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The value of smart charging strategies for electric fleet owners: a case study based on various office buildings

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Summary

Several market-ready smart charging options are available to optimize the charging situation of electric vehicles (EV) at building sites. The value of these options is often overlooked. This study provides insight into the value of different smart charging options, focusing on representative office buildings in the Netherlands. The value of the smart charging options is determined based on a three-layered model. Firstly, this model determines the EV-uptake and charging needs. Secondly, this model fits EV charging needs with the relevant parking and building profile. Thirdly, this model determines costs and benefits of different smart charging strategies.

Keywords: Smart charging, EV (Electric Vehicle), optimization, solar energy, load management

1. Introduction

An important driver for the rising number of battery electric vehicles is the electrification of commercial and public fleets. In order to facilitate this transition, fleet owners often opt for a charging strategy where they combine charging at home or public charging with charging at their own buildings, such as office locations, parking garages and distribution centers. In most cases, charging at the building site of the fleet is a crucial part of the strategy. This both fits the driving pattern of the fleet and is cost-effective. In the Netherlands, electricity tariffs at building sites are significantly lower (0,10 €/kWh) than at home (0,20 €/kWh) or at public chargers (0,30 €/kWh).

Due to the driving pattern of fleets, cars are often plugged in simultaneously. Therefore, charging of electric vehicles in an uncontrolled way leads to high peaks in electricity demand. This restricts the number of cars that can be charged at the building site and causes increased electricity costs. Controlled charging, also known as smart charging, has the potential to mitigate peaks by shifting the charge load to a low demand period [1].

Several market-ready smart charging options are available to maximize the part of the fleet that can charge at building sites. The value of these options is often overlooked by both electric fleet owners and other stakeholders such as DSOs. Therefore, this study investigates the value of different smart charging options for fleet and building owners. This study focusses on four representative office buildings in the Netherlands. These buildings are selected as representative for over 200 buildings of *Rijksvastgoedbedrijf*, the Dutch Central Government Real Estate Agency (CGREA).

The smart charging options that are included in this study are: EV-only load balancing, load balancing, PV in combination with load balancing and charge point optimization (CPO). The purpose of these smart charging options is to prevent costly and time-consuming grid upgrades while transferring as much available electricity as needed to parked cars at the building site.

1.1. Contribution to body of research

Various previous studies have investigated the value of smart charging options in relation to distribution grids and electricity markets [1]–[4]. Only few studies have explored smart charging options to optimize the use of local AC grid infrastructure and energy profiles in buildings [5], [6]. In those studies, little attention is paid to cost benefits of deploying smart charging infrastructure at building sites. This paper provides insight into the economic viability of smart charging strategies at office buildings.

2. Methodology

The value of the different smart charging options is determined based on a three-layered model. Before this, different market-ready smart charging options are defined.

2.1 Definition of market-ready smart charging options

This study takes 4 market-ready smart charging options into consideration. These options are illustrated and explained in Figure 1 below.

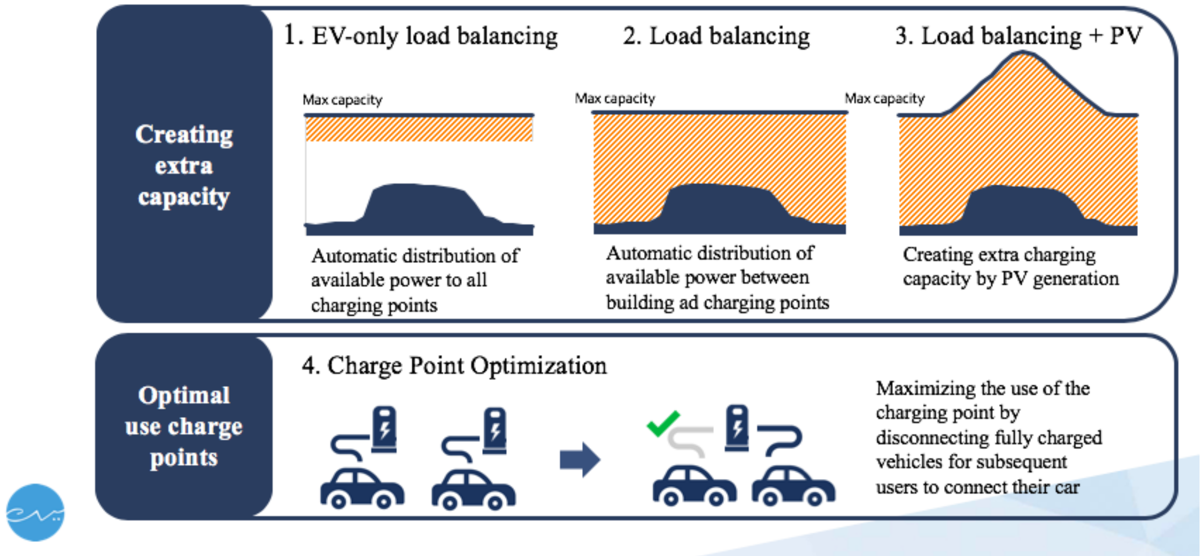


Figure 1 - Market-ready smart charging options included in this study

2.2 Application of a three-layered model

In this study a three-layered model is constructed to find the most cost-effective way to maximize the number of charging sessions at fleet's own site. The three layers are depicted in Figure 2 and explained below.

Figure 2 - Schematic overview three-layered model

2.2.1 EV uptake and charging needs

The purpose of the first layer of the model is to determine the EV growth path and resulting charging needs. EV uptake is based on the prognosis of EV growth. The relevant fleet for the purpose of this study is the fleet of the Dutch government. In its purpose to take on an example role in the transition towards zero emission mobility, the Dutch government has set an ambitious growth path. Figure 3 below shows the expected growth of the EV fleet of the Dutch government (referred to as the CGREA fleet) and the growth of electric cars in the Netherlands in general (referred to as the Dutch fleet).

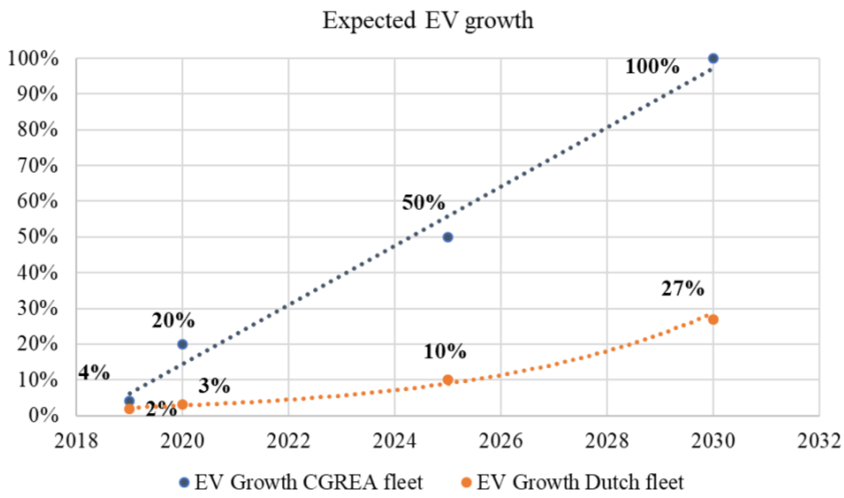


Figure 3 - Expected growth of the Dutch EV fleet and the CGREA EV fleet

Charging needs

Rising numbers of EVs cause an increasing energy demand at office buildings of the Dutch government. In order to determine the charging need of the growing fleet the follow factors are taken into consideration:

- *Number of EVs in fleet in 2019, 2020, 2025 and 2030*
- *Charging volume per session based on current average charging volume at office buildings (14 kWh)*
- *Number of kilometers per workweek and number of charging sessions needed*

Charging points required

The number of charging points required depends on the parking profile of the fleet. In theory, a charging point can be used multiple times per day but this is only the case if the arrival times show overlap with the departure times of the fleet. The parking profile that is applied in this study is an average office parking profile where parking hours are relatively long and there is no overlap in arrival and departure times.

2.2.2. Fit with building and parking profile

The purpose of the second layer of the model is to determine the fit of the EV charging demand with the usable charging capacity per smart charging option.

Representative office buildings
This study is applied to four representative office buildings. These offices are selected as representative for the buildings of the CGREA based on building size and function. This study covers a relatively small, medium and large building as well as a parking garage.

Available charging capacity at the office building per smart charging option
The available charging capacity per smart charging option is depicted in Figure 4 and explained below.

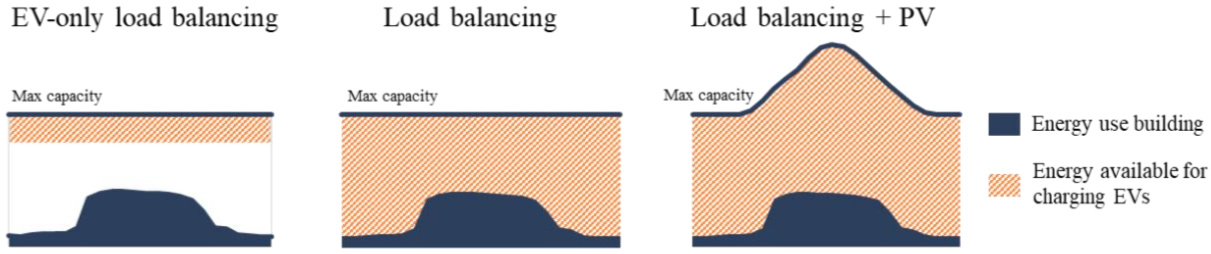


Figure 4 - Available charging capacity per smart charging option

EV-only load balancing evenly distributes the available charging capacity over all charging points. The available charging capacity is fixed over time and can be calculated by:

$$C_{EOLB} = G - P \tag{1}$$

Where: C_{EOLB} is available capacity [kW]
G is the grid connection capacity [kW]
P is highest measured (hourly) peak usage over a full year [kW].

Load balancing evenly distributes the available charging capacity over all charging points. However, in contrast to EV-only load balancing, the available capacity varies over time. A smart-meter constantly measures the energy used by the building and the unused capacity is made available for the charging points. The available charging capacity for load balancing can be found by:

$$C_{LB_t} = G - U_t \tag{2}$$

Where: C_{LB} is the available capacity in time-step *t* [kW]
G is the grid connection capacity [kW]
U_t is the electricity use by the building in time-step *t* [kW]

Load balancing plus PV is the combination of load balancing and PV energy generation. The extra capacity created by PV is found by determining the solar potential:

$$E_{PV} = A\ \eta_s\ IRR\ \ \eta_o\ \eta_a \tag{3}$$

Where: E_{PV} is the electricity production of the installed PV system (kWh)
A is the area covered by the PV system (m^2)
η_s is the efficiency of the PV system (-), equal to 17%
IRR is the irradiance of the location inkWh/m2/year. In this study we used the hourly irradiance measured in the Bilt [7].
η_o is the orientation efficiency (-) and equals 99%, as the orientation of the panels is assumed to be South East
η_a is the angle efficiency in (-) and equals 100%, as the panels are assumed to be angled at a 40 degree angle to the surface

Usable charging capacity

In the previous step the method for determining the *available* charging capacity per smart charging option was discussed. In this step we determine the *usable* charging capacity considering the parking profile of the fleet. The usable capacity is found by the following steps:

1. Determine the relevant parking profile
2. Determine the max capacity that can be used by the EVs simultaneously
3. Determine the usable charging capacity

2.2.3. Cost-benefit analysis

The third layer of the model focuses on the cost-effectiveness of the smart charging options. For each option the Net Present Value (NPV) is determined, which is found by:

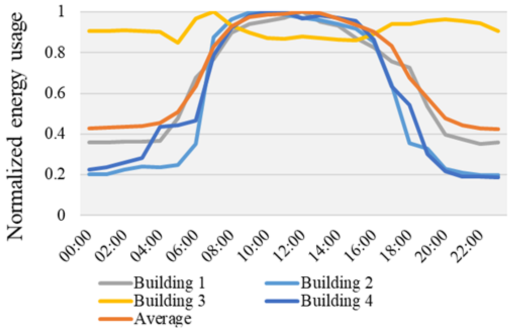
$$\mathrm{NPV} = \sum_{i=0}^{n} \frac{B_i - C_i}{(1+r)^i} \qquad (4)$$

Where:	NPV	Net Present Value of the project at the beginning of the first year (*i*=0)
	B_i	benefits of the project in year *i* [€/year]
	C_i	costs of the project in year *i* [€/year]. Yearly cost consists of the operational expenditures (OPEX). In year 0 the costs can also include investment costs (capital expenditures). The OPEX consist of the charging costs and in the scenario with PV OPEX also consist of operation & maintenance (O&M) of solar panels.
	r	is the discount rate [%]. In this study set equal to 3% (based on werkgroep discontovoet (2015).
	n	lifetime of the project [years]

3. Results

3.1. Representative office buildings

Figure 5 shows the daily electricity consumption profiles of the selected office buildings. The electricity profiles of the offices (Building 1, 2 and 4) have similar patterns and are characterized by peak demand around noon. The consumption profile of the parking garage differs, this profile is much more constant compared to the office building use.



Nr.	Annual electricity use kWh	Grid connection kW	Peak usage kW
1	1,219,191	1,072	320
2	255,220	153	120
3	118,528	82	24
4	152,115	68	66

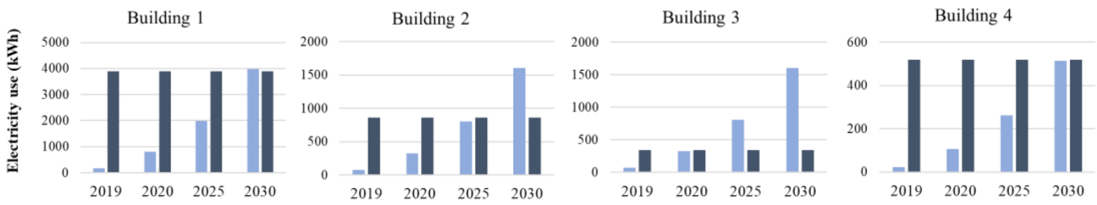
Figure 5 - Daily electric consumption profile of selected office buildings based on the energy monitoring tool of the CGREA

3.2. EV charging need

Figure 6 shows the daily EV demand in 2019, 2020, 2025 and 2030 based on the average kilometrage of 15,000 km/year.

For the purpose of this study, it is the purpose to charge as much electricity as possible at own building sites. This way the relative low electricity tariff is fully exploited and it is made certain that there is sufficient charging infrastructure for the fleet.

To give an idea about the magnitude of order if all EVs need to charge at the building sites, the energy use of the building is also shown. This figure shows that daily EV energy demand with a full electric fleet (in 2030) is equal or higher to the daily energy use by the building itself. This emphasizes the need to think ahead and take measures in order to be able to accommodate this demand.



	Building 1				Building 2				Building 3				Building 4			
	2019	2020	2025	2030	2019	2020	2025	2030	2019	2020	2025	2030	2019	2020	2025	2030
EVs	16	76	190	379	7	31	77	153	7	31	77	153	2	10	25	49
Charging sessions/day	13	61	152	303	6	25	62	122	6	25	62	122	2	8	20	39
Total charge demand (kWh)	168	796	1,990	3,969	73	325	806	1,602	73	325	806	1,602	21	105	262	513

Figure 6 - Daily electricity demand by EVs and by the buildings

3.3. Fit with building and parking profile

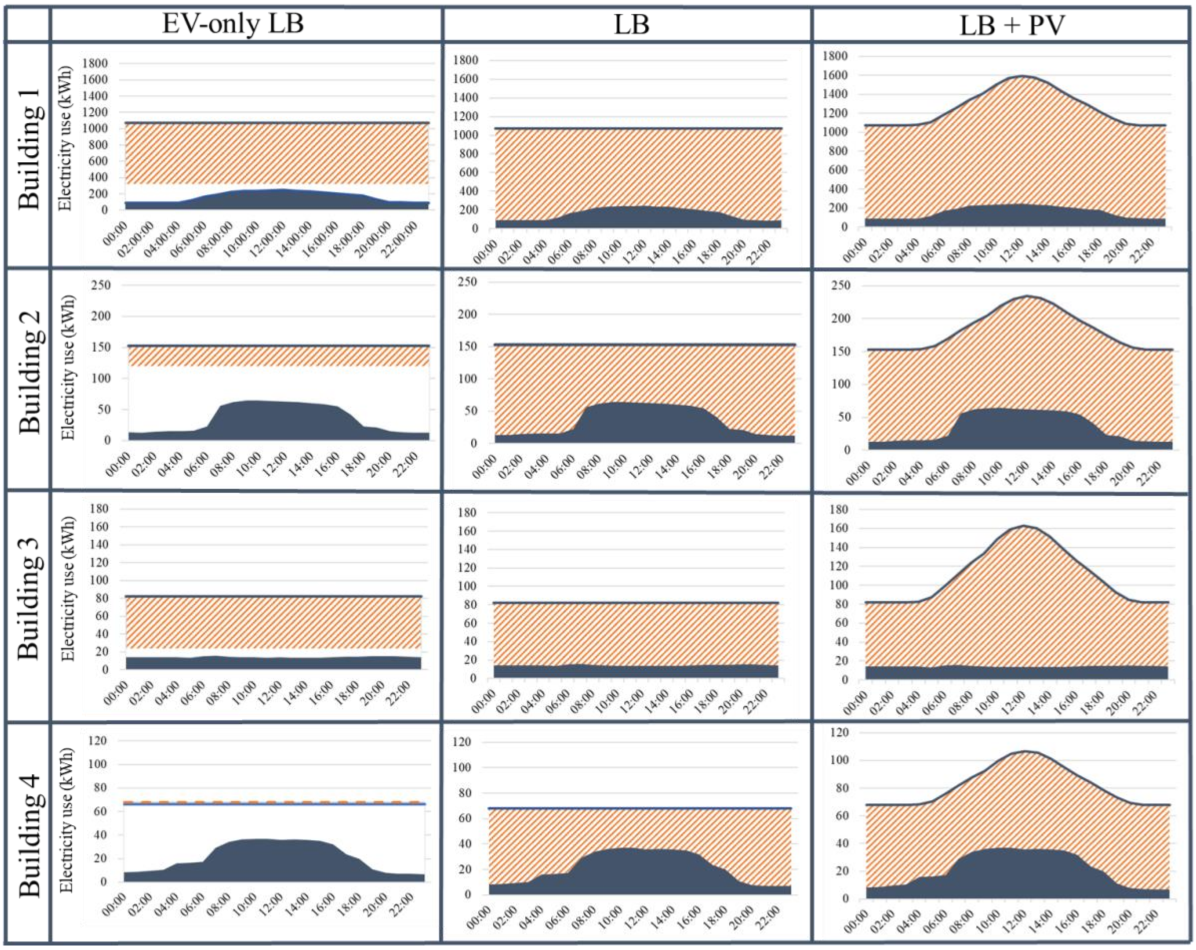


Figure 7 - Available charging capacity per smart charging option and per building. The orange striped area displays the available charging capacity and the blue area display the energy use by the building.

Figure 7 illustrates the *available charging capacity* per smart charging option. These results show a difference in impact per smart charging option depending on the building profile. For building 2 and 4, load balancing clearly results in more available charging capacity compared to EV-only load balancing. For building 1 and 3, the impact of load balancing is limited compared to EV-only load balancing. For all buildings, PV generation results in extra charging capacity during the day.

The *usable charging capacity* depends on the parking profile. Figure 8 illustrates the results with regard to usable charging capacity for building 2, in a scenario with 20% EV and with the deployment of load balancing. The left figure shows the available capacity. The middle figure shows the maximum usable capacity by the EVs (based on their parking profile and their maximum charging capacity) displayed by the green area. In the right figure the usable charging capacity is by the EVs is displayed in light blue.

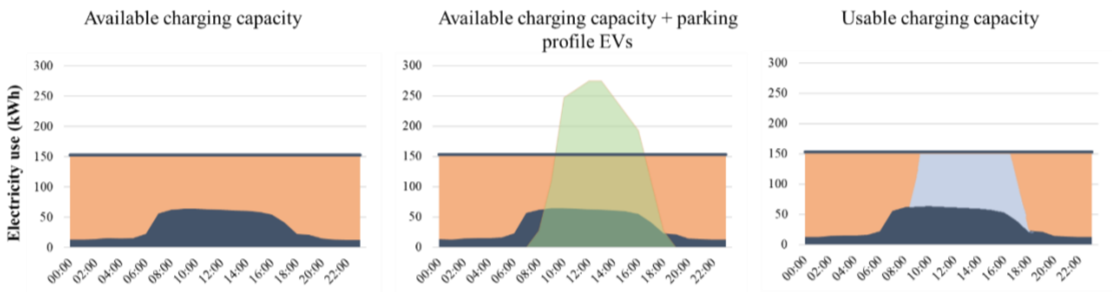


Figure 8 - The available charging capacity, the available charging capacity and the maximum usable capacity by the EVs based on the parking profile, and the usable charging capacity

Figure 9 compares the charge demand by the fleet (dark blue) with the usable charging volume per smart charging option.

Figure 9 - A comparison of the EV energy demand and the usable volume per smart charging option

The key findings are discussed below:

- *Uncontrolled charging* is already problematic after 2019.
- *EV-only load balancing* provides sufficient energy for charging up to and including 2020.
- *Load balancing* is in most scenarios able to provide sufficient charging capacity up to and including 2025 to charge all EV energy demand at own site.
- *Load balancing plus PV* is the scenario which can charge the largest share of EV energy demand in 2030. However, even with the deployment of PV for some buildings the EV energy demand is too high to charge all demand at own building site.

The number of charging points required for EV-only load balancing, load balancing and load balancing plus PV is equal to the number of EVs that charge per day. This is the implication of an average office parking profile with relative long parking durations and limited overlap in arrival and departure times.

Only in the case of Charge Point Optimization (CPO) a lower number of charging points are needed. This follows from the results in Figure 10 below.

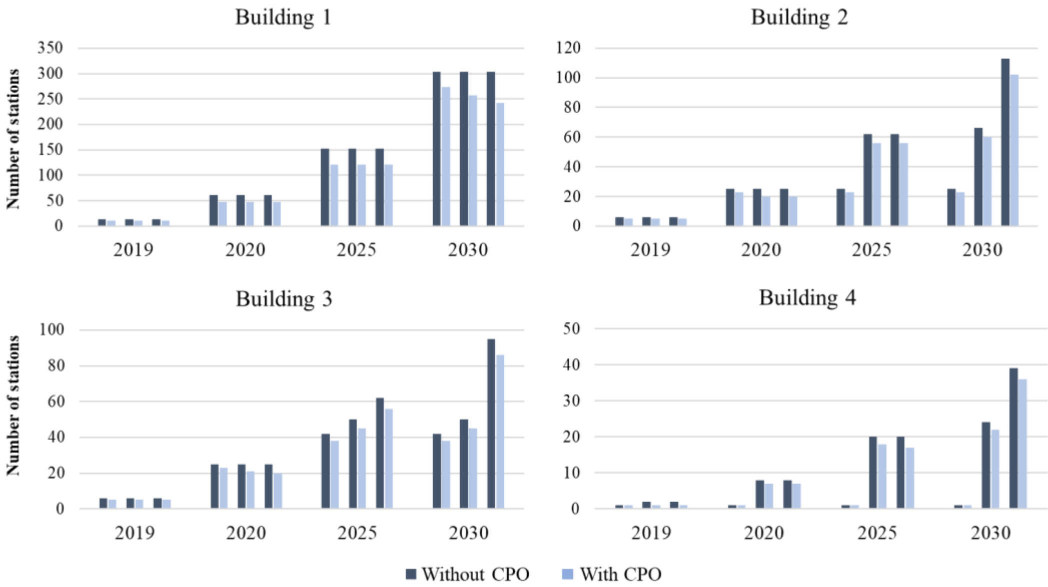


Figure 10 - Charging points needed with and without CPO

3.4. Cost-benefit analysis

In this section we discuss key findings with regard to the cost-effectiveness of the 4 smart charging options. The NPVs for all smart charging options for building 1,2, 3 and 4 are shown in Figure 11, Figure 12, Figure 13 and Figure 14.

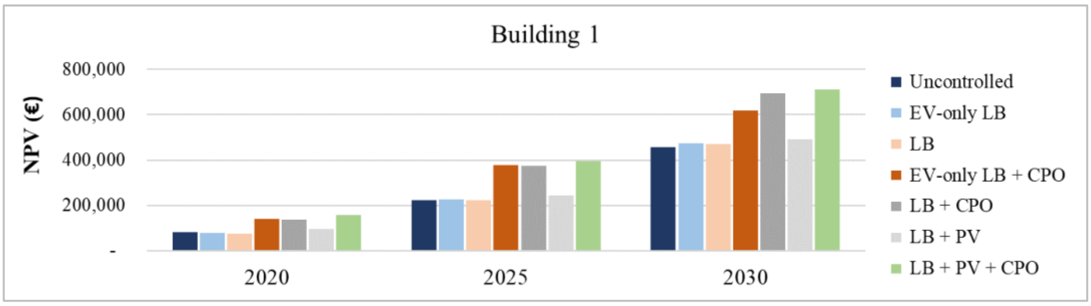


Figure 11 - NPVs for all smart charging options for the years 2020, 2025 and 2030 for building 1

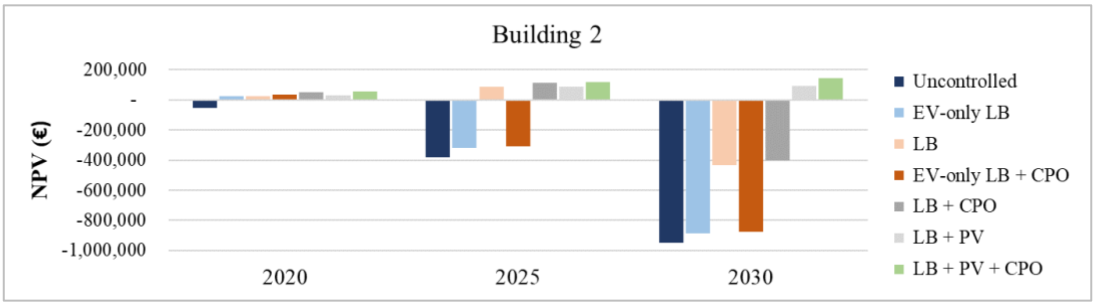


Figure 12 - NPVs for all smart charging options for the years 2020, 2025 and 2030 for building 2

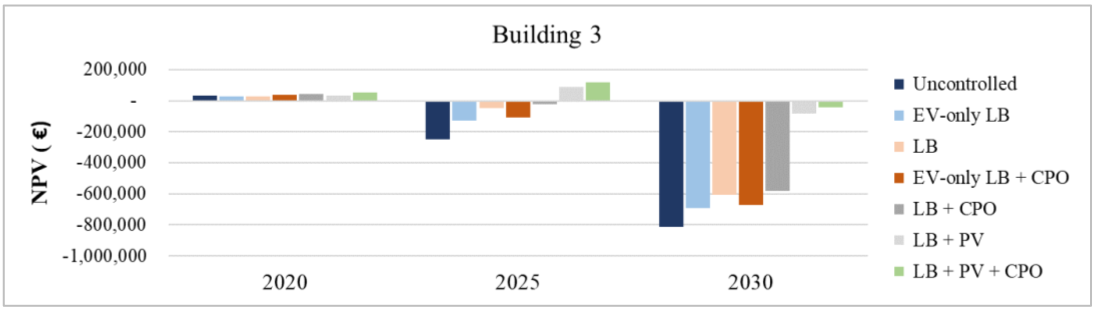


Figure 13 - NPVs for all smart charging options for the years 2020, 2025 and 2030 for building 3

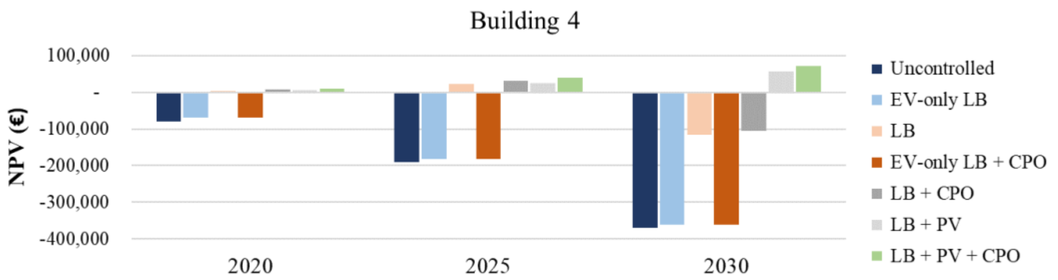


Figure 14 - NPVs for all smart charging options for the years 2020, 2025 and 2030 for building 4

Firstly, it follows that the most profitable smart charging options are the options where the largest share of the charging need of the fleet can be fulfilled at the building site. The significant price difference between the public charging tariff and the low charging tariff at own site drives this result. It implies that the investment in charging infrastructure at own building sites is always off-set.

Secondly, the deployment of PV is profitable in most cases. Firstly, this finding is due to the economic viability of installment of PV at building sites in the Netherlands. Secondly, this finding underpins that PV can help to create more or even sufficient capacity for charging at building sites and results in a profitable business case. However, dynamic load balancing plus PV does not yield in the best results in all cases. For example, in the case of EV shares of 20% and 50% for building 2, 3 and 4, the most profitable business smart charging option is load balancing plus CPO. This is a less costly investment with the same result.

Thirdly, comparison of the different smart charging options without PV results in the following findings:

- ***CPO from 2019 till 2030:*** deployment of CPO is always cost-effective. The scenarios with a combination of a smart charging option and CPO results in the best business cases. This is simply the result of fulfilling the same charging needs with fewer charging points.

- ***EV-only load balancing plus CPO only until 2019:*** in the case of low charging demand (4% EV share in 2019), the scenario with EV-only load balancing plus CPO results in a profitable business case. In 2019, this scenario also proves to be the best business case compared to the other scenarios (for building 1, 2 and 3).
- ***Load balancing plus CPO from 2020 until 2030:*** in 2020 (20% EV share), the most favorable business case is the scenario with load balancing plus CPO. This is because EV-only load balancing is no longer able to provide sufficient charging capacity for these buildings. The deployment of load balancing at these building creates sufficient charging capacity to meet the EV demand. The higher investment costs of load balancing (compared to EV-only load balancing) are off-set by the extra EVs that can be charged at own building site at a lower charging tariff.

4. Discussion

The cost-effectiveness of the 4 smart charging options is the implication of the significant price difference between the electricity price at building sites (0,10 €/kWh) and public charging (0,30 €/kWh). Investments in smart charging options that provide sufficient charging capacity at building sites are offset due to this price difference. This is relevant for fleet owners but also for building owners such as parking garages.

The findings of this study depend on current electricity price differences. Developments such as declining price differences may alter our findings. It is therefore key to keep track of electricity price developments in general and the public debate about energy tax structures in specific.

This study does not determine the NPV of a scenario with a grid upgrade. It is expected that a scenario with a grid upgrade can result in a profitable NPV. This study does not determine whether a grid upgrade may be more or less cost-effective than smart charging. It is worthwhile for DSOs to study this and create incentives for building owners to opt for smart charging methods instead of grid upgrades. One clear incentive is already in place: grid upgrades come with uncertainty for the fleet or building owner and are time consuming.

This research considers only 4 smart charging options which are selected based on market-readiness at this stage in time. The market is, however, in rapid development and other smart charging solutions will soon be market ready. At that point it would be worthwhile to consider the economic value of these smart charging options as well. One example would be peak reduction of the building as a whole in general or specifically by way of vehicle-to-building (V2B).

5. Conclusion

The main implication of this study is that smart charging is a cost-effective way to optimize the utilization of charging infrastructure at office buildings. It follows that smart charging strategies are not only effective in accommodating a higher of share of EVs compared to uncontrolled charging but also result in a more profitable business case for fleet and building owners.

The value and effectiveness of the 4 smart charging options depends on actual charging needs and therefore the stage of the transition of the fleet. In this case study it was found that the most profitable strategies are combined strategies of CPO (from the start), load balancing (from 2020 until 2025) and PV (mostly from 2025 onwards). Based on these results we suggest a phases approach in the application of smart charging strategies. In the scenario of CGREA, we recommend the approach depicted in Figure 15.

It remains relevant to also consider other strategies and think ahead. For building owners, it is in particular relevant to consider options to actually lower the building peak. Smart charging strategies come with this possibility. Another option to accommodate higher shares of EVs would be to opt for a grid upgrade. This option is left unconsidered in this study.

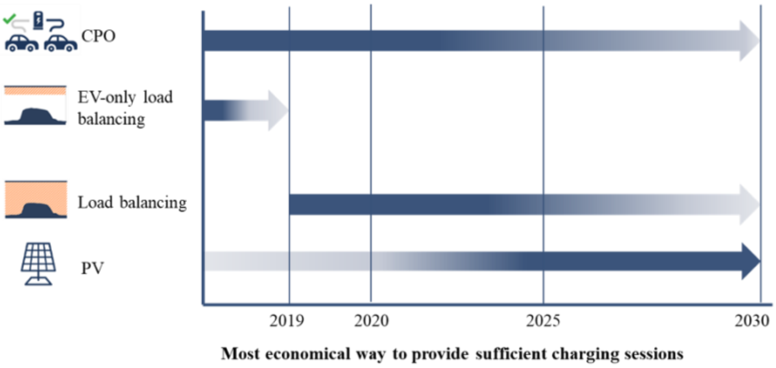


Figure 15 - The most economical way to provide sufficient charging sessions at own site

References

[1] Y. Wang, D. Infield, and S. Gill, “Smart charging for electric vehicles to minimize charging cost,” 2017.

[2] Y. Cao, S. Tang, C. Li, P. Zhang, and S. Member, “An Optimized EV Charging Model Considering TOU Price and SOC Curve,” vol. 3, no. 1, pp. 388–393, 2012.

[3] W. Kempton and J. Tomi, “Vehicle-to-grid power fundamentals : Calculating capacity and net revenue,” vol. 144, pp. 268–279, 2005.

[4] R. A. Verzijlbergh, *The Power of Electric Vehicles*. 2013.

[5] M. van der Kam and W. van Sark, “Smart charging of electric vehicles with photovoltaic power and vehicle-to-grid technology in a microgrid; a case study,” *Appl. Energy*, vol. 152, pp. 20–30, 2015.

[6] H. K. Nguyen and J. Bin Song, “Optimal Charging and Discharging for Multiple PHEVs with Demand Side Management in Vehicle-to-Building,” vol. 14, no. 6, pp. 662–671, 2012.

[7] KNMI, “Zonnestraling in Nederland.”

[8] Werkgroep discontovoet, “Rapport werkgroep discontovoet 2015,” 2015.

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Diede Streng is a graduate of the Master Student Energy Science at Utrecht University. As part of this study program she performed a research internship at EVConsult. The focus of this internship was to evaluate the cost-effectiveness of smart charging options at building site of large fleet owners. During her masters she gained valuable knowledge on energy markets and the national grid and she is pursuing a career as strategist in the energy market.

Laura Telders-Laméris is project manager at Rijksvastgoedbedrijf and leads a project team set up in preparation for deployment charging infrastructure at over 200 buildings of Rijkstvastgoedbedrijf. Laura has broad experience with the transition towards smart buildings. Laura has a background in Real Estate & Housing and studied at the Technical University of Delft (MsC).

Ioannis Lampropoulus is a postdoctoral researcher at Utrecht University. His current research focuses on the planning and operation of power systems, demand side management, and renewable energy sources. He holds a Dipl. Ing. degree from the Department of Electrical & Computer Engineering, National Technical University of Athens, a M.Sc. degree (cum laude) in Sustainable Energy Technology from Delft University of Technology, and a Ph.D. degree in Electrical Energy Systems from Eindhoven University of Technology.

Tim van Beek is founder and managing partner of EVConsult, an independent consultancy firm specialized in the transition towards electric mobility, with a team of over 20 experts working on projects across Europe. Tim has vast experience with projects centered around the deployment of both public and private charging infrastructure for electric vehicles including for the city of Amsterdam, various OEMs, and organizations with a large fleet such as Schiphol Taxi and Rijksvastgoedbedrijf. Tim studied engineering at the Technical University of Delft (MsC)