ElectroOptimize

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Executive Summary

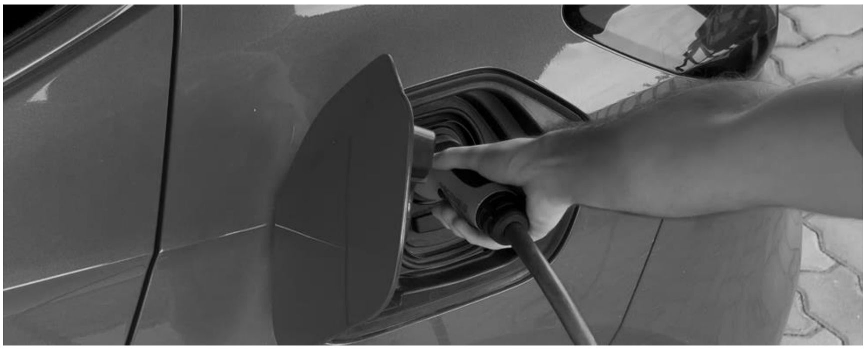
The rapid growth of **electric vehicles (EVs)** presents both significant issues and opportunities for the management of electricity grids. Renewable energy, for example from wind and solar, is intermittent, often generating mismatches between supply and demand that threaten system stability. At the same time, EVs spend most of their lifetime parked, leaving their batteries largely idle. This situation highlights the main issue: while the grid struggles with volatility, a vast distributed **storage resource** remains unexploited. Aggregating EVs into **Virtual Power Plants (VPPs)**, digital platforms that manage distributed resources as a single energy unit, can transform this idle capacity into a valuable source of flexibility for the power system.

Our project set out to explore how EV fleets could reliably provide **balancing services** while ensuring mobility needs are fully respected. The objective is to design predictive tools to estimate available **flexibility**, coordination methods to manage large fleets and bidding strategies to maximize returns while limiting exposure to risk. By aligning technical innovation with regulatory opportunities, we aim to show how EVs can evolve from passive consumers into active enablers of the energy transition.

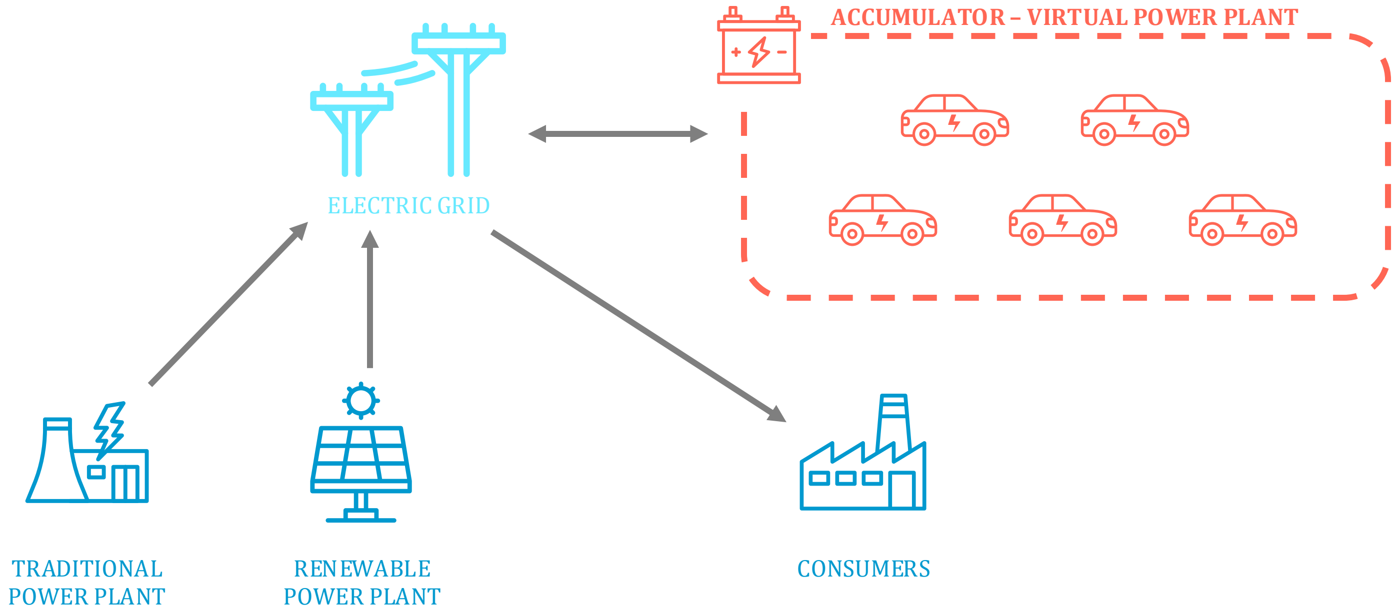
The key driver enabling this development is the new **regulatory framework TIDE**, which from January 2025 shortens dispatch intervals to 15 minutes and introduces zonal pricing. These changes make it feasible and profitable for EV batteries, with their limited duration, to participate in balancing markets, especially in congested urban areas where flexibility is most valuable. Alongside regulation, our research advanced technical solutions: scalable, decentralized coordination methods that allow tens of thousands of vehicles to act in unison and a penalty-aware bidding model that integrated the risk of financial sanctions directly into market strategies.

The expected result is a reliable, profitable and scalable framework for EV-based VPPs. Fleet operators gain new revenue opportunities, grid operators secure vital flexibility and society benefits from a smoother integration of renewable energy. By combining regulation, technology and market design, EV fleets can play a decisive role in building a resilient and sustainable electricity system.

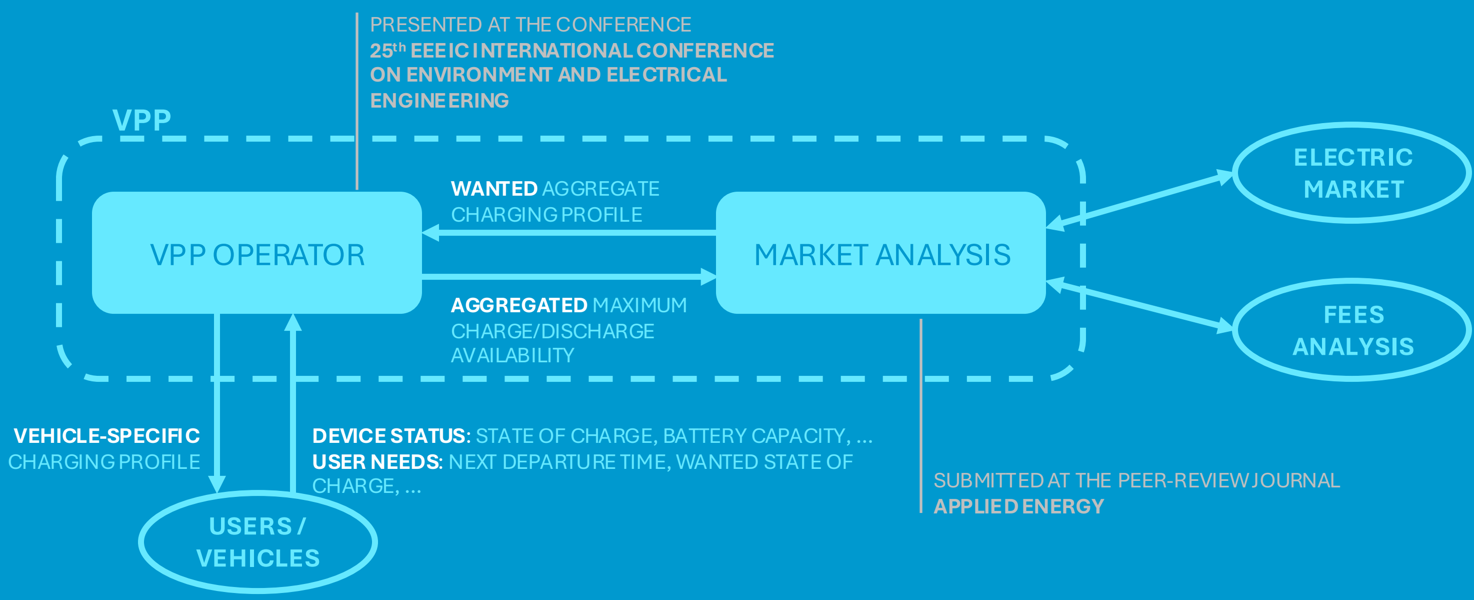
Key Words
Virtual Power Plants (VPPs), Electric Vehicles (EVs), Flexibility, Decentralization, Penalty-Aware Bidding



VIRTUAL POWER PLANTS AND STANDARD ELECTRIC GRID INTERACTION



VIRTUAL POWER PLANTS MANAGEMENT MODEL



Project Description written by the Principal Academic Tutor

The diffusion of EVs is transforming the energy landscape, bringing both opportunities and challenges for electricity grid management. Renewable energy sources are clean but inherently intermittent, creating frequent mismatches between generation and demand. In parallel, EVs spend most of their lifetime parked, with their batteries unused. This combination highlights a paradox: while the grid struggles with volatility and flexibility shortages, a vast distributed storage resource remains untapped.

Harnessing EVs as VPPs offers a promising solution. By aggregating thousands of individual vehicles into coordinated units, it becomes possible to transform idle capacity into decentralized storage that can help stabilize the grid, absorb renewable fluctuations and reduce reliance on conventional backup generation. However, realizing this potential requires overcoming both regulatory and technical barriers.

A crucial step is represented by the TIDE regulatory framework. By shortening dispatch intervals from one hour to fifteen minutes and introducing zonal pricing, TIDE creates the conditions for EV fleets to participate meaningfully in balancing markets. At the same time, it sets strict requirements for Balancing Service Providers (BSPs), demanding high reliability, precise forecasting and careful risk management.

The core problem can therefore be framed as follows: **how to integrate dispersed EV batteries into the power system as a reliable and scalable source of flexibility, under new market rules and without compromising user mobility.** Addressing this problem requires advances in predictive modelling, fleet coordination, and market design to ensure that EV-based VPPs can move from theoretical promise to practical reality.

Team Description by Skill

The ElectroOptimize team is composed by eight students with diverse engineering backgrounds, allowing the project to integrate technical, mathematical and managerial expertise:

- **Giacomo Oliviero, Marco Magnanini, Matteo Biadialetti** – Computer Engineering: provided strong programming and software skills, contributing to the design of APIs, data acquisition from energy markets and the implementation of algorithms.
- **Francesca Orlando** – Management Engineering: focused on competitor analysis and business-oriented aspects, linking technical progress with regulatory feasibility and market positioning.
- **Nicolò Toia, Marco Ronchetti, Lucio Antonio Rosi** – Mathematical Engineering: applied advanced modelling and optimization skills to the development of centralized and decentralized coordination strategies and to the formalization of bidding approaches.
- **Flavio Bordin** – Aerospace Engineering: brought systems engineering expertise and supported the development of robust architectures, bridging algorithmic design with overall system reliability.

The project was organized into two main sub-teams. The **Algorithms team** (Marco M., Marco R., Lucio, Flavio) concentrated on designing and testing centralized and decentralized coordination architectures, ensuring computational scalability and stability. The **Energy Markets team** (Nicolò, Matteo, later joined by Giacomo and Francesca) focused on regulatory analysis and the implementation of bidding strategies. Francesca provided input on market analysis, while Giacomo enabled data collection to support algorithm design.

This division allowed each group to specialize in its own domain. The multidisciplinary combination of coding, optimization, market analysis and system engineering ensured that the final outcomes were both technically robust and aligned with regulatory and business requirements.

Goal

The goal of ElectroOptimize was to investigate how fleets of electric vehicles (EV) can be aggregated into Virtual Power Plants, enabling them to provide balancing services to the electricity grid while preserving their primary mobility function. The increasing share of renewable generation creates variability in electricity supply and idle EV batteries represent an opportunity to address this challenge.

To achieve this, the team set four main objectives: (i) quantify the flexibility that EV fleets can safely provide to the market, taking into account mobility and emergency constraints; (ii) design and test coordination strategies to align predicted flexibility with actual performance, comparing centralized and decentralized approaches; (iii) develop a bidding strategy that embeds penalties for non-delivery directly into the optimization process, ensuring both profitability and reliability under the Italian TIDE regulation; (iv) benchmark existing VPP solutions and regulatory frameworks across Europe to inform business models and go-to-market strategies.

Understanding the Problem

To ensure electric grid stability, supply and demand must be kept in perfect balance at every moment. This has become increasingly challenging with the rise of renewable energy sources. Solar and wind power, while essential for decarbonization, are unpredictable and variable, leading to frequency deviations, congestion and costly reliance on backup systems.

Traditional energy storage systems are costly and resource-intensive, thus struggle to cope with this ever-increasing instability. As this situation worsen, grid operators need more flexible, fast-acting resources to maintain grid stability and make the energy transition sustainable.

Exploring the opportunities

At the backbone of grid stability is the ancillary service market. Traditionally supplied by large power plants, these services consist in the ability to take fast-response energy actions to balance the grid. Due to the intrinsic difficulty for traditional plants to provide these services, they are an ideal entry point for agile energy storage systems.

At the same time, the widespread use of EVs present a unique opportunity: although primarily used for mobility, they spend most of their time parked, with batteries ready to store or release energy. Aggregating these idle EVs into a unified system, namely a virtual power plant, makes them behave like a single large power station, supplying or absorbing power when needed. This allows us to provide Ancillary services locally and in near real time, supporting renewable energy integration while creating economic incentives for fleet operators and EV owners.

Generating a Solution

To turn this vision into practice, the project developed both algorithmic and market-oriented solutions.

On the technical side, we designed a control model to determine when EVs can safely provide flexibility, ensuring user mobility is never compromised. Two coordination strategies were tested: a centralized optimizer, effective for small fleets but limited in scalability, and a decentralized approach, which partitions vehicles and enables parallel decision-making, proving robust for tens of thousands of EVs.

On the market side, we proposed a penalty-aware bidding strategy tailored to the TIDE framework. Unlike traditional approaches, penalties for non-delivery are embedded directly into the optimization, balancing profitability with reliability. Finally, APIs were developed to ensure interoperability with partner platforms, supporting real-world integration.

Together, these components form a scalable and reliable framework that allows EV fleets to participate in balancing markets, unlocking new revenue streams for operators, enabling greater renewable integration and strengthening grid resilience.

Main References

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