economics of the investments and EV user satisfaction impact.

Part VI summarizes our research's key findings and conclusions and points out the multiple benefits of overall investment.

Finally, an Annex provides granular details on the many assumptions of the research.

Part II: Methodological approach

This research takes roots in our previous research which analyzed the impact of a package of low-carbon technologies for different building use cases. For both studies, and this one, the same modelling approach was used and details regarding assumptions and modelling can be retrieved in their Annex and the Annex of this short paper.

Scope and assumptions

We look at an extensive scope of geographies (13) and building sectors (5), i.e., 65 use cases, for which we deploy EV smart charging infrastructure and microgrids (rooftop PV + battery energy storage).

The reference building design, from which we analyze smart charging and microgrid addition, incorporates already electrical heating with a heat pump and a building management system providing energy efficiency at operations. It also incorporates an uncontrolled (no time management) EV charging system.

Grid maximum import power is set at 100% of the building peak load (without EV charger load) in order to identify associated issues when adding chargers.

To each use case is associated a set of rich parameters, documented technically, and cost wise: geography related features (electricity dynamic tariffs, weather), sector-related assumptions and assets under consideration, including their usage scenario (building occupancy, EV charging rules and scenario), financial objectives (hurdle rate) and investment project assumptions (see Annex for details).

Smart charging and Microgrid impact Modelling

The study is conducted with proprietary Schneider Electric's Energy Management Simulation Framework (EMSF), a powerful and flexible simulation which allows to perform time-domain simulations of environments where an energy management process is at stake (Beguery, 2023).

The EMSF platform provides a smart dispatch algorithm for the EV batteries and the Microgrid battery if any.

Each building sector load profile is built from DOE archetypes (US DOE, 2023). Weather data (solar irradiation and temperature) helps to adapt building consumption patterns by geography.

Box: Estimating EV presence and charging scenarios

A key assumption is the definition of on-site EV presence and charging scenarios. The maximum number of EVs, which we estimate from the number of installed chargers (no queuing), depends on a combination of primary parameters we retrieve or estimate (See Annex for details):

1. The EV penetration rate in the car stock depends on the considered geography (1%-70% range) which we consider to be the share of EV users among the occupants coming by car.
2. The level of car usage vs other transportation means (how many occupants come to the building by car e.g., 80%).
3. The users eligible to EV charging: type of occupants allowed to charge (e.g., workers vs visitors in a hospital, e.g., workers and guests in a hotel). This requires mapping the occupants according to their status (e.g., patient in hospital, guest in hotel). The number of eligible EV users is calculated for each building based on occupancy and policy assumptions. This value represents the maximum number of EVs that could be parked and charged on-site under full adoption and peak building occupancy conditions.
4. The daily allowed charging schedules (arrival/departure and/or duration), in order to limit the number of EV chargers (e.g., morning and afternoon periods at office), and/or satisfy the occupants (e.g., duration time for retail customer for the strip mall archetype).
5. The weekly schedule: EV user behavior (e.g., charging at work only for the office worker, with two charging periods during the week).
6. The variability of arrival time, duration, and trip length (so state of charge at arrival) using Probability Density Functions.

Overall, the number of coincidental charging can vary from a few units (e.g., in Retail strip mall or Hotel in 2025) to more than one hundred (e.g., in Office in 2035) in some geographies (Exhibit 2).

Exhibit 2 also shows that only a given proportion of the occupants of a building (blue cells) has the right to charge their vehicle such as staff members at workplaces (e.g., hospital, large office, secondary school) or guests (e.g., small hotel, strip mall).

Details about EV charging policy are discussed in the EV charging assumptions subsection of the Annex.

Towards Net Zero Buildings - The investment case for smart integration of EVs

Exhibit 2. Regional battery-EV penetration rate (cells), number of EV charging stations per site in 2025 and 2035 in the 13 geographies (colored cells), and maximum ratio of potential EV users to occupants per sector (blue cells).

		Legend													Potential EV users among occupants
		Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W	
Regional EV penetration rate	2025	2%	3%	8%	14%	5%	1%	1%	30%	1%	5%	3%	3%	3%	
Hospital	2025	1	1	2	3	2	1	1	6	1	2	1	1	1	19%
Large office		7	10	25	44	16	4	4	93	4	16	10	10	10	100%
Secondary school		2	2	6	10	4	1	1	20	1	4	2	2	2	8%
Small hotel		1	2	4	7	3	1	1	12	1	3	2	2	2	19%
Strip mall		1	1	3	4	2	1	1	9	1	2	1	1	1	90%
Regional EV penetration rate	2035	25%	33%	36%	55%	35%	11%	14%	70%	25%	39%	27%	27%	27%	
Hospital	2035	5	7	8	11	7	3	3	14	5	8	6	6	6	19%
Large office		78	102	111	170	108	34	44	216	78	121	84	84	84	100%
Secondary school		17	22	24	36	23	8	10	46	17	26	18	18	18	8%
Small hotel		11	14	15	23	15	5	7	28	11	16	12	12	12	19%
Strip mall		7	10	10	16	10	4	4	20	7	11	8	8	8	90%

There are three distinct optimization stages to address the equation of the building owner/investor:

1. EV charging station preprocessor

The behavior of the EV charging station (all charging points) is modeled through a preprocessor that builds an annual time series with the power consumption of the station, which is later used in the "Microgrid dispatch optimization" stage.

To that end, the preprocessor uses a stochastic scenario builder for the arrival/departure time and charging needs on each charger, and a rule-based algorithms to simulate the charging behavior.

For smart charging, at each time step, the algorithm goes through the list of present vehicles and decides about charging power. The vehicles will only charge if their departure time is close (less than 1 hour), if there is excess photovoltaic production not consumed by the building or if the energy purchase price is low.

The charging power of each EV is equal to the minimum between:

- o The charging points maximum power,
- o The power required to provide all the energy required by the EV before its departure (in consequence, the charging is smoothed, since it is not necessary to deliver the full charge in one simulation step),
- o The available grid power (i.e., grid power limit, minus building power, and minus charging power of the EVs already processed by the algorithm), or, in case of excess PV production, the excess PV power.

2. Microgrid dispatch optimization

For a given microgrid design (i.e., a specific configuration and sizing of the PV and Battery), a time domain simulation is executed. The simulation uses multiple data sources and a model predictive control to compute the dispatch of the stationary battery.

The outcomes of this stage are the time series resulting from the simulation, as well as a comprehensive set of key performance indicators (KPIs).

Note that the dispatch optimization stage is repeated for 35 designs with 6 PV sizes x 6 battery sizes (i.e., 35 simulations, without no PV no Battery):

- o the maximum tested PV size depends on the available roof space of each use case assumed to be 70% of the total roof space, for all segments,
- o the maximum tested battery size is equal to 25% of the average daily electrical load of the building (without the EV load).

3. Microgrid design optimization

Using the results obtained for all microgrid designs assessed, the best design is selected, according to the customer's targets.

Among the 35 microgrid sizes, a multi-criteria sizing rule is implemented for year 2025:

- o Exclude microgrid sizes with an IRR smaller than 1.2 times the hurdle rate, or, if all sizes were to be excluded, simply select the one with the highest IRR,
- o Among the remaining simulations, select the one with the lowest bill.

Finally, for the 2035 horizon, the best microgrid sizing selected in 2025 is kept for investigating the impact of an increased EV penetration on the performance of the design, i.e., assess whether this design remains relevant over time.

Key outputs of interest

As for our previous research, simulations allow to sort out several relevant KPIs addressing stakeholders' questioning:

- Investor: Profitability levels on investments (Internal rate of return here),
- Building operator or occupant: Energy, CO2, and bill savings on a yearly basis,
- Grid system operator: Peak load levels,
- EV user: EV user satisfaction with respect to state of charge at departure².

² The specific KPI is defined as the percentage of departures in the year for which the EV leaves with a SOC greater than 90%.

Key finding 1: Smart charging is essential to avoid peak issues

This chapter deals with the impact of EV charging on building's peak load demand.

We analyze the impact of deploying a smart charging system instead of uncontrollable charging, then the impact of deploying a microgrid for the 2025 EV penetration rate (low case), and for the 2035 EV penetration rate (higher case).

Uncontrolled charging leads to peak issues

A first order of business is to understand if uncontrolled charging generates peak issues. Exhibit 3 shows that this is generally the case in the 2025 EV penetration rate scenario. Peaks are observed as high as 150% of the maximum allowed power – we recall that grid power import limit is defined as equal to the annual building peak power excluding EV charging. Overall, 80% of use cases exhibit an overload, and 20% an overload higher than 120% of the power grid limit.

Exhibit 3. Building (with EVCS uncontrolled charging) peak power relative to the grid power limit (%). EV-2025-share scenario. We recall that grid power import limit is defined as equal to the annual building peak power excluding EV charging.

	Legend													
	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W	
Hospital	101,4	100,0	101,3	101,4	101,3	100,2	101,3	100,0	100,3	101,3	101,4	100,4	102,1	
Large office	106,1	103,1	119,8	128,3	112,1	100,0	101,6	113,0	100,1	112,1	103,5	107,9	103,3	
Secondary school	104,8	101,4	115,5	127,7	110,0	100,2	102,3	103,2	101,9	110,0	103,5	105,6	104,3	
Small hotel	109,7	100,0	137,2	144,2	117,5	101,4	100,0	100,0	100,0	117,5	100,0	146,5	146,7	
Strip mall	121,7	109,3	133,5	151,0	134,8	104,5	117,7	109,1	121,3	134,8	110,9	131,1	132,3	

Region wise:

- There is a strong regional variability because of vastly different weather zones (defining building peak power) and EV penetration rates as highlighted in Exhibit 2,
- India, Spain, Italy experience lower EV penetration (all equal to 1% in 2025) so do not exhibit a peak issue, while Denmark, China, and to a lesser extent Norway, have the highest EV penetration (respectively 14%, 8% and 30% in 2025). India and Norway have a high maximum allowed power because of their heating/cooling needs, and EV power is small in comparison, leading to limited peak impact. Conversely, China, France and the UK have milder weathers and non-negligible EV penetrations (respectively 8%, 5% and 5% in 2025). The peak impact is thus higher in these regions.

Sector wise:

- Hotel and Strip Mall archetypes have higher peak issues with time window of charging imposed by EV guests charging pattern opening hours,
- For the Hospital sector, there are few chargers with respect to occupancy, so the building load stays proportionally much larger than the EV load (same reasoning for the secondary school sector).

Smart charging contributes to prevent peak issues

Smart charging optimization intends to reduce the bill by maximizing charging at time of low prices, while limiting peak power demand. This leads to typical time series as shown in Exhibit 4.

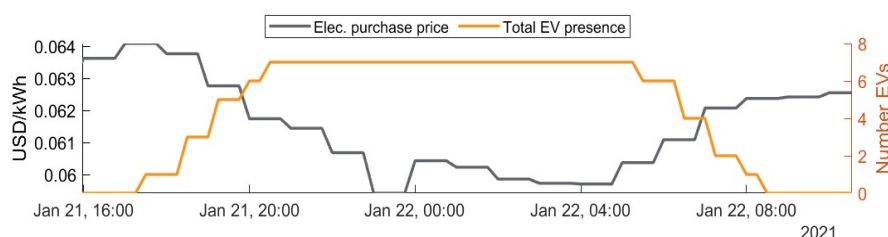
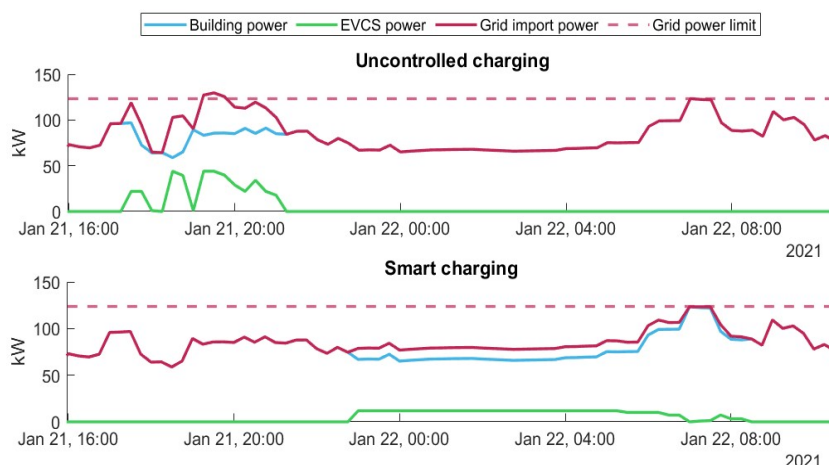


Exhibit 4. Illustration of an EV charging scenario in the Denmark-Small-Hotel case during the night of January 21 to the morning of January 22, comparing smart charging and uncontrolled charging strategies.

- Top: EV Charging Station presence and electricity tariff time series.
- Middle: building power demand time series under uncontrolled charging.
- Bottom: building power demand time series under smart charging



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Looking at the Small hotel sector in Denmark, we can observe for the smart charging case that:

- the EVCS load is shifted towards lower prices period,
- charging is spread over a longer time,
- charging is stopped at 7am to avoid going above the grid power limit,
- charging resumes between 7:30am and 8:30am as departure time approaches and cars need to be charged to keep a good satisfaction rate.

With smart charging, the overload is corrected in all use cases, as shown in Exhibit 5, while keeping EV satisfaction at very high levels (see Exhibit 5).

Exhibit 5. Building (with EVCS smart charging) peak power relative to the grid power limit (%).

	Legend										<= 100	> 100 & < 120	>= 120
	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W
Hospital	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
Large office	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
Secondary school	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
Small hotel	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
Strip mall	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0

Combining Smart charging with a Microgrid further enables peak reduction

When adding a microgrid optimized for maximized profitability (see Part IV), the grid power limit is still respected as the stationary battery controller imposes it. What is more is that such controller further reduces the peak power below the grid power limit in 2/3rd of the cases (Exhibit 6), as this allows to minimize the electric bill. Still, EV satisfaction is maintained and even slightly improved (see Exhibit 6).

Exhibit 6. Building (with smart charging and Microgrid) peak power relative to the grid power limit (%)

	Legend										<= 100	> 100 & < 120	>= 120
	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W
Hospital	100,0	62,4	100,0	100,0	66,2	86,9	100,0	96,8	72,8	100,0	63,2	100,0	64,8
Large office	99,1	57,3	100,0	100,0	92,9	98,9	95,3	100,0	80,8	100,0	96,8	84,1	73,9
Secondary school	82,4	62,8	87,5	99,8	41,8	66,2	87,7	99,8	44,7	100,0	47,2	75,5	55,0
Small hotel	100,0	54,4	100,0	100,0	49,2	69,1	96,9	100,0	51,9	100,0	59,7	68,8	55,6
Strip mall	88,0	64,9	100,0	100,0	71,1	57,1	96,3	100,0	70,9	92,2	71,8	100,0	53,3

Region wise:

- Geographies with demand charges (USA Northeast, West or South, Canada) or subscribed power (Spain, France, India) in the tariff structure show lower peak levels. As explained, this results from the operation of the stationary battery which minimizes the power component of the bill.

Optimal Microgrid of today shows a future proof behavior

A final question is whether the stationary battery will manage to keep the headroom below the grid power limit as the EV penetration rate increases over time. In order to assess this, we project the microgrid optimized for 2025 but operated with a 2035 EV penetration level (strong increase of the number of EVs on-site and charging stations) (Exhibit 7).

Exhibit 7. Building (with smart charging and Microgrid, at 2035 EV penetration rate) peak power relative to the grid power limit (%)

	Legend										<= 100	> 100 & < 120	>= 120
	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W
Hospital	100,0	63,4	100,0	100,0	66,2	87,0	100,0	97,0	74,6	100,0	64,6	100,0	65,7
Large office	100,0	66,8	100,0	100,0	86,1	99,9	100,0	100,0	90,3	100,0	100,0	100,0	84,2
Secondary school	84,0	67,5	97,6	100,0	48,9	66,2	87,7	100,0	46,4	100,0	52,7	84,9	64,1
Small hotel	100,0	63,2	100,0	100,0	64,6	69,8	100,0	100,0	58,3	100,0	66,9	93,6	73,1
Strip mall	90,4	81,8	100,0	100,0	81,7	61,1	100,0	100,0	78,9	100,0	83,2	100,0	76,4

We observe that the headroom achieved with stationary batteries for the geographies with demand charges or subscribed power is reduced with respect to a 2025 EV penetration (Exhibit 7) but remains considerable.

It is also important to stress that, even with an increased EV penetration, the smart charging algorithm continues to respect the grid power limit of each use case (as the peaks of Exhibit 7 never exceed 100 %). This could negatively impact the EV satisfaction, but it remains in exceptionally fine levels as shown in Exhibit 20.

Key finding 2: Both smart charging and microgrid strategies are worth the investment

When it comes to economics, as explained earlier, the objective is to ensure viable investments (with respect to the typology of investor profile / building type) i.e. a profitability higher than a targeted one (other said in this report, an Internal Rate of Return of the investment project higher than the targeted discount rate, or hurdle rate, of the average investor of the sector (Minier, 2025).

We look in turn at smart charging, then the addition of a microgrid. For each step, we evaluate the OPEX (bill), CAPEX and IRR. Finally, we look at the impact of a higher EV penetration rate (2035 estimates) of a microgrid investment in 2025.

Smart charging investment is attractive, adapting timely to the electricity rate or avoiding grid connection costs

Overall bill reduction is moderate

When looking at the overall bill variation (Exhibit 8), there are savings in most cases but generally small.

Exhibit 8. Annual building energy bill variation (%) when comparing smart charging vs uncontrolled charging

	Legend										< -10	>= -10 & < 0	>= 0
	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W
Hospital	0,0	-0,1	0,0	0,0	-0,1	0,0	0,0	0,0	0,0	0,0	0,0	-0,2	-0,1
Large office	0,0	-0,4	0,2	-0,2	-0,7	0,0	0,0	-0,1	0,0	0,0	-0,1	-0,8	-0,5
Secondary school	0,0	-0,7	0,3	-0,1	-1,0	0,0	0,0	-0,1	-0,3	0,0	-0,3	-0,9	-1,3
Small hotel	-0,2	-2,6	-3,6	-1,4	-1,5	-0,2	-0,2	-0,3	-0,7	-0,3	-2,0	-11,0	-19,2
Strip mall	0,0	-2,3	0,7	0,0	-2,1	-0,8	0,0	0,0	-1,7	-0,1	-1,3	-8,2	-9,9

These low savings are due to the low weight of the EV load consumption compared to the overall building consumption (Exhibit 9 - top) Exhibit 9 Relative weight of the EVCS annual electricity consumption, to the annual total electricity consumption (building and EVCS) (top), and same for EVCS bill to total energy bill (bottom) for the reference case i.e., uncontrolled charging.

Exhibit 9. Relative weight of the EVCS annual electricity consumption, to the annual total electricity consumption (building and EVCS) (top), and same for EVCS bill to total energy bill (bottom) for the reference case i.e., uncontrolled charging

	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W
Hospital	0,4	0,4	0,6	1,0	0,6	0,1	0,4	0,4	0,4	0,6	0,4	0,4	0,5
Large office	0,7	1,0	2,5	4,3	1,6	0,1	0,4	2,3	0,4	1,6	1,0	1,0	1,1
Secondary school	0,9	1,0	3,1	5,0	2,0	0,1	0,5	2,5	0,5	2,0	1,0	1,1	1,2
Small hotel	1,6	2,9	6,2	10,1	4,8	0,4	1,7	4,4	1,6	4,8	3,1	3,5	3,5
Strip mall	3,9	3,5	11,2	13,8	7,8	0,9	4,3	8,0	4,1	7,8	3,8	4,6	4,5

	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W
Hospital	0,4	0,4	0,5	0,8	0,6	0,1	0,4	0,4	0,4	0,6	0,4	0,6	0,6
Large office	0,8	1,7	2,5	4,4	2,3	0,1	0,4	2,6	0,7	1,7	1,4	3,2	2,2
Secondary school	0,9	1,7	2,6	4,4	2,8	0,1	0,5	2,4	0,7	2,1	1,4	2,6	2,6
Small hotel	1,5	4,7	7,1	7,6	4,9	0,4	1,4	3,3	2,0	4,6	4,2	13,0	20,8
Strip mall	4,0	6,8	11,9	13,7	8,9	1,5	4,3	7,8	5,6	7,9	5,9	13,6	18,7

There are a few use cases showing smart charging leading to a slight bill increase (red cells in Exhibit 8) when smart charging algorithm prioritizes spreading of the EVCS power instead of charging during low price hours, such as to avoid peaks in the EVCS power.

Targeted profitability is achieved

Conversely, the profitability of the investment (using the Internal Rate of Return - IRR³) is significantly positive (Exhibit 10). Even when the total bill reductions are small, smart charging CAPEX being small too (see Annex), IRRs are attractive in most cases⁴.

In 17 cases, IRR is below the hurdle rate optimization threshold⁵ (red and orange cells). But in 4 of these cases, the peak import in uncontrolled mode is > 120% of max import power. Therefore, if grid reinforcement costs were accounted in the profitability calculations, IRR could be acceptable in these cases.

³The IRR here corresponds to the real discount rate that sets the Net Present Cost of the investment project equal to zero.

⁴IRR are bounded at 0 (non-viable project after 30 years) and 200 (highly profitable).

⁵ Large Office: 6.8%, Large Public Hospital: 3.2%, Small Hotel: 6.4%, School Secondary 7.1%, Retail Strip Mall 6.9%. See "Box: Microgrid optimum sizing" for more details about the way to choose these Hurdle rates.

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Exhibit 10. Internal Rate of Return of Smart charging investment vs Uncontrolled charging (%).

	Legend													= 0	> 0 & < HR*	>= HR*
	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W			
Hospital	66,9	200,0	9,1	12,2	123,4	200,0	0,0	4,3	0,0	4,7	89,0	200,0	200,0			
Large office	0,0	200,0	0,0	20,5	178,6	0,0	0,0	17,2	0,0	13,3	40,7	200,0	200,0			
Secondary school	0,0	200,0	0,0	4,7	175,8	140,9	0,0	12,3	178,5	0,0	111,0	200,0	200,0			
Small hotel	66,5	200,0	120,5	25,6	90,4	138,2	27,5	24,8	183,7	45,3	161,1	200,0	200,0			
Strip mall	2,3	200,0	0,0	0,0	106,9	200,0	0,0	0,0	200,0	9,4	142,6	200,0	200,0			

*HR: hurdle rate. 3,2% for Hospital, 6,8% for Large office, 7,1% for Secondary school, 6,4% for Small Hotel and 6,9% for Strip mall

Region wise:

- We see strongest profitability for regions having demand charges and subscribed power in their tariff structures (France, Spain, India, Canada, USA Northeast, South and West), as smart charging optimization spreads charging over time, and limits maximum power,
- Much smaller IRRs are seen for countries having a pricing structure based on wholesale prices (Denmark and Norway) and for the UK, but these are still matching profitability targets in most sectors,
- Use cases with no profitability must be looked at carefully as some of them may require grid connection upgrades, hence additional costs which could improve profitability (e.g., China, Australia, Italy).

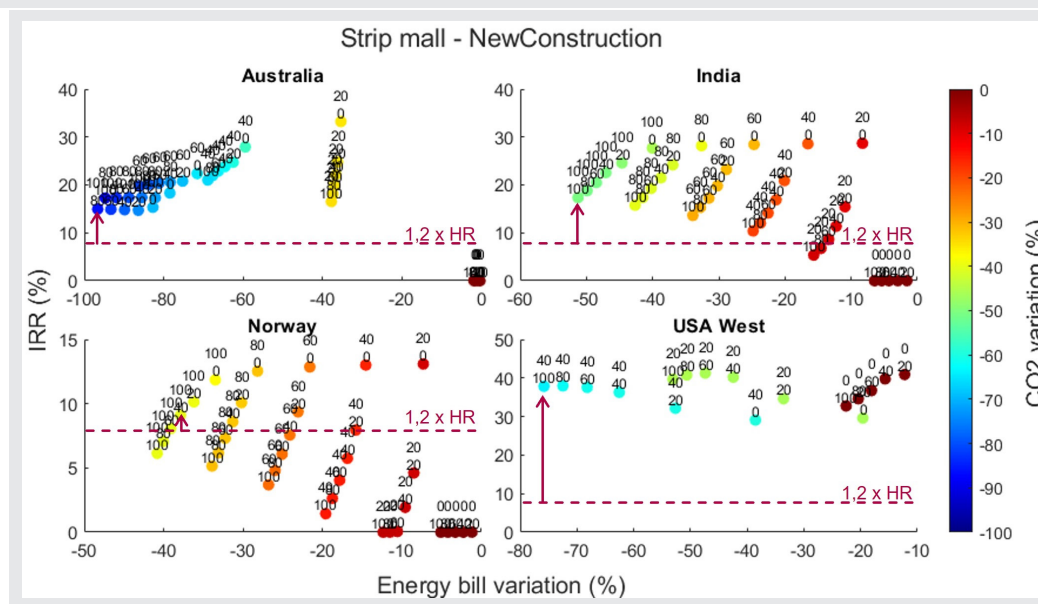
The investment case is improved when adding a microgrid in all cases

We look here at how we size the microgrid to match the targeted optimization, then analyze the operational cost and financial performance for the best microgrid design.

Box: Microgrid optimum sizing method and visualization tool

To help in the microgrid size optimization, we have designed a scatter plot for depicting all the tested PV and battery sizes in a use case (Exhibit 11). Each dot represents a microgrid design (i.e., PV and battery size), with two numbers on top of each dot. The top number is the PV size, given as a percentage of the maximum tested PV size in the use case. The bottom number is the battery size, also as a percentage of the maximum tested battery size in the use case.

Exhibit 11. Illustrative scatter plots of the strip mall sector for 4 regions, showing hurdle line (horizontal line), and selection of the optimum microgrid (arrow). The points with the highest IRR (upper region in the plots) and with highest bill savings (left region in the plots) are the best.



- The dots are spatially arranged according to the energy bill variation and the IRR achieved with the corresponding microgrid size. The IRR calculated by EMSF is lower bounded at 0, and upper bounded at 200%, for visualization.
- The color of the dots indicates the CO2 emissions variation (operational emissions only).
- Finally, the three KPIs displayed are relative to the state of the building prior to the implementation of the microgrid (i.e., building and EVCS equipped with smart charging).

There is a vast range of performance evolution with respect to geographies, which typically reflects the diversity of weather (heating and cooling load, solar irradiation), retail tariff structure and EV load at least.

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As explained in Part II (Methodological approach), the optimal microgrid size of each use case is selected using a multi-criteria sizing rule:

1. Exclude microgrid sizes with an IRR smaller than 1.2 times the hurdle rate, or, if all sizes were to be excluded, simply select the one with the highest IRR,
2. Among the remaining simulations, select the one with the lowest bill.

The implementation of this rule is represented by the red lines depicted on the scatter plots of Exhibit 11.

Note that selecting an appropriate hurdle rate is a complex task (see Annex for details) since this rate depends both on the type of investor and the investment project being evaluated. Considering this, and to fulfill the main goal of the report, we chose one generic investor profile per building sector. To obtain the hurdle rates of the different investor profiles, we use a technical support document of the United States Department of Energy (U.S. Department of Energy, 2022). This document provides estimations of the hurdle rate usable by various investors (households, companies of different sectors and public entities) when evaluating an investment on a high efficiency appliance⁶. Overall, selected hurdle rates for the five sectors are the following ones: Large Office: 6.8%, Large Public Hospital: 3.2%, Small Hotel: 6.4%, Private School Secondary 7.1%, Retail Strip Mall 6.9%.

Microgrid designs massively incorporate PV and batteries

The best microgrid design is selected among the 35 tested designs for each use case, according to the multi-criteria sizing rule described in the methodological chapter, leading to optimal sizing for the PV panels and for the stationary battery (Exhibit 12).

Exhibit 12. Optimal microgrid sizing (top chart PV size, bottom chart battery size) for the 65 use cases. In % of max PV size, in % of max battery capacity.

	Legend												
	= 0	= 20	= 40	= 60	= 80	= 100							
	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W
Hospital	100	100	100	100	100	100	100	100	100	100	100	100	100
Large office	100	100	100	100	100	100	100	100	100	100	100	100	100
Secondary school	100	60	100	20	80	100	100	100	100	100	60	20	40
Small hotel	100	100	100	80	100	100	100	100	100	100	100	0	100
Strip mall	100	60	100	20	80	100	80	100	100	100	60	20	40

	Legend												
	= 0	= 20	= 40	= 60	= 80	= 100							
	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W
Hospital	100	100	100	20	100	40	80	0	100	100	60	80	100
Large office	60	100	40	0	40	0	20	0	40	100	0	20	80
Secondary school	100	100	100	0	100	100	40	20	100	100	100	20	100
Small hotel	100	80	100	0	100	80	100	0	100	100	60	20	100
Strip mall	80	100	100	0	60	100	20	40	100	100	80	0	100

- On one hand, rooftop solar PV brings value by substituting part of the grid imports with self-production, and by the direct selling of excess production back to the grid (in authorized regions). All use cases except one exhibit rooftop solar PV, with most of deployments at maximum potential. However, for certain use cases of Denmark and USASouth, the sizing optimization avoids PV sizes greater than 20% of the maximum PV size, partly because these two regions present relatively high PV CAPEX and small grid electricity price⁷. Note that these two regions present relatively high PV CAPEX and small grid electricity prices.

- On another hand, not all use case designs include stationary storage (e.g., Norway, Denmark), as the value that it can bring is highly dependent on the electricity tariff structure of each use case. In these cases, its deployment is not providing enough value (e.g., as low PV potential so low PV self-dispatch, small spread of TOU rates, or no demand charges / subscribed power that require the suppression of power peaks).

Overall significant bill reduction

Exhibit 13 addresses OPEX. It shows that bill reductions are significant across all cases.

Exhibit 13. Annual energy bill variation (%) when deploying the optimized microgrid on top of smart charging, relative to deploying smart charging only.

	Legend												
	< -10	>= -10 & < 0	>= 0										
	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W
Hospital	-15,9	-19,9	-25,1	-12,4	-20,9	-5,8	-15,3	-2,9	-20,5	-15,5	-15,9	-29,3	-28,9
Large office	-10,0	-15,5	-14,8	-7,7	-13,8	-2,4	-9,9	-2,1	-14,2	-10,1	-8,3	-19,7	-22,5
Secondary school	-88,4	-76,0	-78,7	-23,4	-89,8	-37,8	-94,2	-28,8	-73,1	-81,7	-80,5	-36,2	-68,0
Small hotel	-51,7	-52,4	-47,3	-25,0	-45,1	-17,9	-48,7	-9,7	-43,8	-48,4	-47,4	-12,6	-57,1
Strip mall	-96,6	-83,3	-83,0	-27,8	-94,5	-51,3	-99,3	-37,9	-80,8	-84,6	-88,6	-28,7	-75,8

⁶ In particular, a high efficiency water heater.

⁷ We also observe that medium PV sizes have been selected in the Secondary School and Strip mall use cases of Canada, USA Northeast and USA South. In such cases, Higher PV sizes got excluded because they make the building becoming net producer sites (i.e., PV farm-like) on a yearly basis (i.e., annual sales of energy exported to the grid exceed the annual costs of imported energy).

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Region wise:

- Bill savings achieved by the microgrid are strongly influenced by the ratio between the annual PV production and the overall energy needs (building and EVCS consumption). This ratio is considerably low in India and Norway, because of the remarkably high building consumptions in such regions. We also observe moderate savings in certain use cases of Denmark and USA South. This is explained by the small PV sizes in such use cases, again leading to a small PV production in comparison to the energy needs. Note that the multi-criteria sizing rule has not selected bigger PV sizes as they would excessively penalize the IRR.

Sector wise:

- Hospital and Large office sectors exhibit moderate savings because they have the lowest PV to rooftop ratios, hence the smallest microgrid designs. This limitation stems primarily from architectural constraints: these building types typically have a low rooftop-to-floor area ratio, as shown in Exhibit 22. Indeed, typical offices and hospital buildings possess a vertical shape with several floors and small roof surface as visible in Exhibit 24. For example, the maximum PV capacity that can be installed on a large office building corresponds to only 5% of its total floor area, whereas in contrast, a retail strip mall can accommodate PV installations covering up to 70% of its floor area. This stark difference significantly impacts the ability of each sector to offset its electricity consumption through on-site solar generation.

Profitability is high

Combining CAPEX and OPEX savings, we can now retrieve the IRRs of the best microgrid sizing as shown in Exhibit 14. Investments are viable in all cases except one as IRRs are much higher than the hurdle rate.

Exhibit 14. Internal Rate of Return (%) of optimized microgrid, on top of smart charging deployment

	Legend													= 0	> 0 & < HR*	>= HR*
	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W			
Hospital	9,9	14,5	7,0	5,1	5,0	4,6	5,7	13,1	5,4	18,7	4,7	4,8	29,9			
Large office	9,9	11,8	10,3	8,8	8,6	30,1	13,3	13,1	9,9	12,9	11,7	10,7	30,5			
Secondary school	17,9	22,6	9,9	8,5	9,9	15,2	13,8	9,4	10,2	23,7	8,9	8,8	38,5			
Small hotel	18,3	20,6	10,6	7,8	8,5	9,3	11,9	13,1	19,8	28,5	7,8	8,7	30,3			
Strip mall	15,0	21,9	9,0	8,9	9,0	17,4	13,5	9,1	16,5	20,9	8,6	5,6	37,9			

*HR: hurdle rate. 3,2% for Hospital, 6,8% for Large office, 7,1% for Secondary school, 6,4% for Small Hotel and 6,9% for Strip mall

Note that it is particularly challenging to sort out insights for the IRR as it is affected by numerous parameters and outputs presenting region and sector variability (e.g., electricity tariffs, CAPEX values, the PV and battery sizes selected, the number of replacements required by the battery, etc.)

Region wise:

- USA West, Canada, and UK regions exhibit the highest profitability, while Denmark, France and USA South and USA Northeast regions are closing the pack.

Sector wise:

- Small Hotel, Secondary school and Strip mall sectors exhibit the highest profitability while Hospital exhibits the lowest one.

Microgrids remain attractive with increased EV penetration rates

We look here at the impact of an increased EV penetration rate i.e., EV presence at the building site.

Overall significant bill reduction

As the number of EVs on site is much larger in 2035, the absolute bill increases. We observe that savings remain significant (Exhibit 15).

Exhibit 15. Annual energy bill variation (%) when deploying the optimized microgrid on top of smart charging if higher EV penetration rate (2035 estimates).

	Legend													< -10	>= -10 & < 0	>= 0
	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W			
Hospital	-15,7	-19,8	-24,7	-12,2	-20,5	-5,8	-15,2	-2,9	-20,4	-15,2	-15,8	-29,4	-29,1			
Large office	-7,1	-17,4	-11,4	-4,4	-11,9	-2,3	-8,9	-2,0	-10,7	-6,7	-6,1	-14,1	-22,2			
Secondary school	-86,7	-70,5	-78,0	-20,5	-85,2	-37,6	-93,2	-28,0	-73,2	-80,6	-74,7	-32,5	-65,1			
Small hotel	-46,0	-45,5	-43,2	-21,9	-38,4	-17,5	-45,6	-9,3	-39,1	-41,3	-42,1	-9,7	-46,1			
Strip mall	-88,5	-66,6	-75,6	-19,7	-78,3	-49,5	-93,8	-35,0	-75,3	-76,5	-71,1	-22,6	-54,0			

Profitability remains high

Exhibit 16 shows the project IRRs if the microgrid invested today (for a low EV penetration rate of 2025) is used with more EV on-site (2035 higher penetration level).

Exhibit 16. Internal Rate of Return (%) of optimized microgrid, on top of smart charging deployment, 2035 EV penetration rate

	Legend													= 0	> 0 & < HR*	>= HR*
	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W			
Hospital	9,9	14,8	7,0	5,1	4,9	4,6	5,7	13,1	5,4	18,7	4,8	5,0	30,6			
Large office	5,7	16,4	7,1	3,9	5,6	28,8	12,2	13,1	6,6	7,2	8,8	7,0	32,9			
Secondary school	18,7	23,6	10,9	8,1	10,3	15,2	14,3	9,5	11,2	26,0	9,1	8,9	43,3			
Small hotel	18,4	20,1	10,6	7,8	8,0	9,2	12,0	13,1	20,1	28,8	7,6	4,9	25,8			
Strip mall	17,0	23,4	11,2	8,8	9,7	17,1	14,5	9,2	19,0	25,7	8,9	4,5	29,3			

*HR: hurdle rate. 3,2% for Hospital, 6,8% for Large office, 7,1% for Secondary school, 6,4% for Small Hotel and 6,9% for Strip mall

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Comparing Exhibit 16 to Exhibit 14 shows that the IRRs are of the same order of magnitude. Profitability thus remains high, further reinforcing the attractiveness and future-proof aspect of combining smart charging and microgrid investments.

However, there is a significant profit loss for the large office building in Australia, Denmark, France, and Spain, where the IRRs fall below the 6.8% hurdle rate. There is a sharp increase in EV penetration in these countries, where EV shares more than triple (Exhibit 2). As a result, building power profiles shift from the 2025 EV penetration scenario to the 2035 scenario, with higher daily EV charging demand.

Exhibit 17 compares microgrid parameters for the system optimized for 2025 operations (MG 25) and the one optimized for 2035 (MG 35).

Exhibit 17. Focus on Large-office-case for Denmark, France, Spain and Australia: comparison between the performance of microgrids optimally sized for 2025 and 2035 estimated EV penetration rates.

	Regional EV penetration rate (%)		PV sizing (%)		Battery sizing (%)		IRR optimal MG 25 and 35 (%)		Peak import / Grid import limit (%)	
	2025	2035	2025	2035	2025	2035	2025	2035	2025	2035
Denmark	14%	55%	100	100	0	0	8,8	3,9	100	100
France	5%	35%	100	100	40	0	8,6	10,9	93	100
Spain	1%	25%	100	100	40	20	9,9	10	81	99,3
Australia	2%	25%	100	100	60	40	9,9	8,7	99	100

We observe that the MG 35 design maintains the maximum installed PV capacity (see PV sizing column), similar to MG 25, but features a reduced battery capacity.

For example, battery sizing drops from 40% of the maximum tested size to 0% in France, and by 20 percentage points in Spain and Australia. This suggests that the battery struggles more to “pay for itself” in the 2035 scenario. When battery capacity is reduced, IRR improves across all geographies except Denmark.

We believe the battery loses profitability at higher capacities in the 2035 scenario because PV production is already fully consumed by the building and the EV charging station in both 2025 and 2035.

Additionally, increased EV charging demand pushes the building load closer to the grid import limit, reducing the opportunity to import low-cost energy for battery charging.

Key finding 3: EV user satisfaction remains high

EV user satisfaction is defined as ensuring the right state of charge at departure of the building. An insufficient state of charge could occur in the following configurations:

- If the power limits (EV charging power, EV charging point power, grid power import) do not allow for a complete charge given the presence time of the EV.
- If, during most of the presence, the EV cannot be charged enough (because no excess PV or no low electricity prices), and then, before departure, if the configured "idle time"⁸ and/or power limits are not respectively long or high enough to complete the charge.

To quantify EV user satisfaction, we are using a yearly integrated KPI defined as the percentage of departures in the year for which the EV leaves with a SOC greater than 90%.

EV user satisfaction does not deteriorate with smart charging

We find that, with 2025 EV lower penetration rate, the rules imposed by smart charging do not compromise the EV user satisfaction (Exhibit 18) with respect to uncontrolled charging (uncontrolled charging leads to a 100% satisfaction across all cases), with only slight decreases for the office sector in a few geographies.

Exhibit 18. Share of annual EV departure at state of charge (%) superior to 90% with Smart charging

	Legend													
	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W	
Hospital	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
Large office	99,8	100,0	98,1	98,3	99,1	100,0	100,0	100,0	100,0	99,1	100,0	99,8	99,8	99,8
Secondary school	100,0	100,0	100,0	99,9	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
Small hotel	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
Strip mall	99,7	100,0	99,9	99,9	100,0	100,0	99,9	100,0	100,0	100,0	100,0	99,8	99,8	99,8

EV user satisfaction is guaranteed when adding a Microgrid

Adding a microgrid in 2025 brings more capacity to charge vehicles, what translates into all vehicles being well charged at departure, across all sectors and geographies vehicles (Exhibit 19).

Exhibit 19. Share of annual EV departure at state of charge (%) superior to 90% with a Microgrid on top of Smart charging

	Legend													
	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W	
Hospital	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
Large office	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
Secondary school	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
Small hotel	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
Strip mall	100,0	100,0	100,0	99,9	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0

EV user satisfaction remains high at increased EV penetration rate

When considering a higher penetration rate, but unchanged microgrid sizes and grid power limits, the smart charging algorithm may have troubles providing all the charge required by the EVs. However, Exhibit 20 shows that satisfaction level remains very good levels across all use cases.

Exhibit 20. Share of annual EV departure at state of charge (%) superior to 90% with a Microgrid on top of Smart charging, with a higher EV penetration rate (2035)

	Legend													
	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W	
Hospital	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
Large office	92,7	100,0	89,3	69,3	86,2	100,0	99,8	100,0	96,6	80,0	98,1	97,9	98,7	98,7
Secondary school	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
Small hotel	100,0	100,0	99,8	99,5	99,8	100,0	100,0	100,0	100,0	99,8	100,0	99,7	99,7	99,7
Strip mall	100,0	100,0	99,9	99,7	99,9	100,0	100,0	100,0	100,0	99,9	99,9	97,3	97,6	97,6

The office sector is however subject to a drop of the satisfaction rate KPI. With close to 30% of EV users leaving the office with less than 90% SOC in Denmark, the financial optimization strategy becomes detrimental to the EV users (savings and IRR are favored against EV user satisfaction).

⁸ The time slot right before departure in which the EV is allowed to charge, no matter the price level or if there is no excess PV.

Part VI: Making sense of it all

Building upon our initial research which outlined the concept of Buildings of the Future, we expanded and refined our analysis to integrate smart charging using our in-house Energy Management Simulation Framework.

The conclusion is clear: the combination of smart charging with a well-designed microgrid (PV, Battery) provides multiple benefits to the many stakeholders:

- Avoidance of burden on the grid thanks to EV smart charging and stationary battery management.
- Reduced energy bills (and deep decarbonization as detailed in the Annex).
- Attractive paybacks in a context of rising energy prices
- EV user satisfaction

Our research showed that (Exhibit 21):

1. With respect to peak issues:

- a. Uncontrolled charging leads to peak issues in around 80% of the cases while Smart Charging helps to avoid them without compromising EV satisfaction, in all modeled cases,
- b. The addition of well-designed microgrids further enables peak reduction, and headroom recovery up to 50% (allowing for other electricity demand expansion),
- c. Peak issues are contained when increasing EV penetration rates with a microgrid invested today.

2. When it comes to economics:

- a. Smart charging investment is attractive at noticeable EV penetration rates, adapting timely to the electricity rate and contributes to avoid grid connection costs,
- b. The investment case of adding a microgrid is viable in most cases, thanks the combined use of rooftop PV and stationary battery contributing to significant self-consumption, self-dispatched PV use and export to the grid,
- c. Microgrid investment remains economically sound when the EV penetration rate increases. It is thus future-proof.

3. When it comes to the EV users:

- a. EV user satisfaction does not deteriorate when deploying smart charging,
- b. EV user satisfaction is excellent when adding a Microgrid and remains very good with higher future EV penetration rate, except in a few extreme cases.

This large diversity of results is rooted in the combination of several highly influencing parameters, including:

- The temporal alignment of time varying characteristics, namely the solar irradiance and temperature variations, dynamic tariffs, timing nature of the building process and presence of occupants, EV usage and presence of the EV sometimes driven by local policies,
- The attributes of the dynamic tariffs and in particular the existence and level of demand charges/subscribed power fee or penalties, of sellback mechanisms to the grid, and the large variations of EV presence scenarios,
- The relative weight of the EV load to the building load typically,
- The building characteristics, and particularly the roof to floor ratio, conditioning the performance of the microgrid both for direct PV use and self-dispatch through the stationary battery,
- the photovoltaic production potential of the building, which depends on the prevailing climatic conditions and the available surface for Photovoltaic (PV) panel installation,

This work could find natural extension allowing the following directions:

- Introducing more regions with fresher updated dynamic tariffs (2024), and incentives or subsidies locally available,
- Adding revenues from system services or market based
- Adding grid costs estimates,
- Introducing local EV fleets (e.g., from salespeople in an office, or ambulance in a hospital),
- Assessing the impact of bidirectional EV charging, including their specific tariffs if needed.

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Exhibit 21. Overall benefits of adding a microgrid, to an electrified and efficient building equipped with smart charging. Peak issue containment in % of the grid power limit(top), Profitability with the Internal rate of return in % (middle), EV user satisfaction, as the share of EV users leave the building site with state of charge or at least 90%, at future higher penetration rate (bottom).

	Legend										<= 100	> 100 & < 120	>= 120
	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W
Hospital	100,0	62,4	100,0	100,0	66,2	86,9	100,0	96,8	72,8	100,0	63,2	100,0	64,8
Large office	99,1	57,3	100,0	100,0	92,9	98,9	95,3	100,0	80,8	100,0	96,8	84,1	73,9
Secondary school	82,4	62,8	87,5	99,8	41,8	66,2	87,7	99,8	44,7	100,0	47,2	75,5	55,0
Small hotel	100,0	54,4	100,0	100,0	49,2	69,1	96,9	100,0	51,9	100,0	59,7	68,8	55,6
Strip mall	88,0	64,9	100,0	100,0	71,1	57,1	96,3	100,0	70,9	92,2	71,8	100,0	53,3

	Legend										= 0	> 0 & < HR*	>= HR*
	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W
Hospital	9,9	14,5	7,0	5,1	5,0	4,6	5,7	13,1	5,4	18,7	4,7	4,8	29,9
Large office	9,9	11,8	10,3	8,8	8,6	30,1	13,3	13,1	9,9	12,9	11,7	10,7	30,5
Secondary school	17,9	22,6	9,9	8,5	9,9	15,2	13,8	9,4	10,2	23,7	8,9	8,8	38,5
Small hotel	18,3	20,6	10,6	7,8	8,5	9,3	11,9	13,1	19,8	28,5	7,8	8,7	30,3
Strip mall	15,0	21,9	9,0	8,9	9,0	17,4	13,5	9,1	16,5	20,9	8,6	5,6	37,9

*HR: hurdle rate. 3,2% for Hospital, 6,8% for Large office, 7,1% for Secondary school, 6,4% for Small Hotel and 6,9% for Strip mall

	Legend										<= 50	> 50 & < 80	>= 80
	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W
Hospital	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
Large office	92,7	100,0	89,3	69,3	86,2	100,0	99,8	100,0	96,6	80,0	98,1	97,9	98,7
Secondary school	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
Small hotel	100,0	100,0	99,8	99,5	99,8	100,0	100,0	100,0	100,0	99,8	100,0	99,7	99,7
Strip mall	100,0	100,0	99,9	99,7	99,9	100,0	100,0	100,0	100,0	99,9	99,9	97,3	97,6

We do hope this research contributes to bringing more confidence for decarbonization investment decision of buildings, at the nexus of Energy and Mobility.

Annex



Thomas Edison

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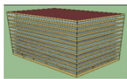
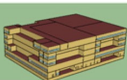
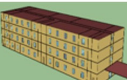
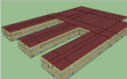
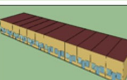
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Buildings assumptions

Load forming

Key data on energy profiles are fed into the model, for a given archetype in each region. This data was retrieved from the US department of energy databases (US DOE, 2023). As shown in Exhibit 22, five building archetypes were retrieved for a recent building (2019 year of construction).

Exhibit 22. Building archetype characteristics

Archetypes	Number of Floors	Building floor surface (m2)	3D view	Grid connexion	Observed maximum annual load (MWh)
Large Office	12	46320		MV	35242
Large Hospital	5	22422		MV	23216
Small Hotel	4	4013		LV	1535
School Secondary	2	19592		MV	6650
Retail Strip Mall	1	2090		LV	1028

Each building load profile comes as outputs from EnergyPlus simulation software (Energy Plus, 2023). Each load profile corresponds to one archetype with a given construction year in each climate zone.

- Building is equipped with a Building Management System and a heat pump instead of a gas boiler to get final building load. Building Management System brings significant advantages in lowering energy demand. The performance per building archetype and region is determined thanks to the Eu.BAC standardized methodology as done in one of our previous studies (Petit, 2021). This technique allows us to determine energy savings per application of the building.
- The heat pump sizing was made by applying a safety coefficient of 1.1 to the peak heating load, with respect to the initial gas heating power (Minier, 2024).

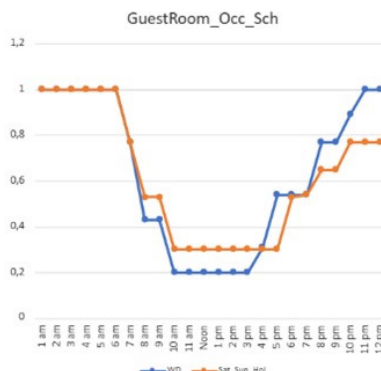
On top of this modified building load are added EV charging stations (see “EV charging assumptions” section) to get the total building load.

Occupancies

Complementary to building load profiles, occupancy are derived from a LBNL database (PNNL, 2022), providing the maximum number of occupants with their presence schedules (Exhibit 23).

Exhibit 23. Maximum occupancy (left) and illustrative occupancy schedule (right) of building archetypes

Archetypes	Occupants
Large Office	2308
Large Hospital	767
Small Hotel	259
School Secondary	6096
Retail Strip Mall	180



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Rooftop potential

The potential of onsite solar in buildings was reviewed in detail in a previous report (Petit, 2022). Based on this report, several assumptions were taken for each building archetype (Exhibit 24).

Exhibit 24. Available roof space according to archetypes for new and retrofitted buildings, and ratio vs Building usable surface

Archetypes	Roof space (m ²)	Max PV size to roof ratio	Building floor surface (m ²)	Roof to floor ratio (m ²)	Max PV size to floor surface
Large Office	3563	70%	46320	8%	5%
Large Hospital	3739	70%	22422	17%	12%
Small Hotel	1003	70%	4013	25%	17%
School Secondary	11902	70%	19592	61%	43%
Retail Strip Mall	2090	70%	2090	100%	70%

EV charging assumptions

As discussed in Part 2, EV charging electrical load is aggregated with the building load by a preprocessor which calculates the energy dispatch according to expert rules. This means that we need to know how many EVs are charging, with their respective power demand, at each time step.

To do so, we first derived an approach to estimate the number of EVs charging on-site, and its maximum, which we took at the number of chargers (no queuing to manage). This maximum depends on a combination of primary parameters we retrieved or estimated (Exhibit 25).

Exhibit 25. EV assumption summary. Ta = arrival time, Tp = presence time, W1-4=EV car wave number

	LARGE OFFICE	SCHOOL	HOSPITAL	RETAIL MALL	SMALL HOTEL
Maximum number of occupants	2308	6096	767	180	259
Users eligible to EV charging at maximum building occupancy	2308 (workers)	487 (workers only)	145 (workers only)	162 (guest & workers)	50 (guests & workers)
Daily schedule / EV fleet behavior incl. Normal distribution	Tp ~ N(3:00, 0) W1 : Ta ~ N(8:00, 0.5) W2 : Ta ~ N(13:00, 0.5)	Tp ~ N(3:00, 0) W1 : Ta ~ N(8:00, 0.5) W2 : Ta ~ N(13:00, 0.5)	Tp ~ N(3:00, 0) W1 : Ta ~ N(8:00, 0.5) W2 : Ta ~ N(13:00, 0.5) W3 : Ta ~ N(20:00, 0.5) W4 : Ta ~ N(2:00, 0.5)	Tp ~ N(2, 0.75) W1 : Ta ~ N(12:00, 1) W2 : Ta ~ N(15:00, 1) W3 : Ta ~ N(18:00, 1)	W1 : Ta ~ N(19:00, 2.0)
Trip distribution conditioning SOC at arrival	(Normal 40 km, std 15 km) x 3 days	(Normal 40 km, std 15 km) x 3 days	(Normal 40 km, std 15 km) x 3 days	Normal 70 km, std 30 km	Normal 120 km, std 45 km
Weekly schedule	Mon, Tues, Wed, Thu, Fri : 0.5 W1, 0.5 W2 Sat : 0.3 * W1	Mon, Tues, Wed, Thu, Fri : 0.5 W1, 0.5 W2	Mon, Tues, Wed, Thu, Fri, Sat : 0.5 W1, 0.5 W2, 0.25 W3, 0.25 W4 Sun: 0.25 W1, 0.25 W2, 0.17 W3, 0.17 W4	Mon, Tues, Wed, Thu, Fri, Sat, Sun W1, W2, W3	Mon, Tues, Wed, Thu, Fri, Sat, Sun W1

1. The EV penetration rate in car stock in the different geographies (see in Exhibit 2) which we built thanks to various sources and databases (BNEF, 2024) (IEA, 2024) (DNV, 2024) (DNV, 2024) (DNV, 2024), is taken as the share of EV users among the occupants coming by car.

2. The car usage versus other transportation means to go to the building site (i.e., among occupants, how many come by car e.g., 80%).

3. The number of building occupants which are EV users and eligible to charge: Not all occupants are allowed to charge (e.g., workers vs visitors in a hospital, e.g., workers and guests in a hotel). This necessitated to map the occupants according to their status (e.g., patient in hospital, guest in hotel). The number of eligible EV users is calculated for each building based on occupancy and policy assumptions. This value represents the maximum number of EVs that could be parked and charged on-site under full adoption and peak building occupancy conditions.

- Working buildings, such as large offices, schools, and hospitals, provide charging access primarily to employees. These buildings implement time-slot policies to distribute charging demand, typically allowing half of the fleet to charge in the morning and the other half in the afternoon.
- Guesting buildings, including hotels and retail malls, offer EV charging to guests and visitors. Charging behavior in these buildings is modeled based on arrival times and expected durations of stay.

4. The daily allowed charging schedules (arrival/departure and/or duration), in order to limit the number of EV chargers (e.g., morning and afternoon periods at office), and/or satisfy the occupants (e.g., duration time for retail customer for the strip mall archetype). The maximum number of users eligible for EV charging, assuming full EV adoption among occupants and peak building occupancy, is essential for estimating the maximum number of EVs that may arrive during a charging wave, which in turn informs the required number of chargers per scenario i.e., building sector x geography.

5. The weekly EV presence schedule: EV user behavior (e.g., charging at work only for the office worker, with two charging periods during the week).

6. The variability of arrival time, duration, and trip length (so state of charge at arrival), knowing EV car is selected as being a modern car with long range and performant charging (60 kWh of battery capacity, 450 km range, 22 kW AC charge with 0.95 efficiency) using normal law Probabilities Density Functions:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right)$$

With σ^2 the variance of the normal law and μ its mean value.

Hence to compute, car arrival time $T_a \sim N(\mu(T_a), \sigma(T_a))$, presence time $T_p \sim N(\mu(T_p), \sigma(T_p))$ and trip length $D \sim N(\mu(D), \sigma(D))$, we sample their associated normal laws using inverse transform sampling over an entire year of simulation with a timestep of $\delta t = 15$ min for arrival and presence time and with a distance step of $\delta_D = 10$ km for trip length.

The following paragraphs give details about the EV charging behaviors per building type.

Large Office sector

The large office scenario represents a high-density workplace with a maximum occupancy of 2308 individuals. For instance, in Norway, such a building has an annual electrical load of close to 35242 MWh, excluding electricity consumed for EV charging. Due to the country's substantial heating requirements and the building's fully electric design, this represents one of the highest electricity consumption levels in the market study.

We assume a car usage rate of 80% with each car transporting a single worker. Additionally, we consider that every EV owner is willing to charge his vehicle at the workplace whenever possible. All occupants are eligible for EV charging in this scenario.

To optimize the use of the charging infrastructure, daily mandatory charging schedules are imposed by a site policy. One group of vehicles charges in the morning and another group charges in the afternoon. Hence EV arrivals are following a two-wave distribution:

- Wave 1 (W_1): Morning arrivals centered at 08:00 ($T_a \sim N(08:00, 0.5)$)
- Wave 2 (W_2): Afternoon arrivals centered at 13:00 ($T_a \sim N(13:00, 0.5)$)

Presence time is modeled as $T_p \sim N(3 \text{ hours}, 0.0)$, consistent with typical half-workday durations. Trip lengths follow a normal distribution with a mean of 40 km and a standard deviation of 15 km per day. Each EV is assumed to charge one day out of three meaning that charging demand corresponds to three times the daily trip distribution. Weekly planning assumes equal distribution of arrivals across weekdays, with reduced activity on weekends.

By default, each wave accounts for the maximum number of EVs that may arrive during a charging window—this is typically limited by the number of chargers available on site. The “Weekly schedule” line in Exhibit 25 shows how the charging waves are weighted throughout the week. For example, the weekday schedule (Monday to Friday) assigns 50% of arrivals to the morning wave (W_1) and 50% to the afternoon wave (W_2). On Saturdays, only the morning wave (W_1) is active, with a reduced weight of 30%.

Secondary School sector

The school scenario includes a total occupancy of 6096. Staff members are considered eligible for EV charging. For instance, in Norway, such a building has an annual electrical load of approximately 6650 MWh, excluding electricity consumed for EV charging.

Based on existing literature, there is on average one support staff member for every three teachers and fifteen students per teacher. Accordingly, we estimate that 8% of total occupancy are staff members and 92% are students (USAFacts, 2025), (vie-publique.fr, 2024), (Wang, 2024), (Ministère de l'Éducation Nationale, 2022). In total 487 individuals are considered eligible to charge their electric vehicle. We assume a car usage rate of 80% with each car transporting a single worker. Additionally, we consider that every EV owner is willing to charge his vehicle at the workplace whenever possible.

The EV arrival pattern mirrors that of the office, with two charging waves at 08:00 and 13:00 with similar presence time and trip length distributions. Each EV is assumed to charge one day out of three meaning that charging demand corresponds to three times the daily trip distribution. The weekly schedule reflects standard school operations, with weekday activity and no weekend presence.

Large Hospital sector

The hospital is modeled with 767 occupants. In Norway, such a building has an annual electrical load of approximately 23216 MWh, excluding electricity consumed for EV charging.

In the absence of precise data, we rely on sectoral norms and publicly available information to estimate occupancy and electric vehicle (EV) charging behavior in hospital environments. The staffing structure is assumed to follow a typical ratio of one healthcare professional—comprising both physicians and nurses—for every five patients. This corresponds to a configuration where one physician and one nurse collectively address approximately ten patients. In addition to clinical staff, hospitals hire support function people such as administrative and technical staff, with an estimated ratio of one support staff member for every two physicians. Daily visitor flow is approximated at one visitor per four patients, reflecting common patterns observed in hospital settings. These ratios were used to infer the relative shares of each group within the building's total occupancy. Based on this approach, most of the occupants are patients, followed by visitors, healthcare staff, and support personnel. These relative weights serve as the basis for estimating the number of individuals per category. Accordingly, we estimate that 19% of total occupancy are staff members and 81% are patients or visitors. In total 145 individuals are considered eligible to charge their electric vehicle.

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We assume a car usage rate of 80% with each car transporting a single worker. Additionally, we consider that every EV owner is willing to charge his vehicle at the workplace whenever possible.

To optimize the use of charging infrastructure, daily charging schedules are implemented. To reflect the continuous operations of a hospital, employees are modeled as working either day or night shifts, allowing vehicle plug-in opportunities in the mornings, afternoons, evenings, and early mornings. Arrival times are distributed across four distinct waves to represent the 24-hour operational cycle:

- Wave 1 (W_1): Morning arrivals at 08:00 - $T_a \sim N(08:00, 0.5)$
- Wave 2 (W_2): Midday arrivals at 13:00 - $T_a \sim N(13:00, 0.5)$
- Wave 3 (W_3): Evening arrivals at 20:00 - $T_a \sim N(20:00, 0.5)$
- Wave 4 (W_4): Night arrivals at 02:00 - $T_a \sim N(02:00, 0.5)$

Presence time is modeled as $T_p \sim N(3 \text{ hours}, 0)$. Trip lengths are modeled as $D \sim N(40 \text{ km}, 15 \text{ km})$. Each EV is assumed to charge one day out of three meaning that charging demand corresponds to three times the daily trip distribution. Weekly planning assumes equal distribution of arrivals across day-shift weekdays and night shift weekdays, with reduced activity on nights and Sundays.

By default, each wave accounts for the maximum number of EVs ($\max_{EV \text{ number}}$) which may arrive during a charging window—this is typically limited by the number of chargers available on site. The “Weekly schedule” line in Exhibit 25 shows how the charging waves are weighted throughout the week. For example, the Monday-to-Saturday schedule assigns 50% of $\max_{EV \text{ number}}$ to the morning wave (W_1) and 50% to the afternoon wave (W_2), 25% to the evening wave (W_3) and 25% to the early morning wave (W_4). These weights are reduced on Sundays to reflect lower activity levels.

Retail Strip Mall sector

Retail environments host 180 occupants, and, for example, has an annual electrical load of approximately 1028 MWh in Norway, excluding electricity consumed for EV charging.

The estimation of the EV parking patterns in this sector differs from the workplace scenarios. We assume a car usage rate of 80% with each car transporting an average of 1.5 people. Additionally, we consider that 40% of EVs drivers are willing to charge their vehicle at the shop location. An Occupancy-related-coefficient of 80% is applied to account for partial building usage, as full occupancy is not maintained throughout the day. We estimate that 90% of the occupants are visitors and 10% are workers. In this scenario, only visitors are eligible for EV charging. Therefore, the maximum number of EVs ($\max_{EV \text{ number}}$) which may arrive during a charging window is given by:

$$\max_{EV \text{ number}} = \text{People arriving by car share} \times \text{Car per number of people} \times \text{Charge in building share} \\ \times \text{Occupancy related coefficient} \times \text{Visitor over total occupants} \times \text{Total occupants' number} \times \text{EV total share}$$

with:

- People arriving by car share = 0.8
- Car per number of people = 1/1.5
- Charge in building share = 0.4
- Occupancy related coefficient = 0.8
- Visitor over total occupants = 0.9
- Total occupants number = 180
- EV total share the country dependent EV penetration rate listed in Exhibit 25.

According to PNNL data (PNNL, 2022), occupancy in this sector is primarily concentrated in the afternoon and exhibits dispersed arrival patterns. To model EV arrival patterns, the strip mall scenario includes three distinct normal arrival waves centered throughout the afternoon:

- Wave 1 (W_1): Midday arrival - $T_a \sim N(12:00, 1)$
- Wave 2 (W_2): Afternoon arrival - $T_a \sim N(15:00, 1)$
- Wave 3 (W_3): Evening arrival - $T_a \sim N(18:00, 1)$

Presence time is shorter, modeled as $T_p \sim N(2 \text{ hours}, 0.75)$, reflecting typical shopping durations. Daily trip lengths are longer and more variable than in other scenarios modeled as $D \sim N(70 \text{ km}, 30 \text{ km})$. The weekly schedule is consistent with consumer behavior with mostly equal visitation across all days of the week.

Small Hotel sector

Hotels present a unique profile, with 259 occupants and 50 occupied guest rooms. For example, such a building in Norway has an annual load of 1535 MWh, excluding electricity used for EV charging.

We assume a car usage rate of 80% with each car transporting at least one guest who booked a unique room. Additionally, we consider that every EV owner is willing to charge his vehicle upon arrival at the hotel. In this scenario, only guests are eligible for EV charging.

EV arrivals are concentrated in the evening; therefore, a single arrival wave is used as $T_a \sim N(19:00, 2)$, with longer presence times than in other sectors due to overnight stays modeled as $T_p \sim N(12 \text{ hours}, 0)$. Trip lengths are the longest among all scenarios ($D \sim N(120 \text{ km}, 45 \text{ km})$). The weekly schedule is constant across all days reflecting stable guest behavior.

All in one, the number of chargers per geographies and sectors can be retrieved for 2025 and 2035 contexts (Exhibit 26).

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Exhibit 26. Regional battery-EV penetration rate (grey cells), number of EV charging stations per site in 2025 and 2035 in the 13 geographies (colored cells), and maximum ratio of potential EV users to occupants per sector (blue cells).

		Legend													Potential EV users among occupants
		Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W	
Regional EV penetration rate	2025	2%	3%	8%	14%	5%	1%	1%	30%	1%	5%	3%	3%	3%	
Hospital		1	1	2	3	2	1	1	6	1	2	1	1	1	19%
Large office		7	10	25	44	16	4	4	93	4	16	10	10	10	100%
Secondary school	2025	2	2	6	10	4	1	1	20	1	4	2	2	2	8%
Small hotel		1	2	4	7	3	1	1	12	1	3	2	2	2	19%
Strip mall		1	1	3	4	2	1	1	9	1	2	1	1	1	90%
Regional EV penetration rate	2035	25%	33%	36%	55%	35%	11%	14%	70%	25%	39%	27%	27%	27%	
Hospital		5	7	8	11	7	3	3	14	5	8	6	6	6	19%
Large office		78	102	111	170	108	34	44	216	78	121	84	84	84	100%
Secondary school	2035	17	22	24	36	23	8	10	46	17	26	18	18	18	8%
Small hotel		11	14	15	23	15	5	7	28	11	16	12	12	12	19%
Strip mall		7	10	10	16	10	4	4	20	7	11	8	8	8	90%

Regional assumptions

Beyond EV penetration rates, assumptions related to geographies are about weather and energy prices and sometimes asset costs assumptions.

Weather and Energy data

The weather profile from ASHRAE was assigned as shown in (Exhibit 27).

Exhibit 27. Weather data assumptions

ASHRAE code	Climate Code	Original City	Region Equivalent
7A	Very cold	International Falls	Canada (Ontario)
6A	Very cold	Minneapolis	Norway (NO1)
5A	Cold	Buffalo	Denmark and USA Northeast
4A	Mixed	New York	Eastern China (Zhejiang), France, UK, and Spain
3A	Warm	Atlanta	Italy
2A	Warm	Tampa	Australia (Queensland)
3B	Warm	El Paso	USA South (Florida)
1B	Warm	New Delhi	India (Uttar Pradesh)
3C	Warm	San Diego	USA West (California)

Gas has a simple tariff rate which varies across regions but not across sectors. Gas CO2 content is the same for all regions. Electricity on the contrary varies both from a grid CO2 content and tariff perspective (Exhibit 28 and next section).

Exhibit 28. Gas cost, and Gas and Electricity CO2 content

Region	Gas Cost (USD/kWh)	Gas CO2 Content (kgCO2/kWh)	Electricity CO2 Content (kgCO2/kWh)
Australia	0,06	0,2	0,93
Canada	0,03	0,2	0,13
China – Eastern	0,06	0,2	0,64
Denmark	0,1	0,2	0,19
France	0,07	0,2	0,05
Italy	0,08	0,2	0,24
India	0,06	0,2	0,74
Norway	0,1	0,2	0,011
Spain	0,08	0,2	0,27
UK	0,04	0,2	0,25
U.S. Northeast	0,05	0,2	0,39
U.S. South	0,03	0,2	0,39
U.S. West	0,03	0,2	0,18

Grid CO2 content is not considered varying over time (neither on an hourly basis, nor as an average over project lifetime).

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Dynamic tariffs

For the sake of consistency and comparison, 9 tariffs out of 13 were taken identical to the ones of our 2 previous studies (mostly 2021 prices were taken to avoid impact of the recent EU energy crisis). On top of it 4, new tariffs were extracted from available offers in Norway (NO1 bidding zone), the UK, Australia (Queensland province), and India (Uttar Pradesh region). For each of the 13 selected geographies, we have one representative dynamic electricity tariff of the market. We primarily sourced these tariffs from either the electricity market regulator or a major electricity retailer operating in the respective region.

It is important to note that we excluded subsidies and incentives from our data collection as they often vary significantly across years and baselines.

Exhibit 29. Commercial tariff structure of selected geographies (without VAT)

	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W
TOU / fixed	v		v		v	v	v		v	v		v	v
TOU /variable		v		v				v			v		
Fixed price	v			v			v			v	v	v	v
Subscribed power					v	v			v				
Demand charges		v									v	v	v
Sellback	v	v		v	v	v	v				v	v	v

It is worth to note that:

- During the time of use of the energy, the electricity rate can be either constant or variable, so the split in the table. Singularly for Denmark and Norway, customer electricity price is directly the wholesale spot price,
- A Demand charge component is a fee based on the highest rate of power consumption (in KW or kVA) that a business uses during a specific, short time interval (often 15 or 30 minutes) within a billing cycle,
- A Subscribed power component is a recurring fee based on subscribed power limit which can be constant or based on TOU pattern like in Spain. In case the subscribed power limit is exceeded, penalties might be applied to the customer bill,
- Sellback is the process of selling surplus of electricity generated by customers back to the grid, often resulting in credits or compensation on their energy bills,
- Tariff structures may vary over time (e.g., for weekends or seasons),
- More details regarding tariff structures can be found in the Annex of our previous research (Minier, 2024).

Asset cost assumptions

PV and battery costs

PV and battery costs vary regionally (Exhibit 30) and were taken as in previous work (Minier, 2024). These are coherent with observed market prices in 2025 (GLS, 2025), noting LFP Battery pack prices were observed at as low as 45\$/kWh in 2025 (BNEF, 2025).

We excluded subsidies and incentives from our data collection as they often vary significantly across years and baselines. Also, it is worth to note that:

- Neither was cost taken for design study for PV & battery, nor for permitting or commissioning costs,
- No cost was taken for Operations and Maintenance costs for PV or Batteries unless a battery replacement cost at same CAPEX (no cost improvement) every 15 years or 6000 cycles calendar lifetime,
- No degradation of performance (losses) for the battery or PV,
- No replacement costs for PV (operational all along project lifetime).

Exhibit 30. Installed PV and Battery costs

Region	PV cost (USD/W)	Battery cost (USD/kWh)
Denmark	1	275.5
Italy	0.8	275.5
China	0.5	236.2
USA	1.3	269.8
USA	1.3	269.8
USA	0.69	188.9
Canada	1.3	269.8
France	1	275.5
Spain	0.6	275.5
India	0.65	215.9
Australia	1.2	333.3
Norway	1	275.5
UK	1.1	275.5

Smart Controls

Microgrid controller costs (battery control) do not vary per geography or building type with CAPEX at 10k€, O&M costs at 1K\$/year and replacement cost at 3k\$ at 10-year lifetime.

Cost of deploying Smart charging vs direct uncontrolled charging vary according to number of deployed chargers per site (Exhibit 31). and baselines.

Exhibit 31. Cost of adding smartness to uncontrolled charging (\$/charger)

Number of chargers	Control cost (\$/charger)
< 10	300
10< < 20	225
20< < 50	150
50< < 100	110
>100	75

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Financial definitions and assumptions

The following paragraphs provide definitions for the profitability related KPIs used throughout this document. These definitions are based on the manual (Short, Packey, & Holt, 1995).

Inflation models the change of prices in goods and services over time. For instance, let us suppose that a certain transaction requires a cashflow CF in the present (i.e., in year 0). If we assume a constant inflation rate i^9 , we can deduce that in n years the same transaction will lead to a cashflow equal to:

$$CF \times (1 + i)^n$$

On another note, when evaluating cashflows it is necessary to consider the “time value”: i.e., the fact that ten dollars received today are worth more than ten dollars received later the future, because the ten dollars received today can be immediately invested and yield interests. Discount rates are typically used to model this phenomenon and allow to calculate the equivalent present value of future cashflows, to be able to compare them in a fair manner. For instance, let us take the cashflow for year n previously calculated ($CF \times (1+i)^n$). Assuming a constant nominal discount rate d_n , the present value of such cashflow can be calculated as:

$$PV = CF \times \frac{(1+i)^n}{(1+d_n)^n}$$

Therefore, the present value of a future cashflow increases if the inflation rate is increased, but it decreases if the nominal discount rate is increased¹⁰.

It should be kept in mind that, in the previous equations, CF is a cashflow expressed in present dollars. To compute the cashflow that the same transaction will produce in n years, we multiply it by $(1+i)^n$ (this is equivalent to expressing the cashflow in “dollars of year n ”). Finally, we can compute the equivalent present value of that future cashflow by dividing it by $(1+d_n)^n$.

The present value calculation can be simplified if we define an additional rate, d_r :

$$PV = CF \times \frac{(1+i)^n}{(1+d_n)^n} = CF \times \frac{1}{(1+d_r)^n}$$

This rate is known as the real discount rate, and is equal to:

$$d_r = \frac{1+d_n}{1+i} - 1 = \frac{d_n - i}{1+i}$$

Net present cost (NPC)

The net present cost is a KPI in which the present value of all the cashflows of a project are calculated and summed together (cashflows corresponding to costs are positive and those corresponding to incomes are negative).

$$NPC = CF_{year\ 0} + \frac{CF_{year\ 1}}{(1+d_r)^1} + \frac{CF_{year\ 2}}{(1+d_r)^2} + \dots + \frac{CF_{year\ N}}{(1+d_r)^N}$$

In the above expression, $CF_{year\ n}$ is the net cashflow of year n , calculated as costs minus incomes and expressed in present dollars (since the inflation is already accounted for in d_r). N is the lifetime of the project in years.

Here below is an NPC calculation example, for an investment project like the ones addressed in this report. In year 0, there is an investment cost (term CAPEX), to pay for the assets installed for the project (e.g., BMS, heat pump, microgrid). Every year, these assets lead to operational expenditures (term Annual OPEX), to pay for their maintenance for instance. But the assets also yield incomes (term Annual incomes), which in the projects addressed in this report are the energy bill savings. There might also be replacement costs at some points of the project lifetime (term Replacement in year j). Finally, the installed assets can be sold at the end of the project for their salvage value (term Salvage in year N).

$$\begin{aligned} NPC = & CAPEX + \frac{Annual\ OPEX - Annual\ incomes}{(1+d_r)^1} + \frac{Annual\ OPEX - Annual\ incomes}{(1+d_r)^2} + \dots \\ & + \frac{Annual\ OPEX - Annual\ incomes + Replacement}{(1+d_r)^j} + \dots + \frac{Annual\ OPEX - Annual\ incomes - Salvage}{(1+d_r)^N} \end{aligned}$$

Note that in an NPC calculation, we should only include the cashflows related to the investments being evaluated. For instance, for the projects addressed in this report, we include the costs associated to the low-carbon technologies installed (BMS, heat pump, microgrid). Consequently, we also include the bill savings enabled by these technologies. However, we do not include the costs that existed in each building prior to the installation of such technologies (e.g., the initial energy bill).

A negative NPC indicates that the returns of the project are worth more than the costs, and the investment is therefore economically viable. A positive NPC indicates the opposite, that the returns are worth less than the costs. Note that, in an NPC calculation, increasing the inflation rate causes an increase of the relative weight of later cashflows over sooner cashflows¹¹. Conversely, increasing the nominal discount rate causes an increase of the relative weight of sooner cashflows over later cashflows. Among the sooner cashflows, the CAPEX typically stands out.

⁹ Note that i , and the other rates used here are annual rates (but analogous calculations can be done with monthly rates, weekly rates etc.).

¹⁰ For plausible values of the inflation rate and of the nominal discount rate (i.e., i within [-100%, 100%] and d_n within [0, 100%]).

¹¹ For positive values of the inflation rate.

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Internal rate of return (IRR)

The internal rate of return is the value of the discount rate that makes the NPC of a project equal to 0, that is, right at the point where the returns of the project are worth the same as the costs.

In theory, there are two different internal rates of return:

- The real IRR corresponds to the real discount rate that sets the NPC equal to zero, i.e., $IRR_r = \{d_r | NPC = 0\}$
- The nominal IRR is the nominal discount rate that sets the NPC equal to zero. Therefore, its calculation requires assuming a value for the inflation rate, which is avoided with the real IRR. $IRR_n = \{d_n | NPC = 0\}$

Unless stated otherwise, the IRR provided in this report are expressed in real terms (and not nominal). Note also that the real IRR values delivered by EMSF are lower bounded at 0.

Discounted payback

The discounted payback is the minimum number of years required for the cumulated net present cost of the project to become 0:

$$Discounted\ payback = \{j | CF_{year\ 0} + \sum_{n=1}^j \frac{CF_{year\ j}}{(1 + d_r)^j}\}$$

In practice, the discounted payback indicates how much time is necessary for the net savings of the project to compensate the investment cost of year 0, plus de potential replacement costs. In EMSF, the discounted payback is lower bounded at 0 and upper bounded at the number of lifetime years of each project.

Practical use and relation between KPIs

There are several aspects to consider when using the profitability KPIs defined above:

- A discount rate is a measure of the “time value” which can greatly vary from one investor to another, as it depends on the context of the investor (type of investor, conditions of access to capital, etc.) and on the specific context of the project being evaluated (expected risk, planned horizon, etc.). For industrial and commercial investors, a typical guideline is to select a discount rate equal to the minimum acceptable rate of return (typically called the “hurdle rate”). In this case, it is common for a company to select a discount rate equal to its weighted average cost of capital (WACC)¹². The reasoning behind this guideline is that the WACC is representative of the “opportunity cost of capital” (that is, the typical returns of alternative investments within the company’s reach).
- Both the calculation of the NPC and of the discounted payback require defining a hurdle rate for the project. This is avoided with the calculation of the real IRR, but to extract useful conclusions, this KPI is compared to the hurdle rate of the project à posteriori (i.e., an IRR greater than the project hurdle rate means that it is viable, and vice versa).
- Both the real IRR and the discounted payback are normalized with respect to the size of the initial investment of the project. Therefore, they are suitable to compare investment opportunities of different nature and sizes (one of the reasons why IRR is selected as the main profitability KPI for this report, since the studied building sectors require vastly different investment sizes). However, when assessing a precise opportunity, it is necessary to combine the use of these normalized KPIs with other non-normalized KPIs, such as the NPC or the total CAPEX, which inform about the size of the investment.
- In fact, although the three KPIs mentioned above measure profitability, they do not provide the same information. Consequently, each investor must choose the best suited KPI to his objectives. It is also possible to use several of them in a complementary way.

Hurdle rates

For the private sector, companies set a discount rate equal to their minimum acceptable rate of return, also known as “hurdle rate,” and this hurdle rate is chosen as the weighted average cost of capital (WACC) of the company. The reason for this is that the cost of capital reflects the return that the company obtains with its typical activity.

This same reasoning can be extended to other investors different than private companies, such as public investors (e.g., for a public hospital). To obtain the approximate hurdle rates of the different investor profiles, we use a technical support document of the United States Department of Energy (U.S. Department of Energy, 2022). This document provides estimations of the hurdle rate usable by various investors (households, companies of different sectors and public entities) when evaluating an investment¹³. To do so, they assimilate the hurdle rate to the cost of capital (leaving out any potential project premiums or discounts).

Finally, it is important to highlight that, although the hurdle rates are obtained from US data, we use them for all geographies. This choice is possible because the resulting hurdle rates are only used for illustrative purposes. It allows to have a single and coherent data source. Overall, selected hurdle rates for the five sectors are the ones in Exhibit 32.

Exhibit 32. Selected hurdle rates

Large Office	Large Hospital	Small Hotel	School Secondary	Retail Strip Mall
6.8	3.2	6.4	7.1	6.9

¹² Average rate at which a company pays for its own sources of capital (equity and debt)

¹³ In particular, a high efficiency water heater.

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Methodological approach

This research takes root in two previous studies mentioned earlier, which analyzes the impact of a package of low-carbon technologies on different building use cases. For both studies, and this one, the same modelling approach was used.

Scope and build-up of relevant assumptions

In this study, we look at an extensive scope of geographies (13) and building sectors (5), i.e., 65 core use cases, for which we deploy EV smart charging infrastructure and microgrids (rooftop PV + Battery energy storage). Each use case is associated to a rich parameter set, described in (Exhibit 33)

Exhibit 33. Synthetic view of the use cases addressed, and the parameters used.

65 USE CASES	5 building segments	TECHNICAL PARAMETERS	Annual thermal and electrical consumption profiles (15-min steps) per load type (e.g., lighting, heating, ventilation, etc.), assuming only one gas-based system (cooking) and electrical-based heating & cooling systems. Vary by geography, building segment.
	13 geographies		EV charging stations. Vary by geography, building segment.
65 USE CASES	Building attributes	COST PARAMETERS	PV system with annual irradiation profiles varying by geography.
			Grid CO2 content varying by geography (but not in time), constant gas CO2 content .
65 USE CASES	North America:	COST PARAMETERS	EV charging stations smart controller cost considered. Vary by geography, quantities.
	Asia:		PV system: capital cost considered (USD/kW), varies by geography, building segment.
65 USE CASES	Europe:	COST PARAMETERS	Battery: capital cost considered (USD/kWh), varies by geography, building segment.
			Microgrid controller: capital and operation costs considered (USD/kW), Replacement cost also considered.
65 USE CASES		COST PARAMETERS	Electricity tariff: complex tariff considered, varies by building segment and geography.
			Gas tariff: Simple tariff considered (USD/kWh thermal) varies by geography.
65 USE CASES		COST PARAMETERS	30 years of project lifetime considered for profitability calculations.
			Salvage value considered for the battery (depending on the level of wear of the last battery replaced)

A full integration of diverse dynamic electricity tariffs

We focused our study on regions where businesses have access to dynamic electricity tariffs. We chose them from leading providers across each region, aiming for broad market representation and easy access to data. For example, for North America, we tapped into the Genability database (Genability, 2023). To avoid skewing results due to the recent energy crisis, all analyses relied on data from 2021, except for Denmark and Spain where specific situations necessitated using data from close-by years, retreated to match 2021, and Australia (recent 2024 tariffs).

While there are great variations and complexities in the design of tariffs depending on local grid and energy mix structure, we were able to take them all into account in our simulations.

Tariff structure plays a crucial role in bill optimization and peak load management. Three key components influence optimization strategies:

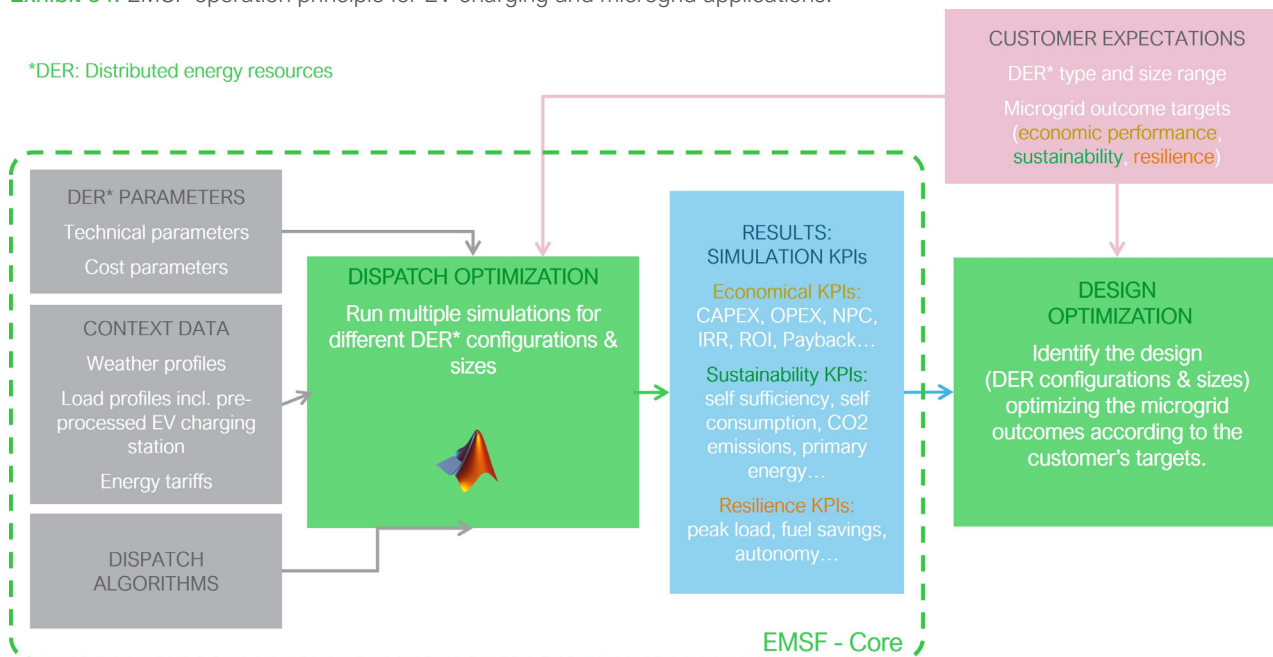
- Time-of-Use Energy Rate Spread: The difference between peak and off-peak energy rates varies significantly across regions (20% to 100% observed), emphasizing the importance of minimizing grid impact through load reduction,
- Power Component: This refers to charges based on peak demand (demand charge in North America or subscribed power in Europe). Understanding the presence and impact of this component is crucial for optimization,
- Energy Sellback Price: This refers to the compensation received for exporting excess energy to the grid. It can be fixed by the retailer, regulator, or based on net metering policies. Depending on the region, the sellback price may be equal to or lower than the purchase price.

A more comprehensive analysis of the variation of these components is available in (Minier, 2024).

Simulation Framework

Exhibit 34 presents the operation principle of EMSF for the microgrid application, including the rule-based approach to EV charging.

Exhibit 34. EMSF operation principle for EV charging and microgrid applications.



As described in the core of the paper, there are three distinct optimization stages to address the equation of the building owner/investor:

1. EV charging station preprocessor:

o The behavior of the EV charging station is modeled through a preprocessor that builds an annual time series with the power consumption of the station, which is later used in the “Microgrid dispatch optimization” stage. To that end, the preprocessor uses rule-based algorithms to simulate the charging behavior.

Uncontrolled charging rule-based algorithm: at each time step, the algorithm goes through the list of present vehicles and decides their charging power. The vehicles can start charging as soon as they arrive.

- The charging power of each EV is equal to the minimum between:
 - o The charging points maximum power,
 - o The power required to reach the EV’s maximum SOC by the next simulation step,

Smart charging rule-based algorithm: at each time step, the algorithm goes through the list of present vehicles and decides the charging power. The vehicles will only charge if their departure time is close or if there is excess photovoltaic production not consumed by the building, or if the energy purchase price is low.

- The charging power of each EV is computed considering:
 - o The charging points maximum power, EV charging station maximum power and grid import power limit,
 - o The availability of excess PV power,
 - o The need power to provide all the energy required by each EV before its departure (therefore charging is smoothed, since it is not necessary to deliver the full charge in one simulation step),
 - o The limitation of the EV charging during high energy cost periods or when the site consumption is in high demand.

2. Microgrid dispatch optimization: for a given microgrid design (i.e., a specific configuration and sizing of the distributed energy resources), a time domain simulation is executed. The simulation uses multiple data sources and, if necessary, a dispatch algorithm for the dispatchable resources. The outcomes of this stage are the time series resulting from the simulation, as well as a comprehensive set of key performance indicators (KPIs).

- o The dispatch optimization stage is repeated for every microgrid design i.e., every combination of PV and battery sizes that needs to be evaluated.

3. Microgrid design optimization: using the results obtained for all the microgrid designs assessed, the best design is selected, according to the customer’s targets.

When considering power limits, we can summarize as follows:

- The grid power limit reference is taken as 100% of the building peak power without EVs. For uncontrolled charging simulations it can be exceeded to reveal the peak issue. Otherwise, this limit is respected by the smart charging algorithm and by the battery controller (in “smart charging” and “smart charging + microgrid” simulations),
- The Subscribed power is a contractual limit (monthly fee) above which penalties occur. For each simulation, EMSF tries to minimize power to avoid penalties associated with this limit.

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Workflow

Given the operation principle of EMSF, the following workflow was implemented for each use case and an **EV penetration horizon of 2025**:

1. Pre-processing:

- The thermal and electrical load profiles of the building are modified to model the installation of a BMS and the substitution of the heating and cooling equipment by a heat pump.
 - Note that a single BMS and heat pump size are selected for each use case (unlike for the PV system and the battery, where multiple sizes are evaluated, as explained below)
- The EV charging station preprocessor is run to compute the load profile of the EV charging station both with uncontrolled charging and with smart charging.

2. Dispatch optimization, for 6 PV sizes x 6 battery sizes (i.e., 35 simulations without no PV no Battery case):

- One-year simulations, with 15-min time steps.
- The maximum tested PV size depends on the available roof space of each use case. For retrofit use cases, the available roof space goes from 10% to 50% of the total roof space, depending on the building sector. For new construction, the available roof space for PV is assumed to be 70% of the total roof space, for all sectors.
- The maximum tested battery size is equal to 25% of the average daily electrical load of the building (after the implementation of the BMS and the heat pump).
- The dispatch is achieved by means of a Model Predictive Control (MPC) algorithm that calculates the setpoints of the battery using forecasts of the energy costs, of the building load profile, of the EV charging station load profile and of the PV production. Its objective function targets the minimization of both the energy and power components of the electrical bill, and the compliance of the grid power limit¹⁴.

3. Design optimization:

- Among the 35 microgrid sizes¹⁵, a multi-criteria sizing rule is implemented:
 - Exclude microgrid sizes with an IRR smaller than 120% of the hurdle rate¹⁶.
 - Among the remaining simulations, select the one with the lowest bill. Or, if all sizes were to be excluded, simply select the one with the highest IRR.

Then, the same workflow was repeated **for a 2035 EV penetration horizon**, except for the “Design optimization” phase. For the 2035 horizon, the same microgrid size chosen for 2025 is selected. This allows us to investigate what is the impact of an increased EV penetration on a microgrid that has been optimized for a smaller number of EVs.

When considering the multi-criteria assessment, we chose a visualization tool that allows us to visualize the entire sizing solution space and how it affects three key criteria: Internal rate of return (IRR), Bill and CO2 savings.

To evaluate the profitability, the report considers both the costs associated with smart charging or microgrid deployment and the savings yielded by it (i.e., the energy bill reduction).

One important detail to note is that project costs and lifecycle costs (except battery replacement when it occurs) are disregarded, but also the potential incentives that could reduce the capital costs. However, the battery replacement costs have been considered.

Results - EV charging station bill

When looking at the EV charging station bill only, we have most of the time savings (geographies and sectors wise) (Exhibit 35), with a large variation from a fraction of % to tens of %. For some cases on the contrary, we get an increase of the bill (about 15% of the use cases). This large diversity of results takes root in the large variations of EV schedules, alignment of EV charging with period of low or high electricity rate, and relative weight of the EV load to the building load typically.

Exhibit 35. “EVCS bill only” evolution when deploying smart charging vs uncontrolled charging.

	Legend												
	< -10	>= -10 & < 0	>= 0										
	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W
Hospital	-3,4	-16,3	-2,2	-3,1	-18,2	-22,4	0,0	-1,2	4,6	-0,3	-9,7	-28,3	-21,2
Large office	-0,3	-22,7	6,7	-4,9	-29,0	-1,0	0,3	-2,1	3,5	-0,9	-7,1	-24,4	-21,4
Secondary school	0,0	-38,7	10,0	-2,4	-36,5	-36,3	0,4	-2,3	-39,2	0,0	-22,8	-34,8	-48,8
Small hotel	-13,3	-55,3	-51,2	-17,9	-31,6	-47,1	-11,0	-10,4	-35,3	-6,3	-47,1	-84,7	-92,3
Strip mall	-0,5	-33,6	6,2	0,2	-23,6	-51,0	-0,3	-0,6	-30,8	-0,8	-22,3	-60,2	-52,6

¹⁴ Both in the smart charging algorithm and in the MPC controlling the microgrid battery, grid power limit is defined as the peak power of the building.

¹⁵ The 0 kW PV and 0 kWh battery microgrid size is excluded.

¹⁶ In the use cases where sellback is authorized, we have also excluded all the microgrid sizes that make the annual sales of exported energy exceed the annual costs of imported energy. This study is focused on optimizing the energy use within a building and does not consider the situation where a building becomes a net producer site (i.e., PV farm-like).

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Region wise:

- We see strongest bill reductions for regions having demand charges and subscribed power in the tariff structures (France Spain, India, Canada, USA Northeast, West and South), as smart charging optimization spreads charging over time, instead of overpassing grid maximum import.
- We see some cases with bill increase like China. This is mainly because, in the smart charging algorithm, the smoothing is prioritized (i.e., in low price hours, the power is reduced to avoid peaks, and this forces to postpone part of the charge to later hours in which the price might increase). Still, these use cases in questions are often the ones for which there are peak issues, so meaning an extra cost is to be considered for grid connection upgrade if no decision of investment in smart charging is taken.

Sector wise:

- We see the Small hotel sector exhibiting the highest reductions while for other sectors, the trend is less obvious. This is to our understanding the shift offered by smart charging if charging can be done during the night instead of at peak price in the evening when guests show up.

While this analysis is relevant, it should be kept in mind that the “EVCS bill only” is approximate, as there is no straightforward way to distribute the power component of the bill (i.e., demand charges or subscribed power) between the building and the EVCS.

Results - CO2 emissions

CO2 emissions levels are reasonable as the reference building are Electric and Efficient buildings. Still, it is worth noting that cooking makes use of gas in Large Hospital, Secondary school and Small hotel archetypes while Office and Mall archetypes exhibit electric cooking. Note that the results displayed below correspond to both thermal load consumption and from electrical grid imports).

Minimal CO2 reductions with Smart charging

As for the overall bill savings, CO2 reductions appear limited on a yearly basis, because grid energy imports are almost the same for Smart charging than for uncontrolled charging (Exhibit 36).

Exhibit 36. CO2 emissions savings from deploying smart charging (%) vs uncontrolled charging

	Legend													
	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W	
Hospital	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Large office	0,0	0,0	-0,1	-0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Secondary school	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Small hotel	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Strip mall	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Significant CO2 reduction with Microgrid deployment

As for the overall bill savings (reflecting notably the impact of PV direct use and the dispatched PV through the battery), CO2 emission reduction is significant (Exhibit 37).

Exhibit 37. CO2 emissions savings from deploying a microgrid on top of smart charging (%)

	Legend													
	Australia	Canada	China	Denmark	France	India	Italy	Norway	Spain	UK	USA NE	USA S	USA W	
Hospital	-12,1	-10,0	-12,1	-11,2	-8,1	-3,4	-12,7	-1,0	-11,3	-11,6	-11,8	-15,5	-15,1	
Large office	-7,6	-7,7	-7,9	-7,9	-7,4	-2,6	-9,1	-2,2	-8,0	-7,5	-8,3	-10,1	-9,8	
Secondary school	-79,8	-49,8	-78,9	-22,7	-55,4	-35,9	-67,8	-12,4	-76,0	-75,5	-55,4	-31,3	-51,3	
Small hotel	-46,7	-25,4	-42,6	-20,7	-20,7	-15,0	-40,2	-2,2	-39,4	-37,7	-31,5	0,6	-36,0	
Strip mall	-86,1	-58,6	-83,1	-29,3	-73,7	-50,5	-72,6	-39,9	-85,0	-84,0	-59,5	-47,4	-64,0	

Region wise:

- As for bill savings, the CO2 reduction achieved by a microgrid is strongly influenced by the ratio between the annual PV production and the overall energy needs (building and EVCS consumption). This ratio is considerably low in India and Norway, because of the remarkably high building consumptions in such regions. We also observe a relatively small CO2 reduction in certain use cases of Denmark and USA South. This is explained by the small PV sizes in such use cases, again leading to a small PV production in comparison to the energy needs. It should be also noted that the grid CO2 content is different per region, which also contributes to the region-wise trends regarding CO2 reduction.

Sector wise:

- Hospital and Office sectors exhibit the worst rooftop to floor ratio so the lower CO2 reductions.
- In the USASouth region, for the hotel sector, there is no PV, therefore no CO2 reduction (but a minor increase because of battery roundtrip losses).

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Acronyms

- Use Case: combination of building sector and geography, EV user behavior, investor profile
- Microgrid: combination of a battery and rooftop PV
- PV: Photovoltaic
- BESS: Battery Energy Storage system
- BMS: Building management system
- EV: Electric vehicle
- EVCS: Electric vehicle charging station (grouping all EV chargers)
- EVCP: Electric vehicle charging point (one charger)
- SOC: state of charge
- EMSF: Energy management simulation framework
- MPC: model predictive control
- KPI: Key performance indicator
- IRR: Internal rate of return
- NPC: Net present cost
- CAPEX: capital expenditure
- OPEX: Operational expenditure
- TOU: time of use

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