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Fleet electrification: minimizing uncertainty and TCO

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Summary
The challenges for the electrification of professional fleets can be met by formulating an electrification strategy tailored to the fleet operator's strategic and operational goals after a quantitative and qualitative analysis. This will help manage and minimize both technical uncertainty and TCO variability. The case studies (parcel delivery, ride-hailing and urban buses) provide insights on the practical application of these principles in the context of the design and operation of charging infrastructure in real daily operations of a business that operates a sizeable electric fleet.

Keywords: fleet, smart charging, TCO, LCC

1 Introduction

Professional fleets are switching to Battery Electric Vehicles (BEV) as a result of the increasing choice of EV models, fossil fuel costs, and regulatory push in the EU and the world. New regulations such as Zero Emission Zones in cities are very relevant for many types of fleets operating in these areas such as transit buses, delivery vans, taxis & ride-hailing services etc.

Each one of these fleets operate in different ways and result in different consumption and charging patterns. Defining an electrification strategy for each fleet is the key to a successful transition to a 100% electric fleet. Fleet operators are making their investment decisions based on economic metrics such as the Total Cost of Ownership (TCO) of their fleet and infrastructure. So far, the available literature has focused on comparing the TCO of ICE vs. BEV [1] or on analyzing the business impact of certain regulations [2]. The dependencies between the optimization of charging, fleet operations and TCO have not gotten so much attention. It is therefore necessary to **define a methodology** to provide fleet operators a clear understanding of the required CAPEX and OPEX and their estimated variability as well as to assess the operational feasibility of the electrification project and its impact on the daily fleet operations.

2 Technical feasibility study: a methodology

The technical feasibility of a fleet electrification project must consider two main aspects: fleet operations and charging infrastructure. The results of the operational feasibility analysis will feed the infrastructure feasibility analysis with the required charging power, energy, and time per EV.

The infrastructure analysis will minimize the uncertainty of key factors that directly affect the TCO. On one hand, there is uncertainty regarding the required OPEX due to the variability of energy demand and the required grid connection power (and the associated grid connection fees). On the other hand, there is uncertainty around the required CAPEX due to the (a priori) unknown grid connection power and the power per EV Supply Equipment (EVSE) or charging station.

To conduct the study, first, the operational constraints must be defined. These will be specific to each fleet and depot/site, but some classification of fleet types is possible based on a few criteria that will set the boundary conditions for the study:

- Variability of the consumption will be lower for fleets with predefined routes
- The management of charging sessions will be simpler when:
  - Operation start- and finalization times (i.e., arrival to/departure from charging depot times) are predictable.
  - Preconditioning power requirements (for cabin and/or battery heating, ancillary services etc.) are lower.
  - All EV-s in the fleet have similar batteries.
  - All EV-s support similar charging powers and have similar Power vs SoC (State of Charge) profiles.

2.1 Case studies: operational constraints of the selected fleets

To illustrate the relevance of the aforementioned factors and how they affect the feasibility study, the following fleet types were studied separately while using the same methodology. All 3 cases presented in this document are based on real fleet and real data (anonymized).

Table1: Fleet types considered for the case studies

	Predefined route	Timetable	Preconditioning power requirements	Dispersion in battery sizes	Dispersion in supported kW vs. SoC
Ride hailing service	No	Predefined, 24/7	Low	High	High
Parcel delivery vans	No	Predefined, nighttime only	Low	Low	Low
Transit buses	Yes	Predefined, mostly nighttime	Medium	Low	Low

2.1.1 Ride-hailing fleet: operational constraints

A ride-hailing fleet operator decided to shift to a fully electric fleet. The fleet operator had selected 5 EV models with different battery capacities and widely differing charging profiles, and they were preparing to dramatically increase their EV fleet with these models. The fleet was to operate 24/7 in a European capital. The features of the 5 EV-models are shown in figure 1.

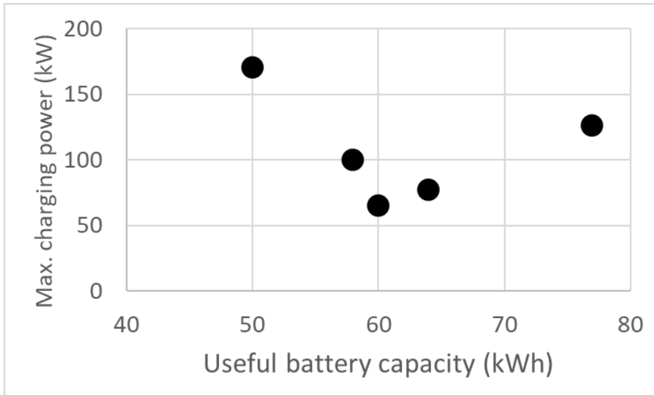

Figure1: Battery capacity and charging power of each EV-model in the fleet

The fleet operator wanted to always have as many cars as possible in service and was able to adjust the timetables for each driver so they could match the start and finalization times of the charging schedule. The work-shift duration was 11h, with 1h for charging and 2 work-shifts per day and vehicle. The allocated time for charging and vacuum cleaning the cars between consecutive work-shifts was 1h. The fleet operator planned to install 50 kW chargers for their fleet.

The operator provided the necessary data regarding consumption (kWh/km) for each model under different real-life scenarios (urban driving vs highway) and provided a statistical characterization of the daily mileage they would expect from each car based on the historical data they had.
The charging infrastructure had to be built from scratch and there was no other relevant electrical load expected to share the grid connection with the charging infrastructure. The task was to define the optimal charging infrastructure, its power, and the grid-connection power to minimize both the CAPEX and the OPEX and, ultimately, the TCO.

2.1.2 Parcel delivery fleet: operational constraints

A parcel delivery company was introducing electric vans in some of their logistics centers. Approximately 30 electric vans of the same EV model were being introduced in each logistics center. The expected daily mileage was well characterized based on historical data from their ICE fleet and they were expected to charge during the night (19:00 to 7:00). In all the sites, the grid connection had to be shared with other electric loads of the installation. During the day, employees would be allowed to use the charging infrastructure to charge their BEV and PHEV-s.

The fleet operator needed to determine the required power for charging their vans and assess the need of upgrades on their grid connection (on each site) based on this and the pre-existing consumption patterns per site. It was not only necessary to manage the peak power at the grid connection point, but also to ensure that no electrical line or phase was overloaded.

2.1.3 Transit bus fleet: operational constraints

A transit bus operator was at the initial stage of their electrification process and preparing for the introduction of the first batch of Battery Electric Buses (BEB) for a pilot project. Charging would take place almost exclusively during the night. BEB-s should be able to depart pre-conditioned when needed, and the thermal pre-conditioning must be done immediately before departure.

2.2 Operational feasibility

The goal of the operational feasibility study is to lay the foundation for the electrification strategy. The study will minimize the uncertainty when formulating the strategy and the associated Objectives and Key Results and will help define the KPI-s for the daily operation of both charging infrastructure and fleet.

Operational uncertainty can be synthetized in one question: how likely is it that a fleet consisting of N target EV-models will be able to provide the desired service? This translates into 2 KPI-s:

- SoC of each EV model at the end of the daily work-shift(s).
- Time (per EV model) to charge up to the required target-SoC.

These indicators depend on the variability of the energy consumption of each vehicle (end-of-work-shift SoC) and the expected duration of the charging process, so both must be assessed.

2.2.1 Operational analysis for a ride-hailing fleet

The ride hailing fleet was the most challenging one from an operational perspective. Figure 2 shows the methodology to conduct this analysis for each EV-model of the fleet.

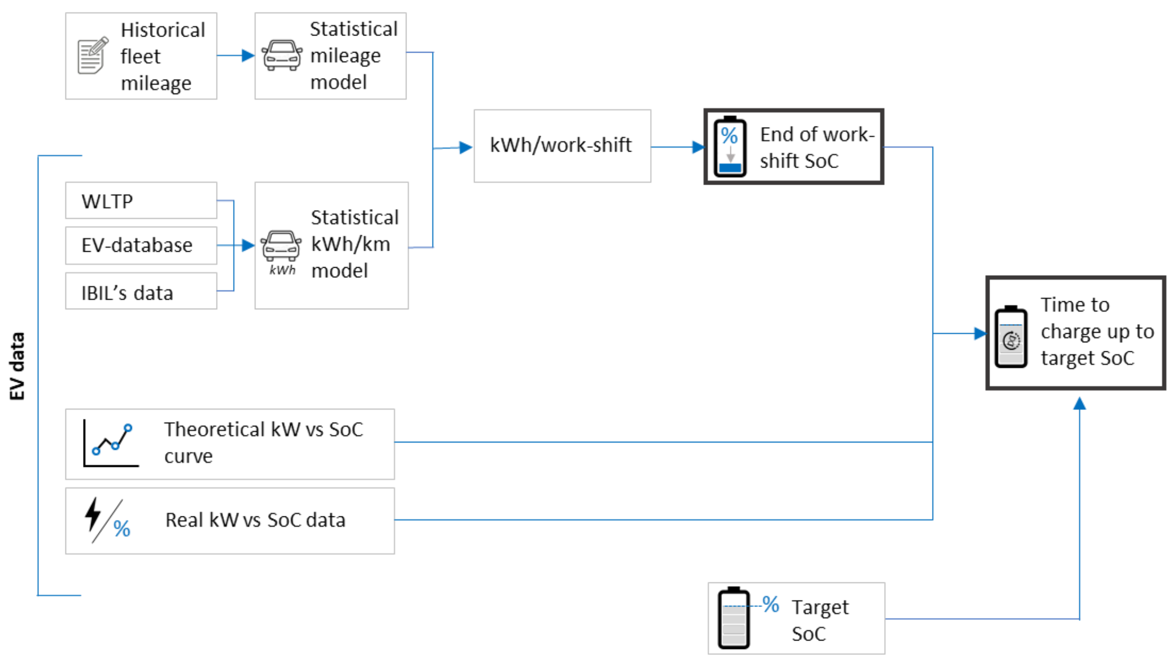

Figure 2: Operations feasibility analysis methodology for each target EV-model

The consumption of each vehicle was modelled based on data from WLTP ratings, www.ev-database.org, IBIL's own data, available research [3], and the historical mileage data from the fleet operator. These data were used to create a normal probability distribution of kWh/km consumption for each EV-model and a probability distribution function for the mileage per work-shift. Based on these probability distributions, a mathematical model was created to calculate the kWh consumption per work-shift and the SoC at the end of the work-shift. The mathematical model was completed with the charge profile of each EV-model to calculate the time required to charge from the estimated end-of-work-shift-SoC up to a certain target-SoC.

A Monte Carlo analysis was conducted by running thousands of iterations on the mathematical model assuming 80% to be the SoC at the start of work-shifts. 10% SoC was selected to be the minimum acceptable SoC at the end of the work-shift. Figure 3 shows that the Blue EV-model would be struggling to meet the operational demands (in more than 75% of the cases, end-of-work-shift-SoC would be <10%, and in 25% of the cases it would be below 2%, i.e., not feasible.

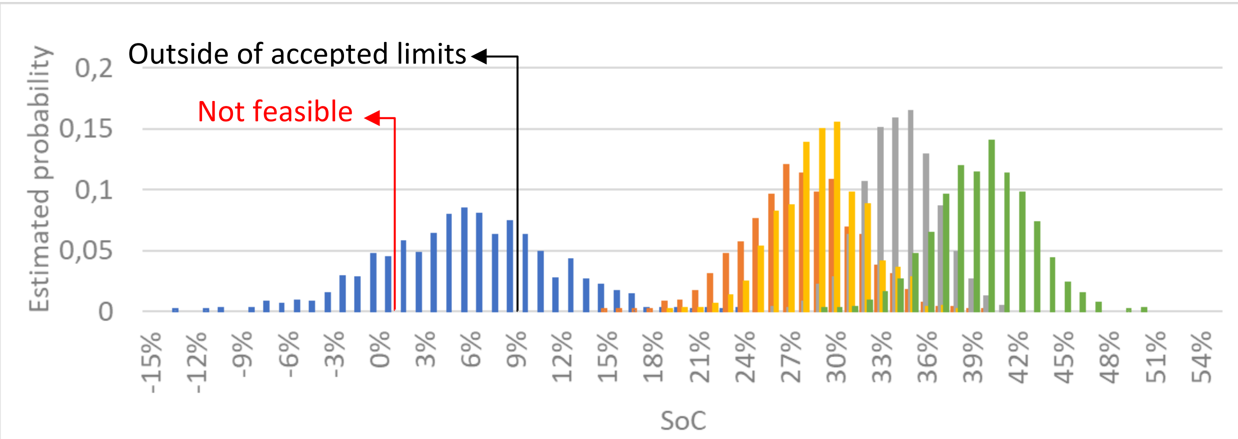

Figure 3: Estimated probability distribution of the end-of-shift-SoC of each EV-model

It was therefore necessary to change the strategy for the Blue model, which had to start its work-shifts with a higher SoC. With a 90% start-of-work-shift-SoC for the Blue model, the end-of-shift-SoC mean was approximately 15% with a 5% standard deviation, i.e., it was within the acceptable operational parameters of the fleet operator (>10% end-of-shift-SoC).

Table 2: End of shift SoC (starting with 80% SoC): statistical characterization of results

	End-of-shift SoC (target: ≥10%) for each EV model				
	Blue ●	Orange ●	Gray ●	Yellow ●	Green ●
Mean	5%	27%	34%	29%	39%
Minimum	-14%	15%	26%	19%	29%
1st quartile (lower 25%)	2%	25%	32%	27%	37%
Median (lower 50%)	6%	27%	34%	29%	39%
3rd quartile (lower 75%)	9%	30%	35%	30%	41%
Maximum	24%	39%	40%	38%	49%

Note: Shadowed results are outside of the accepted operational limits.

To complete the operational analysis, the estimated end-of-shift SoC was input into the model to estimate the time to charge each EV model up to 80% using 50 kW chargers. Figure 4 shows most EV-modes could easily be charged up to 80% within an hour. But, for the Blue model, charging up to at least 90% SoC would be needed to complete the work-shift consistently.

The trade-off was the required charging time for the Blue EV-model, which now was quite likely to exceed the maximum time for charging constraint, albeit lightly (the estimate being that in 75% of the cases the Blue model would reach the 90% target SoC in less than 68').

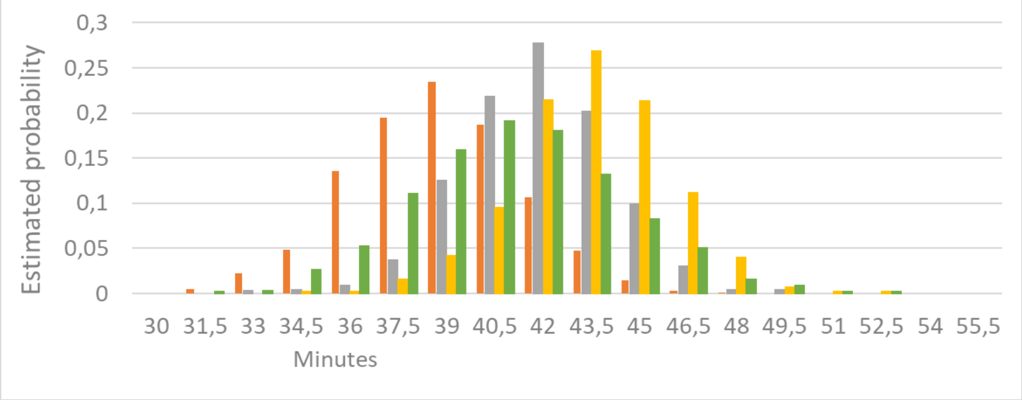

Figure 4: Estimated probability distribution of the time to target-SoC (80%) for each EV-model

With these results, the fleet operator was able to make a straightforward assessment of the cost of installing some higher power charging stations (90 kW was estimated to be enough) for the Blue models vs. the benefit of saving a few extra minutes for charging that model using 50 kW chargers, thus allowing the comparison of the cost of opportunity (loss of a few minutes per work-shift) vs. the additional investment on higher power chargers.

Table 3: Operational feasibility: time to target SoC for different EV models

	Minutes (target: <60') to charge up to 80% SoC*for each EV-model				
	Blue* (90%) ●	Orange ●	Gray ●	Yellow ●	Green ●
Mean	66	38	41	43	40
Minimum	59	30	35	34	32
1st quartile (lower 25%)	61	36	40	41	38
Median (lower 50%)	64	38	41	43	40
3rd quartile (lower 75%)	67	40	42	44	42
Maximum	79	45	49	51	50

* The values shown for the blue EV-model are for a 90% target-SoC instead of 80% as service was not feasible with 80% SoC.

2.2.2 Operational analysis for a parcel delivery van fleet

In this case the fleet was homogeneous, which simplified the estimation, and the results were quite straightforward.

The selected vans allowed AC charging at up to 7.4 kW (32 A, 230 V single phase) for their 47 kWh batteries and the simulations showed that mileage could deviate up to 150% of the typical historic mileage without compromising the feasibility of the service. The conclusion was that the selected electric van model was capable of both covering its work-shift within the predefined operational limits (end-of-shift-SoC ≥10%) and reaching the target-SoC before its departure.

2.2.3 Operational analysis for a transit bus fleet

The main additional constraint in this case was to input the pre-conditioning load as a non-manageable load (the e-buses must be preconditioned immediately before the departure, it makes no sense to heat them hours before their work-shift starts), which effectively reduced both the available time and power for charging the traction batteries.
By including this constraint in the model, the end-of-shift SoC estimation and the time to target SoC estimations were also conducted following the same methodology and the results were positive, showing that the fleet could operate within the defined boundaries.
The thermal pre-conditioning is especially important when combined with the infrastructure feasibility stage as the pre-conditioning will typically be required on the coldest days of the year, which makes the worst-case-scenario a little bit worse (preconditioning will be required on those days when the e-bus arrives to the depot with the lowest SoC).

2.3 Infrastructure feasibility

Besides the inputs and outputs of the operational feasibility analysis, the main additional factors for the infrastructure feasibility study for each target-site are two:

- Historical energy demand: The electricity consumption pattern of the non-EV related loads that share the grid connection with the EV charging infrastructure.
- Site survey: The existing electrical infrastructure on both sides of the meter.

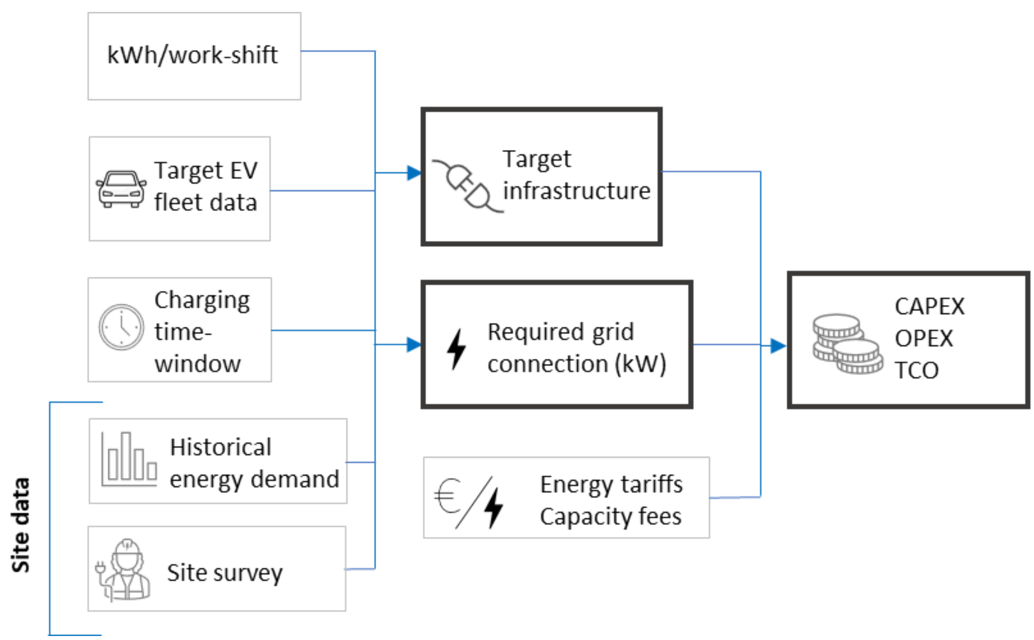

Figure 5: Infrastructure feasibility and TCO analysis model

The variability of these inputs results in uncertainty regarding the TCO. As a result of the Operational Feasibility study, the variability of energy demand for EV charging needs is now well modelled, so at this stage the study must focus on modelling the consumption pattern of non-EV related loads. For this, getting historical data of the meter is crucial. A long time-series of quarter hourly consumption data will provide valuable insights for the analysis.

In the case of the rid-hailing fleet, non-EV related consumption was negligible as the infrastructure had to be using a new dedicated grid connection. For the bus fleet and the parcel delivery fleet, on the other hand, the case was different. These were sharing their grid connections with several electrical loads that could not be managed.

For the sake of simplicity, we will focus on the parcel delivery fleet on the following paragraphs, the methodology for the bus fleet was identical.

The first step was to plot the historical quarter-hourly data in a meaningful way. For this, a box-and-whiskers plot was created showing the most significant statistical parameters for the recorded historical consumption dataset. The resulting dispersion was quite high as shown on figure 6:

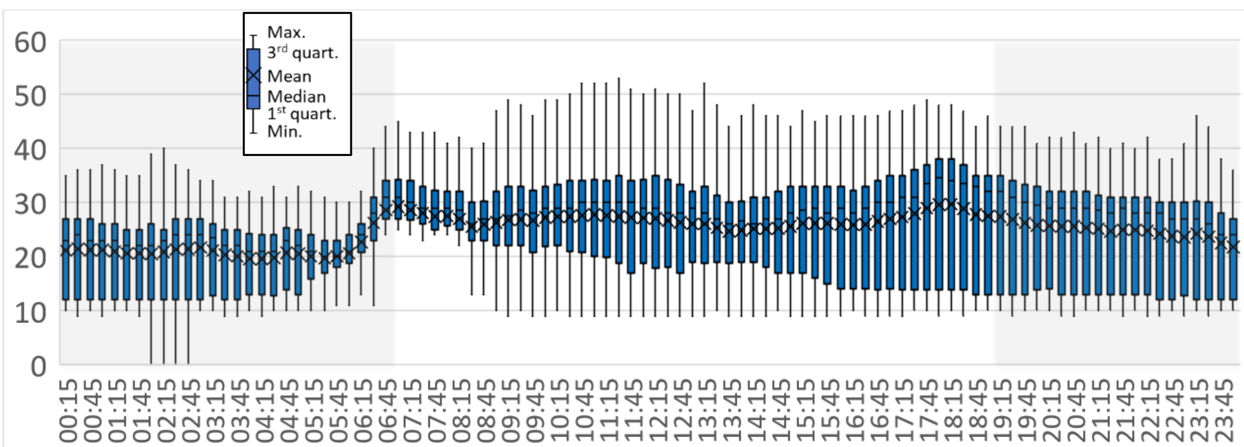

Figure 6: Peak quarter hourly consumption (kW) on site #1, 3-month time series (charging time-window is shadowed).

To reduce the dispersion, a weekly plot was selected, which revealed a clearly visible weekly pattern where different types of day could be identified (for instance, Tuesdays, Wednesdays, and Thursdays showed similar patterns), however, the dispersion of values was still too high.

This variability was reduced by filtering out local holidays and by introducing a seasonal analysis, which clearly showed that peak consumption was happening on the third quarter of the year, in the days leading to Halloween and, in a more sustained way, in the 3 weeks before Christmas. With these insights, it was now possible to confidently define the most challenging case and its probability of occurrence.

The second step was to calculate the potential of smart charging. The model showed that, for site #1, the 28 electric vans they were planning to use (charging at up to 7.4 kW each) could be charged with just 77 kW (additional kW required for EV charging on top of the base load shown on figure 6) instead of the 207 kW that would be required if no smart charging were to be used.

Given that the maximum power capacity of the site (the technical limit at the grid connection point) was 138kW, the additional 77kW could be allocated on top of the night-time pre-existing load (see figure 6). This showed that the project was feasible without any new grid connection.

Additionally, it was possible to optimize the grid-connection fees. The peak quarter-hourly consumption of the pre-existing load was below 35 kW for most of the charging time-window in roughly 80% of the days as shown on figure 6. The analysis of the energy (kWh) demand showed that these peak values were just very short instantaneous peaks (the quarter hourly average consumption was well below these values, with a ratio of 13 kW_{avg} to 35 kW_{peak} approximately).

This methodology was applied for every logistics center that had to be electrified and allowed the fleet operator to choose the optimal grid connection power and to select the most competitive Time of Use energy tariff for their future consumption pattern including both EV-charging and non-EV-charging-related energy demand.

3 Economic feasibility: Estimating the TCO of the project

At this point, the benefits of the proposed methodology arise: The outcomes of the technical feasibility analysis provide valuable insights to calculate the TCO of the project and to estimate the confidence the fleet operator should have on the resulting numbers.

The results of the study provide an estimation of the energy demand for EV-charging on a time basis and the infrastructure study combines these insights with the study of any other loads, so the total energy demand profile of each site can be estimated, and the most convenient energy tariff can be selected.

Some risk-mitigation strategies can also result from these studies to reduce the energy-cost related uncertainty:

- Long-term Power Purchase Agreements (PPA) can help manage the risk related to energy price volatility.
- The installation of battery systems (BESS) for peak shaving might be interesting if sporadic non-manageable demand peaks are likely in the selected site.

4 Business operation: Impact of the electrification

For a successful electrification, the feasibility study is not enough. The electrification strategy must define clear Objectives and Key Results and it must be possible to keep track of the performance of the system with a few meaningful Key Performance Indicators (KPI-s) in a seamless manner. When relying on third parties for the EV-charging service, the results of the feasibility study also facilitate the definition of an acceptable range for each KPI with fleet and site-specific parameters, i.e., fleet, and site-specific Service Level Agreements can be introduced in contracts or future Requests for Proposals for Charging Service Providers.

The following indicators can help get a good understanding of the performance of the system:

- Financial controlling:
    - Cost of Energy per car/driver
    - Average cost of energy
- Operations SLA-s:
    - Successful charge ratio
    - Uptime of the charging system
- Operations performance and reliability
    - SoC at the end-of-shift
    - Charging session duration

The impact of externalities also has to be assessed (some EV arriving with a very low SoC at the end of the work-shift, late arrivals, EVSE failures etc.). Redundancy and oversizing allow a more resilient business operation. It may be necessary to account for additional or higher power charging infrastructure (as seen in section 2.2.1 for the Blue EV-model). The utilization rate of each EVSE is another factor driving this decision (for instance, each charger of the ride-hailing fleet had to provide 24 charging sessions per day, one charger's failure would affect operations).

5 Implementation of the electrification project

To implement the electrification project both HW and SW tools will be required. When the grid connection is only going to be used for EV charging, standard EVSE and electrical installation are the only required HW. If there are electrical loads that cannot be managed (i.e., non-EV-related loads), additional HW will be required: a local Energy Management System (EMS).

In the case of the parcel delivery van fleet and the bus fleet, the feasibility study showed that dynamic power management was essential to ensure that both the contractual and technical limits of the site (grid connection and maximum currents per line/phase) were always respected.

5.1 Implementation of the infrastructure for a parcel-delivery fleet.

This base load variability made necessary the use of a local EMS. The EMS would monitor the load on each phase and line at the grid connection point, and it would update the maximum charging current settings of the EVSE accordingly to ensure that the installation operated within both the installed cable ampacity limits and the power limits of the selected energy tariff.

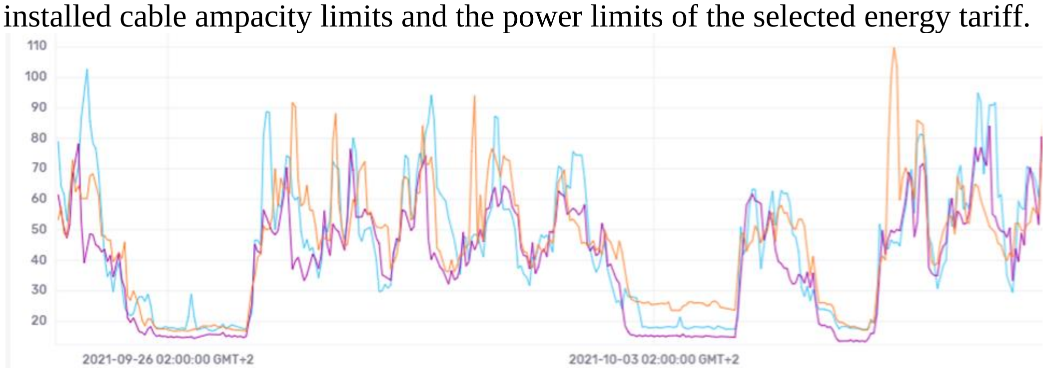

Figure 7: Parcel delivery site#1 in operation: 3-phase currents (A) at the main breaker

The EMS enabled operations with a new grid-connection fee for just 90 kW, leading to OPEX savings and CAPEX savings as a result of avoiding costly new grid connections.

Both the EMS and the EVSE are also connected to the back-end of the Charging Services Provider so the delivery company can keep track of the consumption of each vehicle with real-time data, change charging priorities etc.

6 Conclusions

A methodology for assessing the TCO of fleet electrification projects and the technical feasibility of the project was presented. The methodology's success relies on the availability of high-quality historical mileage data of the fleet and a solid modelling of each EV's charging profile and kWh/km consumption.

The statistical modelling of the expected operational performance of the fleet and the charging infrastructure allows a fact-based, quantitative decision making for the fleet operator. It allows a sound cost-benefit analysis at the investment planning stage, and it also facilitates a good estimate of the fleet operator's OPEX by providing robust estimates of the energy consumption of the fleet. This analysis can also be used to define the required SLA-s when purchasing EV-charging services from a third-party.

An in-depth analysis of the available grid connection and existing baseload also can save costs by avoiding unnecessary investments.

Meaningful metrics can be defined to keep track of the systems performance and to enable a continual optimization as the EV fleet and the associated charging infrastructure grow. To do this, fleet operators should rely on user-friendly SW tools.

Finally, it is important to remark that the use of digital tools for monitoring the charging process does not have to be a separate process, but a part of daily operations of the company. It is therefore important to integrate the EV-charging related digital tools and the fleet monitoring & management systems so the transition to an all-electric fleet is as seamless as possible for fleet operators and drivers.

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