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EV Smart Charging in Buildings: Making the Case for Scale Deployment

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Executive summary

Most existing EV policies are focused on the deployment of public charging infrastructure. However, around 90% of EV chargers installed by 2040 will be in private settings. To evaluate the potential added value of deploying private smart EV charging technology in buildings, the authors conducted a study which demonstrates that coupling EV smart charging with flexible energy sources and loads in buildings offers a decentralized approach to energy systems that is more efficient and affordable for EV drivers than a centralized approach, generating up to 70% in savings for consumers.

Keywords: smart charging, electrical vehicles, V-to-B, V1B, V2B

1 Introduction

Decarbonizing road transportation with EVs is deeply transforming the mobility industry. This trend will rapidly accelerate in the decades to come. But for this major shift to play out with actual benefits to society, one of the major challenges is EV charging infrastructure.

The lack of ubiquitous charging infrastructure could turn into a key bottleneck to a rapid transition to EVs and is increasingly becoming a key concern globally. The cost of charging is also under intense scrutiny across the entire value chain, from consumers to system operations, and a key question is whether these costs can be optimized for rapid adoption.

At the same time, with 300 to 500 million connectors to be expected by 2040 [1], EV charging infrastructure is clearly becoming one of the essential building blocks of tomorrow's smart and decentralized energy system. Tapping into the potential services provided by these chargers, smart charging will play a critical role in removing bottlenecks and accelerating adoption.

Yet, extensive analysis of the potential added value of smart charging remains scarce. Most existing policies have so far focused on public charging infrastructure, even though about 90% of the chargers are expected to be installed in households and commercial buildings. In this report, we provide a unique cost competitiveness analysis of different EV charging approaches in different building settings.

We demonstrate that both consumers and system operators can benefit from smart charging at the building level. We dive deeply into a detailed cost-benefit analysis of local charging optimization in households, multi-dwellings, and commercial buildings.

2 Why smart charging?

Despite these overwhelming advantages, there is still uncertainty as to how EV mobility will develop. This is due to the availability of a resilient and ubiquitous charging infrastructure. Beyond immediate rollout hurdles, the key concern is the potential toll from EV charging on the power infrastructure and the corresponding investments required to upgrade it.

Dealing with such issues in a traditional way will require massive infrastructure investments and come at the expense of consumers. The alternative (and complementary solution) is smart charging.

2.1 Smart charging – customer and grid benefits

While smart charging can benefit multiple stakeholders, we focus our approach on the end user (Figure 1), broadly defined as the category which incurs costs (charging Capex and charging bill), and thus has the most direct interest in opting for the cheapest charging solution. In residential dwellings, the end-user is usually the house owner. In other cases, the end-user may be the building owner, the tenant, or a mobility service provider.

Then, the system operator can also leverage EVs for grid side optimization, which focuses on the response of the EV to a real-time signal from the grid or electricity market (explicit flexibility). The primary beneficiaries of this optimization are the grid and system operators, even though the end-user is ultimately compensated for the service.

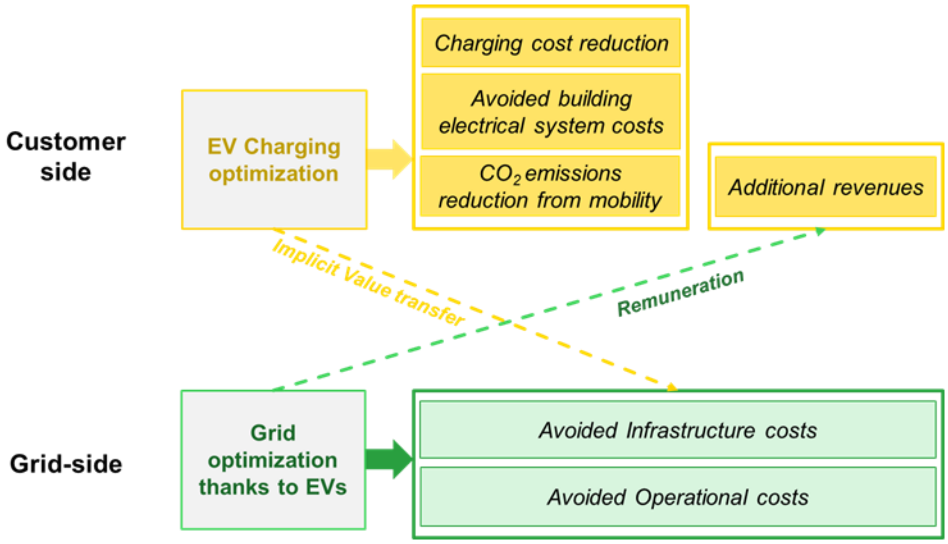


Figure 1: Sources of customer and grid benefits from smart charging under study

The core focus of this paper is to clarify benefits of smart charging at end user level, presenting smart charging methodology and its benefits in different contexts.

2.2 Smart charging framework

While public charging relies on charging optimization that can be done directly with the grid (V-to-G) in buildings, optimization is done with the building loads (V-to-B) or with both in sequence (V-to-B-to-G) (Figure 2). This paper focuses on V-to-B applications, covering residential, commercial, and industrial buildings.

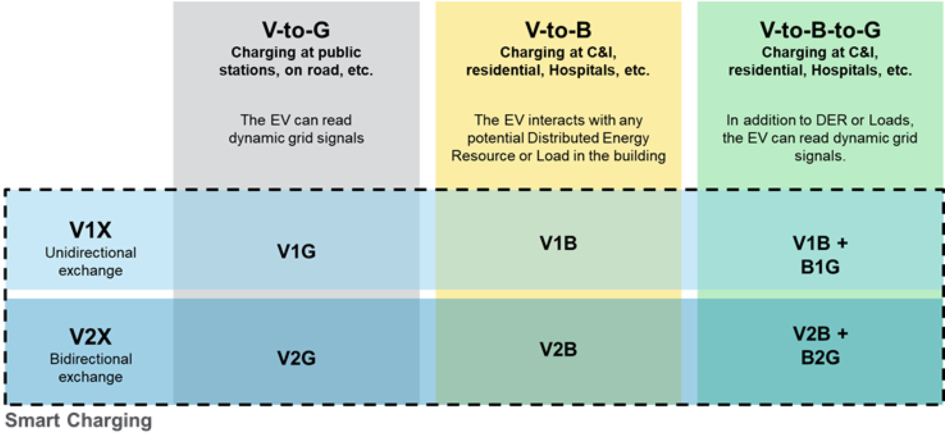


Figure 2: Smart charging framework description

2.3 EV control charging strategies for V-to-B

Residential, commercial, and industrial buildings (V-to-B) may have one of the following EV charging strategies (Figure 3):

- Uncontrolled charging: The electric vehicles are charged at maximum power rating, which can lead to overload at peak consumption, especially in office or residential buildings, where electric vehicles' charging demand are usually at the same time slot. The electricity price and the use of local energy sources are not optimized. This strategy does not require any control system but presents the highest CAPEX (electrical infrastructure) and Opex costs.
- Load management system: The available power is distributed among the electrical vehicles to be charged. Power overloads are avoided and electrical infrastructure costs mastered, although EV charging needs are not considered, and energy use and cost are not optimized.
- Unidirectional smart charging: Each EV plugged into charging station charges with a specific charging profile. The smart charging profiles are set to satisfy EV driver individual needs as a priority. In addition, smart charging profiles are defined so that local energy is consumed first, and the charge is done when the electricity tariffs are most advantageous.
- Bidirectional smart charging: The bidirectional charge of EVs allows us to further optimize the electricity costs while satisfying individual driver needs. In addition, it enables additional monetization opportunities as participation in demand response mechanisms through an aggregator.

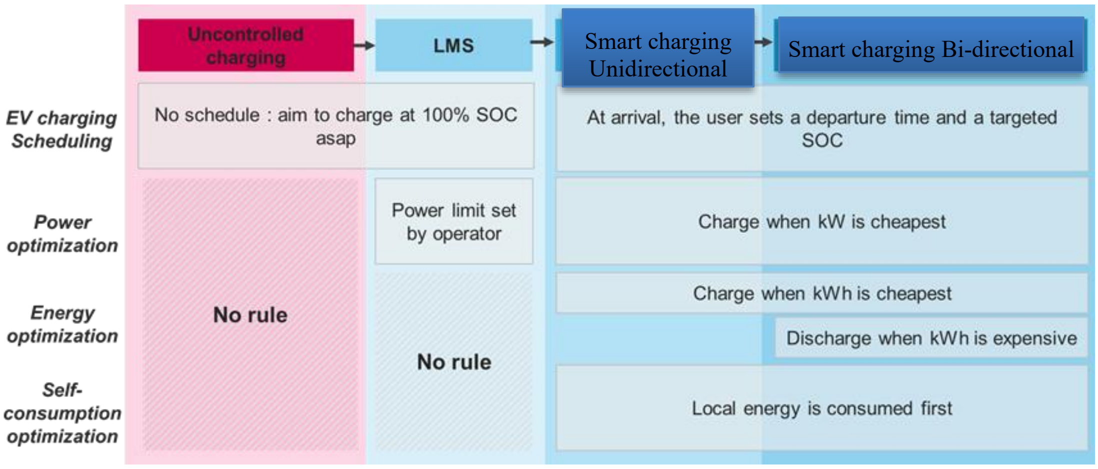


Figure 3: EV charging control strategies and benefits at customer side

3 Smart charging methodology

3.1 Model predictive control for smart charging

Smart charging is used to generate an optimal dynamic setpoint based on several criteria. These include electric vehicle planning, grid energy tariffs, prediction of building consumption, and prediction of local energy sources production, if any.

The Model predictive control (MPC) technique is used to optimize electrical vehicles charging over the next 24 hours, by anticipating energy demands (EV charging and other loads) as well as local renewable production (Figure 4).

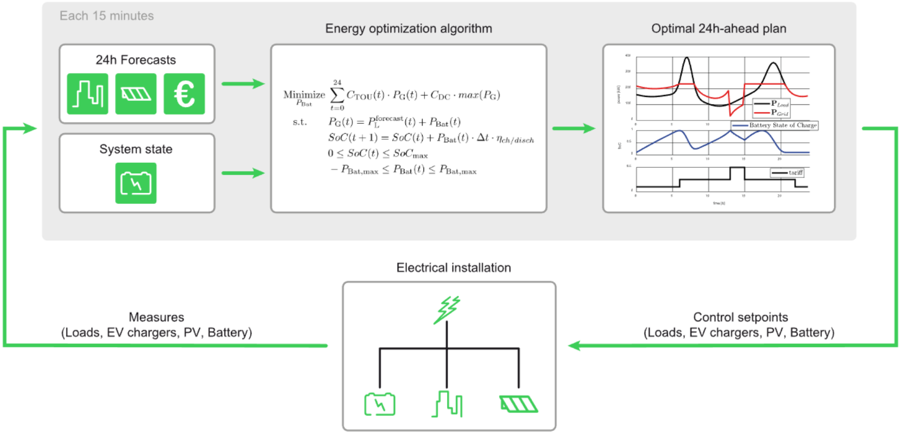


Figure 4: Model predictive control for smart charging

3.1.1 Forecasting energy consumption, EV charging needs, and local production

A forecasting component is used to predict building energy demand and local energy production. This enables short-term energy resource planning and optimizes local energy use.

The forecasting component uses supervised machine learning techniques to learn the relationship between the variables at hand and the variable we intend to forecast.

- Photovoltaic production forecasting is correlated to the solar radiation forecast provided by a weather forecast service.
- Building energy consumption and EV charging needs can be forecast based on historical energy consumption that identifies recurrent patterns. This forecast can be improved by adding additional drivers like weather forecast information or EV charging planning.

The accuracy of the forecast is critical for optimal model predictive control.

3.1.2 Solving an optimization problem

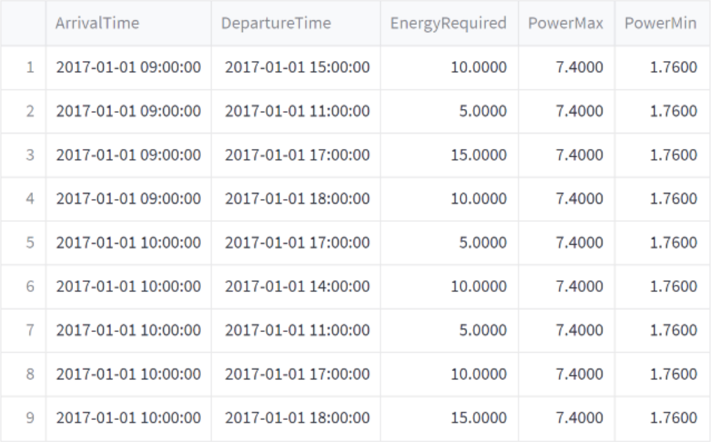
The model predictive controller relies on:

- A model with the description of the electrical network, the assets' characteristics, and constraints that should be respected
- Forecasts over the following 24 hours include the energy consumption of the installation, photovoltaic production, and grid energy tariffs. EV charging demand if not defined by the EV drivers can be forecasted as well.
- Knowledge of the assets' current state, for example, the state of charge of the electric cars

By updating the local controller based on the latest site measures and updating forecast information every 15 minutes, the smart charging algorithms can continuously adapt to prediction and model errors to ensure optimal closed-loop control performance.

3.2 Smart charging – a showcase

A showcase was built up to demonstrate the behavior of smart charging methodology. The showcase is representative of an office building. For the sake of simplicity, it is considered that there are 9 EV charging stations with a maximum capacity of 7kW. Typical values for arrival time, departure time, and energy request needs were considered — see Table 1.



	ArrivalTime	DepartureTime	EnergyRequired	PowerMax	PowerMin
1	2017-01-01 09:00:00	2017-01-01 15:00:00	10.0000	7.4000	1.7600
2	2017-01-01 09:00:00	2017-01-01 11:00:00	5.0000	7.4000	1.7600
3	2017-01-01 09:00:00	2017-01-01 17:00:00	15.0000	7.4000	1.7600
4	2017-01-01 09:00:00	2017-01-01 18:00:00	10.0000	7.4000	1.7600
5	2017-01-01 10:00:00	2017-01-01 17:00:00	5.0000	7.4000	1.7600
6	2017-01-01 10:00:00	2017-01-01 14:00:00	10.0000	7.4000	1.7600
7	2017-01-01 10:00:00	2017-01-01 11:00:00	5.0000	7.4000	1.7600
8	2017-01-01 10:00:00	2017-01-01 17:00:00	10.0000	7.4000	1.7600
9	2017-01-01 10:00:00	2017-01-01 18:00:00	15.0000	7.4000	1.7600

The show case applies the MPC smart charging algorithm to compute the charging schedule for each electrical vehicle. The charging slots are computed in order to satisfy the individual needs of each EV driver, assuring that the electrical vehicle is charged with the requested amount of energy and in the due time. The EV charging schedules are computed so that the overall charge does not exceed the power limit, prioritizing the charge when the energy is cheaper and when there is a local energy production.

Charging schedules and overall impact of three control strategies — uncontrolled charging, load management, and unidirectional smart charging — are evidenced in Figure 5.

Figure 5: EV charging schedules and overall energy consumption for a) uncontrolled charging, b) load management, and c) unidirectional smart charging

As summarized in Figure 6, smart charging is well adapted and brings the highest benefits at each configuration. In any configuration, smart charging assures the satisfaction of the EV driver needs without exceeding the power demand. It allows optimal energy cost, especially when the energy tariffs are variable or time of use type. It allows also to take the most of solar production, when such is available on site.

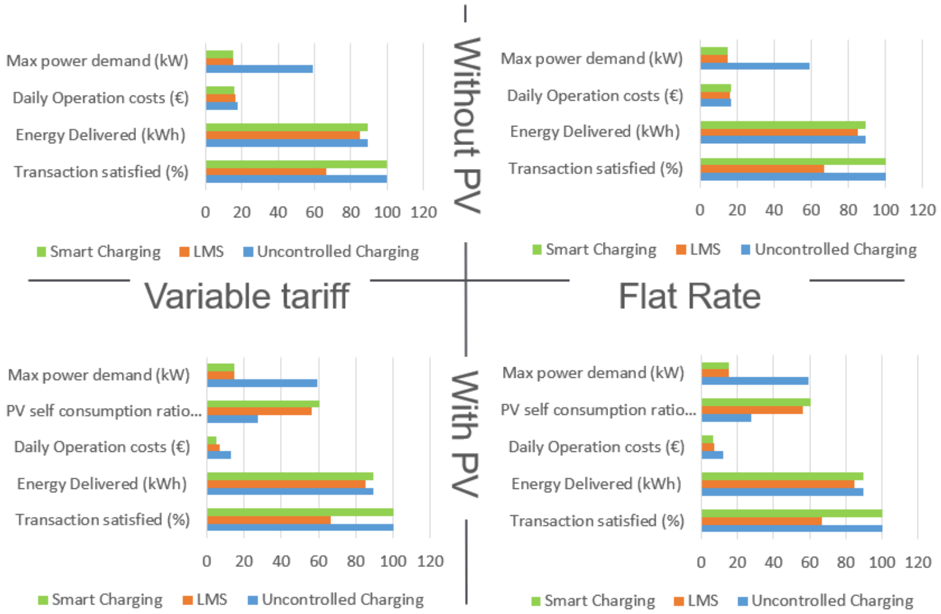


Figure 6: Comparison of three control strategies – smart charging, load management, and uni-directional smart charging at different site configurations

4 Modeling and simulations result at large scale

4.1 Modeling approach

Key parameters influence the optimization are regrouped in three blocks (Figure 7), with each block being influenced by the choices made in the previous one.

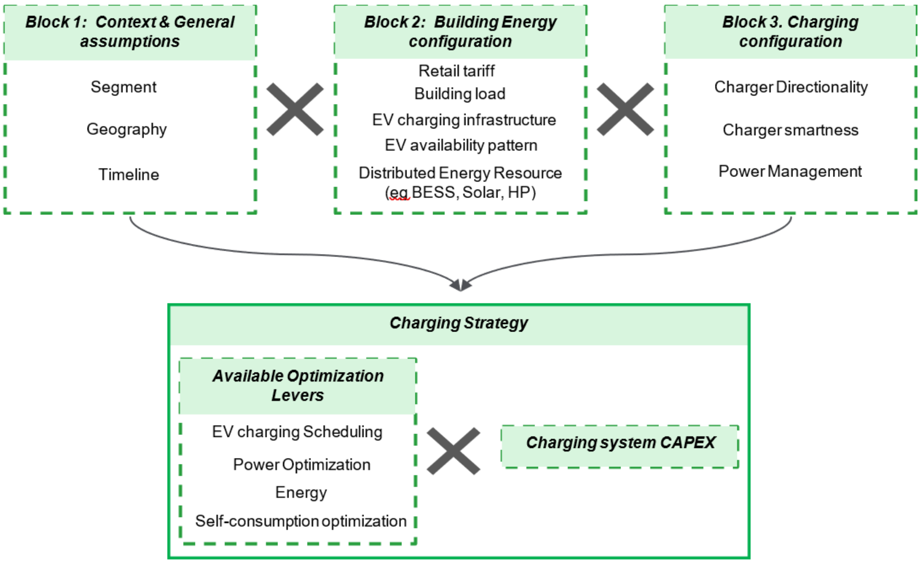


Figure 7: Parameters impacting optimization

As shown in Block 1 of Figure 7, our model focuses on three building types which represent the bulk of end-user charging opportunities: Households (H), multi-dwelling (MD) residential, and commercial and industrial buildings (C&I). Four different geographies are selected to understand how local rules and specificities impact the value of smart charging: France, Germany, Spain, and California state. For each geography, public charging costs are retrieved. This cost is the base element of comparison for our modeling results.

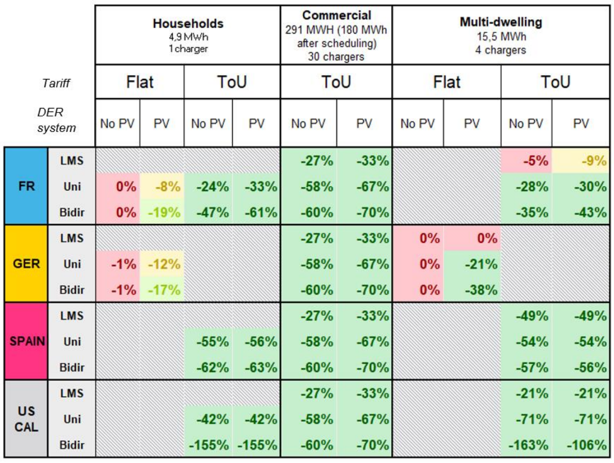
The exact site configuration can then be retrieved (Block 2): Retail electricity tariffs depend on the local retailer offers, building size, and electric loads depend on climate and local behaviors, the number of chargers, and their size difference in each segment (and are derived from market forecasts). Distributed energy resources (PV, BESS) are sized following optimization prior to any charger installation, and their Capex is not taken into account in our economic analysis. Finally, EV presence patterns are designed to reflect driver's behaviors in each segment.

4.2 Results

The smart charging outcomes detailed in Figure 8 account for all four optimization levers discussed above (scheduling, power/demand charge optimization, energy optimization, and self-consumption optimization). These are combined when applicable and differently used across different sectors in different geographies depending on the type of smart charging solution, local constraints, local building profiles, and regulation. The smart charging system optimizes for all of this in each case.

Figure 8 provides an Opex perspective with a focus on the electricity bill, without upfront costs (Capex) of charging. This enables a direct understanding of the impact to the consumer. Compared to uncontrolled charging, smart charging provides significant savings which are further increased if solar PV is available on site.

It is interesting to note that for residential bidirectional cases in California, savings go above 100%, meaning that the EV user actually earns money. This is due to a net-metering policy, in which one's remuneration for injection is higher than the one from the grid. If no control is done, an EV battery can be used to buy energy at a cheap price and resell it at peak price to the grid. Such a scheme should soon become obsolete.



		Households 4,9 MWh 1 charger				**Commercial** 291 MWH (180 MWh after scheduling) 30 chargers		**Multi-dwelling** 15,5 MWh 4 chargers			
Tariff		Flat		ToU		ToU		Flat		ToU	
DER system		No PV	PV	No PV	PV	No PV	PV	No PV	PV	No PV	PV
FR	**LMS**					-27%	-33%			-5%	-9%
	Uni	0%	-8%	-24%	-33%	-58%	-67%			-28%	-30%
	Bidir	0%	-19%	-47%	-61%	-60%	-70%			-35%	-43%
GER	**LMS**					-27%	-33%	0%	0%		
	Uni	-1%	-12%			-58%	-67%	0%	-21%		
	Bidir	-1%	-17%			-60%	-70%	0%	-38%		
SPAIN	**LMS**					-27%	-33%			-49%	-49%
	Uni			-55%	-56%	-58%	-67%			-54%	-54%
	Bidir			-62%	-63%	-60%	-70%			-57%	-56%
US CAL	**LMS**					-27%	-33%			-21%	-21%
	Uni			-42%	-42%	-58%	-67%			-71%	-71%
	Bidir			-155%	-155%	-60%	-70%			-163%	-106%

Figure 8: Reductions in electricity cost of charging in different segments, countries, and cases in 2025 (in % vs. uncontrolled charging in the building)

Compared to public charging, on-site charging (already uncontrolled but even more with a smart one) provides cost benefits across most cases and most often significant savings [3]. All the above savings are potentially magnified with the provision of grid services, which reveal the true value of a fully smart and bidirectional charging strategy (dozens or hundreds of euros in revenues depending on local regulations) [3].

5 Conclusion

A smart charging infrastructure ensures buildings have power availability by minimizing the EV charging infrastructure's impact on the existing power distribution system. Smart charging and digitization technologies are used to create a better, more efficient charging experience that makes it easier to integrate renewable energy and provide resilient power.

Smart charging algorithms for buildings allow reduced cost of charging your electric vehicle by intelligently scheduling charging times to take advantage of low-cost electricity, maximize the use of clean, low-carbon electricity, design the optimal electrical installations, and select the most suitable electricity contract for the charging stations.

EV smart charging is a major enabler of decarbonization of mobility, but also buildings and global energy systems. Coupled with EV smart charging, flexible energy sources and loads in buildings offer a decentralized approach to energy systems that is more efficient and affordable than centralized paradigms.

As a foreword, we believe well-designed policies should encourage promotion of charging at building sites, promotion time-of-use tariffs, and self-consumption.

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Presenter Biography

Stéphane Maravel is Global Head of Strategy and Innovation for eMobility business at Schneider Electric. His mission is to define and provide innovative solutions for the electrification of transportation, a key enabler for a net-zero future. He is a business and team leader with strong strategic vision, entrepreneurial spirit, and passion for creating value for customers and shareholders, with more than 26 years of experience in the industry and a deep expertise in energy management, services, and digital transformation.

Vincent Minier is Vice President Energy Transition Research at the Schneider Electric Sustainability Research Institute^{TM}. Vincent has more than 25 years of experience in industry. Until recently, Vincent was a Platform Fellow at the World Economic Forum and contributed to shaping the Net Zero Carbon City initiative triggering decarbonization investments in cities. Vincent holds a DSc and a PhD degree in Optoelectronics from the National Polytechnic Institute of Grenoble (INPG, France).

Vanya Ignatova is an AI Product Manager, in charge of initiating and following up on projects related to the use of artificial intelligence in various domains – eMobility, microgrid, energy management, and renewable energy usage. She has a PhD in Power Quality and strong expertise in electrical installation sizing, energy management systems, and the new-energy landscape. She joined Schneider Electric in 2006, and has evolved in technical, marketing, and project management positions.