# Strategic Energy Procurement for EV Fleets: A Comparative Study

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***Abstract*—Large fleets for public transport, last-mile deliveries and taxis have traditionally relied on fossil fuels. However, the growing pressures towards the decarbonization of the economy in the face of climate change are driving a shift towards electric vehicles. This transition presents challenges, particularly in procuring energy, that can lead to increased operational costs. This article explores three primary electricity procurement strategies for fleet operators: (i) day-ahead purchases with conventional grid access tariffs, (ii) day-ahead purchases with e-mobility grid access tariffs, and (iii) a hybrid approach combining power purchase agreements (PPA) and day-ahead purchases with conventional grid access tariffs. A case study of an electric bus fleet in Portugal demonstrates cost implications across these strategies. The results show that paying conventional grid access tariffs and hedging electricity with a PPA is the best option.**

***Index Terms*—Electric vehicles, fleet energy procurement, day-ahead electricity markets, power purchase agreements, energy transition strategies.**

## I. INTRODUCTION

The transport sector is responsible for a substantial portion of greenhouse gas (GHG) emissions in the European Union (EU). Projections suggest that the EU's emissions will not fall below 1990 levels until after 2030 [1], [2]. Additionally, while air quality in European cities has improved significantly since the early 2000s, air pollution continues to pose a major health challenge [3]. Therefore, the electrification of transport is crucial for reducing carbon emissions and enhancing air quality, particularly in urban areas. Electric vehicles (EVs) are emission-free during operation, and their use with renewable energy significantly reduces global GHG emissions [4]. Recently, the sales share of EVs in Europe has seen a notable increase. The sales of personal EVs, including battery and plug-in hybrids, reached nearly 3.2 million units in 2023. In the same direction, electric bus sales amounted to 8,000 registrations, light commercial vehicles totaled 150,000 units, and the sales of electric trucks almost tripled, exceeding 10,000 units in 2023 [5]. Figure 1 provides a global overview of the EV stock from 2013 to 2023, demonstrating this fast-paced adoption.

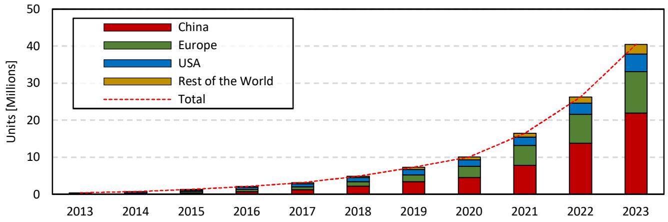

Figure 1. Global EV stock, 2013 to 2023. Source: [5].

However, electrifying fleets poses challenges, particularly in charging infrastructure and electricity demand. For example, ultrafast chargers can exceed 350 kW, and stations with multiple chargers may require over 2 MW of power—comparable to small industrial facilities, even for modestly sized fleets [6]. As a result, fleet operators can engage with energy markets to meet the energy demand when transitioning to EVs. Navigating these markets can be complicated, involving various contracts and agreements when purchasing electricity. In this complex environment, other participants may also be involved in the process of procuring energy, such as aggregators, which can combine different loads and manage flexibility in demand patterns. Furthermore, fleet operators must develop effective charging strategies to flatten peak power demand, reduce electricity costs, and account for unpredictable factors such as driving behavior and weather conditions, which increases the complexity of this transition.

Some studies have addressed issues such as charging strategies, operational costs reduction, and energy procurement. In [7], [8], the authors developed optimization models to minimize the operational costs of charging a fleet of electric buses in the city of Coimbra, Portugal. The models consider a time-of-use tariff following day-ahead market dynamics. In [9], the authors analyzed the total cost of ownership of an electric bus fleet for urban and interurban

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transport and applied a fixed tariff for estimating the costs of electricity. Further, previous research has investigated optimal EV charging strategies to reduce costs, focusing on scenarios integrating renewable energy generation, applicable to both residential [10] and commercial [11] settings.

The literature reveals that most studies utilize a time-of-use tariff scheme to model energy procurement. Therefore, there is a noticeable gap in research comparing different strategies for procuring energy from the grid. In this context, this article examines how fleet operators can strategically acquire electricity to charge their vehicles. We evaluate three main mechanisms to this end: (i) purchasing from the day-ahead market using conventional grid access tariffs; (ii) purchasing from the day-ahead market using e-mobility grid access tariffs; and (iii) partially hedging consumption with a power purchase agreement (PPA), considered in this study with a photovoltaic (PV) plant, while purchasing electricity in the day-ahead market and using conventional grid access tariffs. To illustrate the cost implications, a case study focused on an electric bus fleet in Portugal is presented, using prices from the Iberian electricity market operator and the energy consumption of the fleet.

The rest of this article is structured as follows. Section 2 offers a concise overview of the energy market and the procurement strategies assessed in this study. Section 3 outlines the methodology and details the data collected for the research. Section 4 presents the case study along with the results and discusses their implications. Conclusions are drawn in Section 5.

## II. ENERGY MARKET FUNDAMENTALS

In this section, we briefly introduce some key aspects of the electricity market as well as the characteristics of the electricity procuring mechanisms applied in this research.

### A. *Electricity Markets Functioning*

In this study, we focus on the Portuguese electricity market, which is liberalized and allows consumers to choose their electricity suppliers freely. It is integrated with the Spanish market under MIBEL, the Iberian Electricity Market, where OMIE, the nominated electricity market operator, manages short-term trading. OMIE conducts daily auctions in the day-ahead market to ensure energy supply and consumption for the next day, along with intraday auctions for agents to fine-tune their positions. Buyers are generally large consumers and energy traders who purchase electricity for resale to their clients. Beyond the short-term market, electricity can also be acquired directly from generators through PPAs, via futures markets at OMIP, the Iberian derivatives market operator, or more commonly through energy traders.

### B. *Electricity Procuring Mechanisms*

The components for electricity procurement are detailed below following the Portuguese legislation.

**Electricity bill:** The electricity bill in Portugal consists of three primary elements: electricity and supply costs, grid access tariffs, and charges and taxes. Electricity and supply costs cover the price of electricity consumed and associated services provided by the supplier. Grid access tariffs reflect the costs of delivering electricity from the generation source to the end consumer, including transmission and distribution, maintenance and operation. Charges and taxes are set by the government. We only consider the value-added tax (VAT) in this study.

**E-mobility grid access:** In Portugal, Decree-Law nº 39/2010 [11] regulates electricity for EVs, specifying the conditions for energy trading and registration requirements. Charging station operators and electricity traders for e-mobility must join the electric mobility network for commercial purposes. For cases where electricity is not sold, that integration is optional but it is required if the fleet owner wishes to benefit from e-mobility-specific grid access tariffs. In this paper, we evaluate the benefits of paying or not these grid access tariffs in the context of a fleet operator, even though we do not consider the sale of energy to third-party EV.

**PPAs:** A PPA is a contract between a renewable energy generator and an electricity consumer. Typically spanning 10 to 15 years, the agreement specifies the price, volume and delivery terms for the electricity supplied. PPAs can take two primary forms: physical PPA, where the agreement covers the actual consumption of electricity, and virtual (or financial) PPA, where the parties engage in buying and selling electricity in the day-ahead market and settle the differences between the day-ahead price and the PPA price. PPAs can be structured in different manners (e.g., pricing terms, hourly delivery and risk management) [12]; however, the specifics of these configurations are beyond the scope of this study.

## III. METHODS AND DATA

The methodological approach starts with the mathematical model of electricity procurement strategies, which we consider to be standard market applications. We then collected a variety of datasets, including electric bus energy consumption, PV energy production, and electricity prices. Finally, we developed simulations of different scenarios using the Python programming language. Figure 2 displays a summary of the framework used in this research.

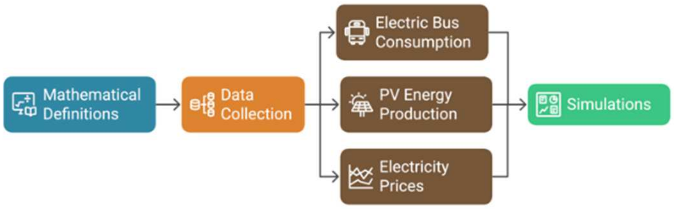

Figure 2. Methodological approach.

In the following, we present the mathematical model used for electricity procurement analysis and the data sources employed in the simulations.

### A. *Mathematical Model*

The mathematical equations below aim to calculate the overall cost, including electricity procurement costs, grid access tariffs, PPA pricing, and taxes. We discuss each element in the following.

**Electricity costs:** Equation 1 gives the electricity procuring costs in the day-ahead market ($C^{DA}$), where $D_t$ is the electricity consumption and $\pi_t^{DA}$ is the hourly price in the day-ahead market in the period $t = \{0, \ldots, T\}$ (in our case, one year).

$$C^{DA} = \sum_{t=0}^{T} (D_t \times \pi_t^{DA}) \tag{1}$$

Equation 2.1 gives the electricity procuring costs ($C^{DA,PPA}$) using a solar PPA as a partial hedge for consumption. The total costs combine two components: (i) the cost of electricity acquired through the PPA ($K_t$), and (ii) the costs related to deficits or surpluses settled in the day-ahead market ($M_t$).

$$C^{DA,PPA} = \sum_{t=0}^{T} (K_t + M_t) \tag{2.1}$$

The first term, $K_t$, given in Equation 2.2, is the product of the hourly solar generation ($S_t$) by the PPA price ($\pi^{PPA}$).

$$K_t = S_t \times \pi^{PPA} \tag{2.2}$$

The second term, $M_t$, shown in Equation 2.3, is the product of the hourly day-ahead price ($\pi_t^{DA}$) by the difference between the electricity consumption and the solar generation.

$$M_t = (D_t - S_t) \times \pi_t^{DA} \tag{2.3}$$

When electricity consumption exceeds solar generation, the consumer purchases all solar output at the PPA price and any remaining demand is met by the day-ahead market. In hours when solar production exceeds consumption, the surplus is bought at the PPA price and resold in the day-ahead market.

**Grid access tariffs:** The conventional grid access tariff ($G^{grid}$) is composed of three terms, namely the contracted capacity costs ($\varphi$), the average power during peak costs ($\sigma$), and the active energy consumption costs ($\alpha$), as shown in Equation 3.1.

$$G^{grid} = \varphi + \sigma + \alpha \tag{3.1}$$

The contracted capacity costs (Equation 3.2) are calculated as the product of the contracted demand ($\tau$), which for this study is set as the maximum charging power, by the contracted demand tariff ($\pi_y^{\varphi}$) per day $y$ in a year ($y = \{0, \ldots, Y\}$).

$$\varphi = \tau \times \sum_{y=0}^{Y} \pi_y^{\varphi} \tag{3.2}$$

The average power during peak costs ($\sigma$) is calculated as shown in Equation 3.3 and depends on the average consumption during peak hours ($\overline{D}_y^{peak}$) and the tariff for peak consumption ($\pi^{peak}$) per day $y$.

$$\sigma = \pi^{peak} \times \sum_{y=0}^{Y} \overline{D}_y^{peak} \tag{3.3}$$

The active energy consumption costs ($\alpha$) is given in Equation 3.4, where I$A_t$ is the active energy consumption in hour $t$ ($A_t$) and $\pi_t^{\alpha}$ is the respective tariff.

$$\alpha = \sum_{t=0}^{T} (A_t \times \pi_t^{\alpha}) \tag{3.4}$$

**E-mobility tariffs:** For the e-mobility grid access tariffs ($G^{e\text{-}mob}$), the costs are based on actual electricity consumption during each tariff period rather than on power usage. The cost is calculated by Equation 4 where $\pi_t^{e\text{-}mob}$ is the e-mobility grid access tariff during hour $t$.

$$G^{e\text{-}mob} = \sum_{t=0}^{T} (D_t \times \pi_t^{e\text{-}mob}) \tag{4}$$

**PPA price:** The PPA price ($\pi^{PPA}$) is equal to the capture price ($\pi^{cap}$) of the solar generation discounted by a market factor $\xi$ (20% in our study), as stated in Equation 5.1. This procedure follows standard market practices [13].

$$\pi^{PPA} = \pi^{cap} \times \xi \tag{5.1}$$

Further, the capture price is the weighted average price a power plant can get in the day-ahead market [14], which is calculated as shown in Equation 5.2.

$$\pi^{cap} = \frac{\sum_t (S_t \times \pi_t^{DA})}{\sum_t S_t} \tag{5.2}$$

**Tax:** The final electricity bill cost is calculated by multiplying the sum of all previously mentioned costs by the VAT ($\phi^{VAT}$), considering a rate of 23% in our experiments.

### B. *Data sources*

Datasets have been collected from on-site measurements, internet databases and simulations. Below, we describe each dataset.

**Electric buses dataset:** The dataset for the electric bus fleet was obtained from SMTUC (https://www.smtuc.pt/), the bus operator in Coimbra. The buses, which are each 12 meters long, are daily assigned to different routes in the city. This dataset includes measurements of the battery packs for each vehicle, recorded at 15-minute intervals over a 14-day period. It contains information on the state of charge (SOC), cell voltage, temperature and date. In this study, we are focusing solely on the SOC levels of the vehicles. To streamline our calculations, we selected seven representative days of the week and used this set throughout the simulations.

**PV generation dataset:** The solar generation was obtained using the *pvlib* Python package [15], [16]. The simulated PV power plant is in the central-east region of Portugal and it is designed to generate a volume of energy equivalent to the yearly consumption of the bus fleet from 08:00 to 20:00, since these hours concentrate most of the solar generation. Our case study considers hourly granularity for a typical meteorological year, represented by a dataset of 8,760 entries.

**Electricity price dataset:** Hourly electricity prices of the day-ahead market were taken from REN's website, the Portuguese Transmission System Operator [17]. Grid access tariffs and hourly tariff levels for medium voltage were taken from ERSE's website, the Portuguese energy regulatory entity [18].

# IV. RESULTS AND DISCUSSIONS

In this section, we describe a case study involving a fleet of electric buses in Coimbra, Portugal, and discuss the results.

## *A. Case Study Characteristics*

We utilized hourly data to analyze the charging costs of seven distinct electric buses over a one-year period. The electricity prices employed in our analysis were sourced from the Portuguese day-ahead market for the year 2024.

**Energy demand profile (electric buses):** Figure 3 presents the charging power per hour for each day of the week, considering the entire fleet.

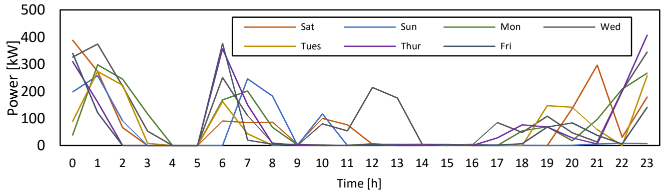

Figure 3. Hourly power demand to the grid per day of the week.

The annual energy consumption of the fleet is 627.3 MWh. Most charging events occur during the night and early mornings, with some taking place during the day. The power peak varies on different days but is typically around 400 kW.

**PV generation profile:** We analyzed the fleet's energy demand from 8:00 to 20:00, which aligns with solar energy production. Based on this, we designed a PV power plant to meet the fleet's average demand during these hours. In this setting, the PV power plant has a 79 kWp capacity, and the generated energy can supply up to 21% of the annual energy consumption (131.7 MWh). To illustrate the PV generation profile, Figure 4 shows the average power output for different seasons of the year.

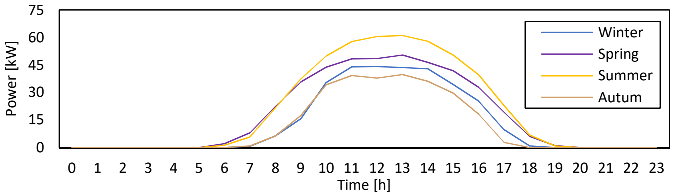

Figure 4. Average hourly solar generation per season.

**Tariffs and prices:** Figure 5 presents the average day-ahead energy price for each hour and the standard deviation. Prices have shown higher values during the early mornings and the late afternoons, with the cheapest hours occurring during the day.

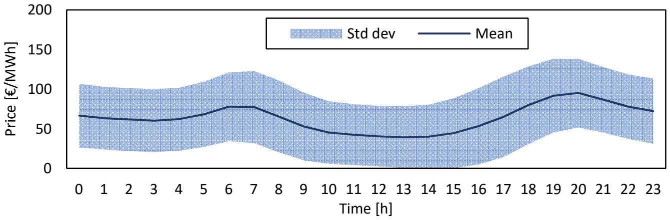

Figure 5. Hourly day-ahead prices in Portugal during 2024.

Table I presents the tariffs applied for the grid access tariffs, the PPA price and the average day-ahead price in 2024.

TABLE I. PRICES APPLIED IN THE CASE STUDY.

| ***Name*** | ***Symbol*** | ***Price*** | ***Description (Unit)*** |
|---|---|---|---|
| Energy (average) | $\pi_t^{DA}$ | 63.63 | Energy (€/MWh) |
| Solar capture price | $\pi^{cap}$ | 41.72 | Energy (€/MWh) |
| PPA price | $\pi^{PPA}$ | 33.38 | Energy (€/MWh) |
| Conventional grid access tariff | $\pi_y^{\varphi}$ | 0.0340 | Contracted demand (€/kW.day) |
| | $\pi^{peak}$ | 0.2258 | Peak power (€/kW.day) |
| | $\pi_t^{\alpha}$ | 0.0108 | Energy during peak (€/MWh) |
| | | 0.0099 | Energy during mid-peak (€/MWh) |
| | | 0.0078 | Energy during off-peak (€/MWh) |
| | | 0.0069 | Energy during super off-peak (€/MWh) |
| e-mobility grid access tariff | $\pi_t^{e\text{-}mob}$ | 0.0432 | Energy during peak (€/MWh) |
| | | 0.0076 | Energy during off-peak (€/MWh) |

## *B. Scenarios Definition*

We evaluate three distinct scenarios in the simulations:

**Day-ahead market:** In the first scenario, the fleet operator purchases electricity from the day-ahead market and pays conventional grid access tariffs. The electricity bill is given by Equation 6.1.

$$P^{S1} = (C^{DA} + G^{grid}) \times (1 + \phi^{VAT}) \tag{6.1}$$

**E-mobility:** In the second scenario, the fleet operator still procures electricity from the day-ahead market but employs e-mobility access tariffs. These tariffs may allow the operator to sell energy to charge third party's electric vehicles, although we do not account for this case in our analysis. Furthermore, e-mobility's grid access tariffs may result in lower costs. The electricity bill is given by Equation 6.2.

$$P^{S2} = (C^{DA} + G^{e\text{-}mob}) \times (1 + \phi^{VAT}) \tag{6.2}$$

**PPA:** The third scenario is similar to the first, with the addition that it considers partially hedging consumption through a PPA, while covering any remaining demand via the day-ahead market. The electricity bill is given by Equation 6.3.

$$P^{S3} = (C^{DA,PPA} + G^{grid}) \times (1 + \phi^{VAT}) \tag{6.3}$$

## *C. Results and Discussion*

Figure 6 presents the results of the simulations.

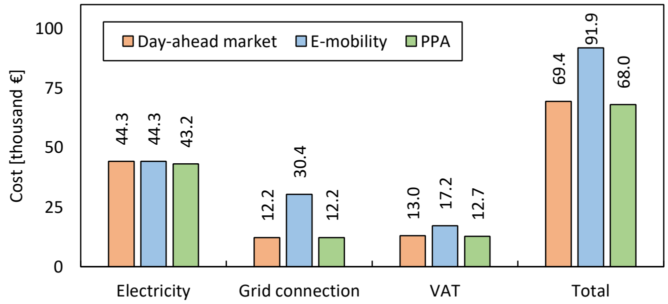

Figure 6. Total costs evaluated per electricity bill component per scenario.

Each component is presented separately to highlight the comparison between the scenarios. The PPA scenario is the most cost-effective for charging the electric bus fleet. Procuring electricity solely in the day-ahead market results in a price that is 2.5% higher. It is important to note that the PPA scenario was calculated knowing the day-ahead prices *a priori*, an advantage that will not be available for a fleet operator contracting a PPA. Therefore, the actual advantages of such a contract would depend on the contract pricing and the fluctuations of day-ahead prices. For the consumption profile used in this article, the grid access tariffs associated with e-mobility were significantly higher. Choosing the e-mobility scenario results in a 150% increase in grid access costs and a 35% rise in total costs compared to the day-ahead market scenario. To deepen the analysis, Figure 7 provides a breakdown of the shares of each component in the final bill for each scenario.

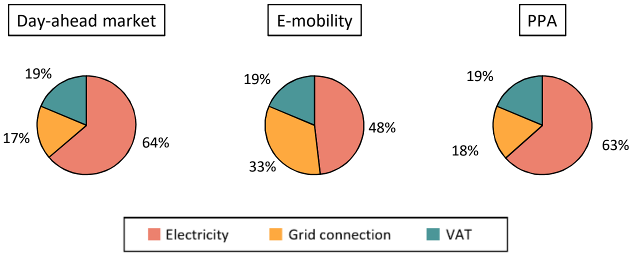

Figure 7. Share of each component in the final electricity bill.

As expected, the electricity purchase remains the dominant share in all cases. The e-mobility tariff, despite being designed to offer cost-competitive access to the grid for EV owners, produces the opposite effect in this specific analysis: the grid access cost portion escalates considerably (33% of the bill share), which leads to higher overall costs compared to the day-ahead market or PPA scenarios. The only clear advantage emerges if the operator intends to engage in energy exchanges with the grid or utilize the charging infrastructure for additional purposes—activities that might justify the higher grid-related costs. The savings provided by signing a PPA are modest in our analysis. Therefore, the decision of entering in a long-term contract can be risky for the fleet operator. The financial performance of these contracts depends on accurately forecasting electricity prices and minimizing the cost compared to the day-ahead market. In this study we only analyzed a single type of PPA, with physical delivery, a fixed price and one power plant. However, there are a multitude of contractual structures that can be analyzed, including changing the delivery profile, the price structure, and even procuring more or less energy from the PV source. Additionally, the fleet operator can analyze procuring from another renewable source, such as wind, which might be a better fit to its energy demand profile. A clear advantage of a PPA contract is that it ensures a clean energy source for the fleet, reducing vehicle emissions and allowing fleet operators to acquire renewable certificates (Guarantees of Origin in the EU) to meet sustainability requirements.

## V. CONCLUSIONS

This article analyzed three scenarios for procuring electricity to charge a fleet of seven electric buses in Portugal. The scenarios include two forms of procuring energy (day-ahead market and PPA) and contracting grid access tariffs (conventional and e-mobility). The results show that different procurement strategies can result in considerably distinct overall costs. Paying conventional grid access tariffs has shown to be more financially attractive compared to the e-mobility's. In this circumstance, a fleet operator who does not intend to resell energy should not opt for the e-mobility grid access tariff. Furthermore, signing a PPA has the potential of reducing the final costs (2% compared to day-ahead market scenario). This result stems from the fact that, in our study, electricity from a PPA costs less than the price in the day-ahead market. Furthermore, contracting through a PPA enables the fleet owner to strategically search for better prices of electricity. Lower prices in a PPA would improve the savings obtained from this procurement mechanism, which is not possible if only trading in the day-ahead market.

While we have addressed some aspects of electricity procurement for charging EVs, we have not explored all the avenues. For instance, various alternatives can be examined to improve our scientific understanding and support efforts to decarbonize transportation and create cleaner cities, opening room for future research. Future work could investigate different PPA structures, as several alternatives have been signed in the European electricity market lately. Moreover, we suggest further research on how fleet operators can engage in the electricity market, take advantage of energy arbitrage and provide ancillary services to grid operators.

## ACKNOWLEDGEMENTS

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