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WORKING PAPER 2026-8

NOVEMBER 2026

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Five Vehicle-to-Grid (V2G) Programs Compared: Business Models, Policy, and Allocation of Benefits

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November 13, 2026

Abstract

Consumer-oriented vehicle-to-grid (V2G) services are moving from pilot projects to commercial deployment, yet their success depends on how business models allocate costs and revenues between electric vehicle (EV) owners and aggregators. This paper evaluates five commercial V2G offers in France, Germany, the Netherlands, and the United Kingdom by combining an incentive-compatibility framework with simulations of 200 EVs over January–June 2025. We compare EV-owner electricity bills, aggregator profits, and two policy scenarios: net metering and retailer–aggregator separation. The results show that V2G can substantially reduce EV-owner bills, but only when business models either limit fees for battery discharging, make V2G cycles less frequent, or compensate consumers for its associated costs. If high arbitrage margins are required (trading only when the gap from low to high price is large), average EV-owner bills fall by 50% compared to an unmanaged-charging baseline. In contrast, low-margin arbittrage can increase charging volumes, thus taxes and network charges, leading to higher EV-owner bills despite greater aggregator profits. Regarding policy choices, we find that net metering can unlock the potential of V2G for intertemporal energy storage by reducing the market price spreads required for profitable arbitrage, while retailer-aggregator separation can improve consumer outcomes when dispatch decisions internalize retail revenues. These findings highlight the importance of designing V2G policies jointly with commercial contracts, as the value delivered to consumers depends not only on energy market revenues but also on how the costs and benefits of battery cycling are allocated.

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Keywords: Vehicle-to-grid (V2G), electric vehicles, retailer–aggregator business models, value allocation, electricity-market arbitrage, distributed energy resources, energy storage
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1 Introduction

Vehicle-to-Grid(V2G) is a socio-technical system that enables the controlled charging of electric vehicles (EVs), and the discharge of stored energy from the battery back into the electricity grid (Kempton & Tomić, 2005; Lund & Kempton, 2008). In order to manage charging and discharging to realize electricity market value, while assuring sufficient autonomy to meet upcoming driving needs, fleets of EVs are generally managed as a virtual power plant (VPP), rather than each EV doing V2G independently. While V2G has long been demonstrated in pilots and fleet applications, recent commercial offers now target private EV owners. This shift is important because household EVs represent a large potential source of distributed storage, but customer enrollment will presumably depends on whether VPPs offer V2G participation that creates value for consumers. In this paper, we refer to these emerging approaches as consumer-oriented V2G business models.

In the European region[1], the consumer-oriented V2G market is most developed to date, with five commercially operating business model examples. Yet, we find no published justification for the design of current business models, nor an analysis of how much each business model financially benefits the EV owner versus the VPP.

These business models exhibit three key characteristics that have not been considered in prior research. First, they typically rely on bundled offerings that combine electricity tariffs, charging infrastructure (EVSE), and V2G management services—the latter encompassing the optimization of charging and discharging strategies. Second, participation generally requires EV owners to invest in dedicated hardware compatible with a specific provider's ecosystem, and enrollment often requires switching electricity suppliers and tariffs. Third, they differ in their incentive structures: some compensate users per discharge event, others offer free or discounted charging, and others provide availability payments (e.g., for keeping the vehicle plugged in and ready to supply energy).

Among the main policy issues that have already received attention in the literature, the most notable is the problem of double taxation (Andersen & Powell, 2025; Hong et al., 2012; Signer et al., 2024), in which storage is taxed twice for each cycle; a consumption tax on charging, and a production charge on discharge of the same energy. Commpounding the penalty, those taxes repeat on each subsequent charge and discharge cycle. Other policy issues remain largely unexplored. For example, bundled offers may create consumer lock-in through switching costs associated with investments in proprietary charging infrastructure and technologies with limited interoperability. Likewise, information asymmetries between EV owners and service providers may generate incentive misalignment. In particular,

[1]European Union (EU) member states and the United Kingdom

service providers may have incentives to perform additional battery cycling when the resulting revenues are allocated primarily to them, while the associated battery degradation costs, energy, network costs and taxes might be borne by EV owners. At the current stage of V2G deployment, one of the principal challenges is ensuring that emerging business models generate sufficient value for EV owners to encourage participation (Kester et al., 2018; Sovacool & Hirsh, 2009), balanced with the need for VPPs to retain sufficient profit to survive and grow as a business (Parkison & Kempton, 2025). Therefore, understanding these incentive structures is essential for assessing which policy interventions facilitate an efficient V2G adoption. Accordingly, this paper addresses the following research question: *How do business model design and policy scenarios influence the value created for EV owners in V2G services?*

To answer this question, we first develop an analytical framework that formalizes the charge and discharge decisions as an optimization problem of both the integrated retailer–aggregator. Based on this framework, we derive a minimum incentive compatibility condition for battery cycling that identifies the alignment on the incentives of aggregators and EV owners to perform charge and discharge cycles. This condition provides a formal characterization of the potential moral hazard arising from information asymmetries in bundled V2G contracts. Second, we develop a simulation framework to evaluate alternative policy interventions: a net-metering scenario to address the double taxation of electricity used for V2G services, and an independent aggregator scenario designed to mitigate the incentive misalignment associated with vertically integrated retailer–aggregator business models. The simulation is calibrated using real mobility and electricity market data.

The paper makes at least three contributions. First, it documents and calibrates emerging consumer-oriented V2G offers in Europe using their contract characteristics, compatible hardware requirements and country-specific regulatory environments. Second, it combines an incentive-compatibility framework with simulation evidence to identify when integrated retailer–aggregator business models create misalignment between aggregator value and EV-owner value, and to quantify how much surplus could be reallocated through charging credits without substantially negating aggregator profit. Third, it quantifies how metering reform and retailer–aggregator separation affect EV-owner bills across the distribution of users, including the role of mobility heterogeneity, market-access constraints and imbalance exposure. The paper therefore contributes to the energy policy literature by showing that business-model design, metering rules and aggregator access cannot be evaluated independently: the same policy can have different consumer and commercial effects depending on the remuneration structure and dispatch incentives embedded in the business model.

The remainder of the paper presents the V2G offers, policy issues, our analytical and simulation framework, results, and policy implications.

2 Background: Sources of value in V2G

Consumer-oriented V2G creates value through three main channels: retail services, energy arbitrage, and network services.

In retail services, electricity providers procure electricity from wholesale markets and sell it to end consumers, including EV owners. They create value by assuming the price risk (and potential profit) associated with fluctuations in wholesale electricity markets—both intramarket and intraday—relative to the fixed or semi-fixed tariffs offered to end users. Intramarket refers to markets that clear at different lead times for the same delivery period (e.g., day-ahead, intraday, intraday continuous), while intraday captures price variations within the day, typically at 15- or 30-minute intervals. In conventional (non-V2G) business models, the retailer's primary source of revenue is the margin between wholesale procurement costs and the retail tariff charged to any load, with load variation historically considered uncontrolled. But an aggregator of V2G or any BTM storage can also shift the timing of that load based on price or anticipated price.

The second type of revenue stream, energy arbitrage, leverages the flexibility of EV batteries to dispatch charging and discharging over time in response to price signals. This arbitrage can occur in two distinct forms. Controlling charging and discharging to achieve customer bill savings, and remunerated by the customer bill–or actively participating in wholesale markets, with payments for the controlled amounts via a separate payment from the wholesale market.

Network services to transmission system operators (TSOs) or distribution system operators (DSOs) manage congestion provide an additional revenue stream by leveraging EVs' flexibility in response to network operators' signals. Unlike energy arbitrage, which is driven by price signals, these services are activated by a command signal from the network operator, based on system needs.

In the case of balancing services, the TSO issues signals to maintain and restore system-wide frequency deviations around the nominal level (50 Hz). In the European context, these markets are structured around four main products: Frequency Containment Reserve (FCR), automatic Frequency Restoration Reserve (aFRR), manual Frequency Restoration Reserve (mFRR), and Replacement Reserve (RR). Each service differs in activation speed and control mechanism, but all contribute to real-time system stability. Although market designs vary across countries, compensation schemes typically combine capacity payments (for availability) and energy payments (for actual energy transfer).

In contrast, congestion management services can also be coordinated by the DSO and operate at a local level. These services aim to alleviate network constraints—such as line overloads or voltage deviations—during periods of peak demand or high distributed generation. EV flexibility can be mobilized to shift or curtail charging, or even inject power back into the grid, thereby contributing to congestion relief within distribution networks. For a comprehensive overview of all the previously mentioned value streams, we refer to Thompson and Perez (2020), which provides a detailed framework for Vehicle-to-Everything (V2X) services.

Despite their potential, most V2G projects providing network services in Europe remain limited in scale. This is in part due to the stringent technical and operational requirements of these services, which demand high reliability, robustness, and predictability. As a result, such applications have primarily been tested in controlled environments—such as private or commercial fleets—where system operators can better manage uncertainty. However, these conditions are not easily transferable to large-scale, customer-oriented V2G applications, where user behavior introduces additional variability.

We note, for comparison, that EU markets are structurally different from the variety of markets in North America. There, arbitrage is available in retail market primarily from distribution utilities which also perform the role of retail service, thus arbitrage that can be performed by an individual who would be credited on their retail DSO energy bill. Furthermore, in most of US wholesale markets, V2G can mainly generate revenue through ancillary services and providing assured capacity (TSO markets in Europe are called RTO markets in the US).

3 Consumer-Oriented V2G Offers in the EU and UK

We define consumer-oriented V2G offers as commercial services targeting private EV owners who primarily use their vehicles for household mobility. This differs from professional V2G offers designed around fleets, depots, or commercial vehicles with more predictable availability for V2G. We focus on the former because privately owned vehicles represent the largest segment of the vehicle fleet and, therefore, the largest potential resource for V2G services. Some estimates indicate that privately owned vehicles account for approximately 85% of the total vehicle fleet in Europe (Waas et al., 2023).

In what follows, we provide an overview of the existing consumer-oriented V2G offers at the time of writing this article, and the emerging features that each business model displays and a qualitative comparison. The dates and contractual attributes reported below are taken from the providers' public webpages and press releases available at the time of writing.

3.1 Commercially available consumer-oriented V2G Offers

To the best of our knowledge, five main consumer-oriented V2G business models are currently commercially available in Europe.

Mobilize Bidirectional (France). Mobilize launched its commercial bidirectional-charging service for private customers in France in 2024, alongside the Renault 5 E-Tech electric and the Mobilize PowerBox Verso. The offer is commercially available, although access remains conditional on compatible Renault Group vehicles, charging equipment and

an associated electricity contract.[2]

Octopus Power Pack (United Kingdom). Octopus Energy launched Power Pack on 15 February 2024 as a mass-market V2G tariff in the United Kingdom. The offer remains available as an add-on to an eligible household electricity tariff, although participation is restricted to compatible vehicle–charger combinations and was initially presented as a beta programme.[3]

E.ON / BMW (Germany). BMW and E.ON announced their commercial V2G programme for private customers on 10 September 2025. The complete package—comprising the BMW iX3, BMW Wallbox Professional, smart meter and E.ON V2G electricity and feed-in contracts—became available to order on 9 February 2026 and has been commercially available since March 2026.[4]

Octopus–Ford PowerDrive (Germany). Octopus Energy and Ford announced their German residential V2G programme on 9 February 2026, with commercial activation promised for summer 2026. At the time of writing, eligible customers can register their interest and obtain an offer, but Octopus continues to describe full tariff availability as forthcoming. The initial programme is restricted to compatible 2026 Ford Capri and Explorer models and the Ambibox bidirectional wallbox.[5]

Hegg Energy / We Drive Solar / Renault (Netherlands). Renault Group and We Drive Solar announced the first large-scale Dutch V2G service for private EV owners, in collaboration with Hegg Energy, on 27 November 2025. Consumer onboarding and operational support were rolled out during 2026. The service is now offered to eligible Renault and Alpine owners using a We Drive Solar bidirectional charging point and a Hegg dynamic electricity contract.[6]

3.2 Bundling conditions of existing V2G offers

A common characteristic of the offers are that they all have a bundling condition, which refer to the contractual arrangements that an EV owner must accept in order to access the V2G service. In particular, these conditions are expressed in two types of arrangements that the EV owner is required to accept for participating on the V2G business modes: have an integrated retail-aggregator and specific hardware requirements which we describe below.

[2]Source: Mobilize bidirectional-charging webpage.
[3]Source: Octopus Power Pack webpage.
[4]Source: BMW Group press release on the E.ON/BMW V2G offer.
[5]Source: Octopus–Ford PowerDrive webpage.
[6]Source: Hegg bidirectional-charging webpage.

3.2.1 Integrated Retail–Aggregator.

All the commercial offers analysed bundle electricity retail services with V2G aggregation. Therefore, EV owners wishing to participate must switch their household electricity contract to the tariff offered by the V2G provider while simultaneously granting that same actor control over the charging and discharging of their vehicle. We refer to this arrangement as an integrated retail–aggregator, whereby a single actor combines the roles of electricity retailer and V2G aggregator.

This integrated arrangement differs from other centralized control architectures (Guille & Gross, 2009), in which electricity retail and aggregation are performed by separate actors. For example, charging and discharging decisions may be delegated to an independent aggregator, a distribution system operator, or a home energy management system. It also differs from decentralized control arrangements, in which EV owners retain charging and discharging decisions and respond directly to market price signals without the intervention of an aggregator.

3.2.2 Specific hardware investments.

Participation also requires investment in a set of compatible hardware required for V2G. Across all commercial offers, this consists of two essential components: (i) a bidirectional EVSE and (ii) a V2G-compatible EV. In all cases, compatibility is restricted to specific vehicle and charger combinations, which are summarized in Table 1.

3.3 Differences on V2G offers

While the bundling conditions described above are common across current consumer-oriented V2G offers, the incentive structures differ considerably. From the perspective of both EV owners and policy makers, four dimensions are particularly relevant because they directly determine the costs and benefits of participating in a V2G service: (i) tariffs for charging energy, (ii) discharge remuneration, (iii) non-discharge remuneration, and (iv) minimum connection requirements.

Charging energy tariffs. Charging tariffs determine the price paid for each kWh used to charge the EV. As Table 1 shows, offers differ not only in price level but also in structure, ranging from fixed tariffs to free charging, to dynamic pricing.

Discharge remuneration Discharge remuneration is the payment received for electric energy exported from the EV.

Discharge credits. Discharge credits are bill credits that allow the EV owner to recover, fully or partially, the cost of recharging energy previously discharged from the battery. They can compensate for the absence of explicit per-kWh discharge remuneration, but their incentive effect depends on whether they cover only the energy component or also taxes and network charges.

Non-discharge remuneration. Non-discharge remuneration includes availability payments, connection bonuses, and lump-sum transfers. These payments may compensate EV owners for participation or connection time, but they do not necessarily align the marginal incentive to discharge and recharge the battery.

Availability remuneration. Availability remuneration compensates EV owners for keeping their vehicles connected and available for V2G operation, rather than for the quantity of energy exchanged. Payments are generally based on the duration of connection and may depend on the timing of availability or compliance with operational requirements.

Lump-sum remuneration. Some business models provide a one-time payment to encourage participation or offset the costs associated with installing compatible charging infrastructure. For example, the E.ON/BMW offer includes an upfront payment to participating customers. An up-front lump sum payment is also a common form of government subsidy for V2G or other storage, e.g. from some US states.

Minimum connection requirements. V2G offers can require EV owners to keep their vehicles connected to the grid for a minimum period to ensure that the aggregator can rely on sufficient vehicle availability so that flexibility can be delivered.

Table 1: Comparison of Vehicle-to-Grid (V2G) Commercial Offers in Europe

Feature	**Mobilize (FR)**	**Octopus (UK)**	**Octopus–Ford (DE)**	**E.ON / BMW (DE)**	**Hegg (NL)**
Integrated retail–aggregator	Yes	Yes	Yes	Yes	Yes
Compatible EV and charger	Renault EVs + Mobilize PowerBox Verso (11 kW AC)	BYD Dolphin + Zaptec Pro, or Nissan/Mitsubishi models + Wallbox Quasar V1	Ford Explorer/Capri + Ambibox wallbox (11 kW AC)	BMW iX3 + BMW Wallbox Professional (11 kW DC)	Renault 5/4 or Alpine A290 + Solar Life wallbox (7.4 kW AC)
Charging energy tariff	€0.121/kWh	Free charging[a]	€0.15/kWh	€0.1991/kWh	Market price + €0.007/kWh
Discharge remuneration	–	–	–[b]	€0.353/kWh	Market price – €0.007/kWh
Availability remuneration	€0.016/15 min	–	€30/month[c]	€0.06/15 min[d]	–
Lump-sum remuneration	–	–	–	€700[e]	–
Minimum connection requirement	No requirement	12 h/day, 20 days/month	300 h/month	No minimum[d]	No requirement

[a] Capped at 210 kWh/month.
[b] No separate per-kWh export tariff is modelled; remuneration is captured through the monthly connection bonus.
[c] Paid only if the EV is connected for at least 300 h/month.
[d] Capped at €60/month, equivalent to 1,000 connected 15-minute intervals; no minimum connection threshold is imposed.
[e] One-off equipment contribution; excluded from recurring monthly bills.

4 Policy Issues for EV Owners in Emerging V2G Business Models

Two policy issues are central for EV owners in consumer-oriented V2G: repeated volumetric charges on electricity temporarily stored in the EV, and moral hazard arising from the bundle nature of current offers.

4.1 Double Taxation

Double taxation arises when electricity used for V2G is treated both as final consumption when drawn from the grid to charge the EV and as newly generated electricity when discharged back to the grid. Taxes, levies, and network charges may therefore be applied repeatedly to electricity that is temporarily stored and later recharged rather than finally consumed. This matters because the energy component is only one part of the EV-owner charging cost; regulated charges can affect the profitability of each discharge–recharge cycle. Table 2 summarizes the relevant country-specific charges.

Table 2: Comparison of regulatory frameworks for customer-oriented V2G

Policy dimension	**France**	**Germany**	**Netherlands**	**United Kingdom**
Network charges				
Charging imports	Time-of-use[a] €0.011–€0.161/kWh	Flat volumetric[b] €0.047/kWh	No volumetric charge	Time-of-use €0.001–€0.072/kWh
Discharging exports	Export credit during peak period –€0.054/kWh	Not remunerated	No network charge	Not remunerated
Taxes				
VAT	20%	19%	21%	5%
Other volumetric taxes	€0.025/kWh	€0.064/kWh	€0.102/kWh	€0.030/kWh
Billing				
Billing method	Net billing	Net billing	Net metering	Net billing

[a] Mobilize benefits from a regulatory derogation (CRE Deliberation No. 2024-136) allowing a dedicated V2G network tariff, including an export credit during the evening peak period.

[b] The Germany calibration uses the Bayernwerk low-voltage standard-load-profile working price for 2026: 4.72 ct/kWh net. A lower controllable-consumption tariff exists under Section 14a EnWG, but is not used in the main household billing calibration.

Network Charges Network charges determine the cost of using the electricity grid for both imports and exports. In the context of V2G, these charges may apply when the EV battery is charged from the grid and again when electricity is discharged back to the grid. Depending on the regulatory framework, network tariffs may be fixed, volumetric, time-varying, or waived for storage-related electricity flows (in whole or in part).

Taxes and Levies Taxes and levies include value-added tax (VAT), electricity excise taxes, and other social or environmental charges applied to electricity consumption. These charges are typically designed for final electricity consumption.

4.2 EV owner's exposure to moral hazard

While the prevalence of bundling in business models for emerging technologies can largely be explained by its ability to reduce adoption barriers—by simplifying consumer decision-making through integrated product and service offerings (Plananska & Gamma, 2022; Priessner & Hampl, 2020; Stremersch & Tellis, 2002)—bundling may also create incentives for anticompetitive behavior and influence how value is distributed among market participants (Dansby & Conrad, 1984; De Cornière & Taylor, 2024; Nalebuff, 2005). In the context of V2G, bundling electricity retail contracts with mobility and flexibility services might create a moral hazard.

Moral hazard arises when one party (the principal) delegates decision-making authority to another (the agent) whose actions are imperfectly observable, thereby creating incentives for the agent to pursue its own interests rather than those of the principal (Holmström, 1979). In customer-oriented V2G business models, EV owners delegate charging, discharging, and electricity market participation decisions to aggregators while having limited ability to observe or verify these decisions. As a result, aggregators may possess incentives to maximize their own profits in ways that are not fully aligned with the welfare of EV owners.

Three characteristics of current V2G business models are particularly relevant in this regard.

First, aggregators possess more information than EV owners regarding electricity market conditions, flexibility revenues, and operational decisions. The asymmetry of information is not necessarily undesirable because one of the principal functions of an aggregator is precisely to reduce the monitoring and cognitive costs that individual EV owners would otherwise incur when participating in electricity markets. Information asymmetry becomes problematic when combined with limited transparency and switching costs. Under these conditions, EV owners may be unable to verify whether charging and discharging decisions maximize their own welfare or primarily the profits of the aggregator, creating the conditions for moral hazard.

Second, the charging and discharging strategies selected by aggregators may influence battery degradation, consequently reducing the long-term value of the EV (Thompson, 2018; Uddin et al., 2017). If EV owners cannot directly observe or verify the optimization strategy implemented by the aggregator, they may be unable to determine whether battery

cycling appropriately balances the revenues that they are receiving against degradation costs. Consequently, aggregators may have incentives to implement charging strategies that maximize their own revenues even when these strategies impose higher long-term degradation costs on EV owners. If these degradation costs are neither transparently measured nor adequately compensateds to the EV owner, aggregators may capture a disproportionate share of the value created through V2G while EV owners bear a larger share of the long-term costs.

Third, switching costs associated with proprietary charging infrastructure and bundled service contracts reduce the ability of EV owners to change providers if contractual arrangements become unfavourable. Switching costs have been suggested as a market imperfection reinforcing the problem of information asymmetry and creating moral hazard (Baron & Besanko, 1987; Salman, 2023; Steinle et al., 2014). In the context of V2G, switching costs limit the ability of EV owners to change V2G providers when contractual arrangements become unfavourable, thus weakening the competitive pressure that would otherwise discipline V2G service providers. That is, even if EV owners suspect that another provider offers more favourable remuneration or battery management strategies, the costs of switching may outweigh the expected benefits, effectively locking consumers into existing contractual relationships. Consequently, switching costs amplify the effects of information asymmetry by imparing EV owners' ability to choose the most competitive aggregator.

5 Analytical framework

We model incentive alignment through a minimum incentive-compatible condition (Fahrioglu & Alvarado, 2000; McAfee & McMillan, 1988; Myerson, 2008): an additional discharge–recharge cycle should not make the EV owner worse off before considering any broader contractual compensation.

5.1 Model setup

We consider an integrated V2G retailer–aggregator that earns revenue from retail electricity services and energy arbitrage through the management of an EV. To simplify modeling of electricity flow and storage, we model only the electricity flowing through the EV battery, excluding household electricity consumption. Furthermore, the metering point is located at the EVSE, allowing EV charging and discharging flows to be measured separately from household demand (if household demand were added to the model). Together, these assumptions enable us to isolate the value-allocation dynamics associated with the addition of V2G in a simplified setting.

The model is defined over periods $t \in \mathcal{T}$, EVs $n \in \mathcal{N}$, and electricity markets $m \in \mathcal{M}$. Sequential market participation allows the aggregator to update financial positions before physical delivery.

Electricity markets differ in their bidding deadlines and gate-closure times. As a result, the integrated-aggregator may progressively update its financial position as new

information becomes available before physical delivery. For a given delivery period t, the integrated-aggregator may therefore hold simultaneous positions in several markets, such as day-ahead, intraday auction, and continuous intraday markets. Let $q_{t,m}$ denote the net energy position traded in market m for delivery during period t, where $q_{t,m} > 0$ represents a sale of energy to the market and $q_{t,m} < 0$ represents a purchase of energy from the market.

Although financial positions are taken sequentially across markets, to not create costly imbalances for the electricity system they must ultimately be matched by physical energy exchanges with the EV fleet. Let $x_{t,n} \in \mathbb{R}_+$ and $y_{t,n} \in \mathbb{R}_+$ denote, respectively, the charging and discharging power of EV n during period t, expressed in kW at the EVSE level. The charging and discharging efficiencies between the EV battery and the EVSE, containing the metering point, are denoted by η_c and η_d, respectively. The financial-physical balance condition is therefore given by:

$$\sum_{m \in \mathcal{M}} q_{t,m} = \sum_{n \in \mathcal{N}} \left(\eta_d y_{t,n} - \frac{x_{t,n}}{\eta_c} \right) \Delta t, \quad \forall t \in \mathcal{T}. \tag{1}$$

This constraint links financial market positions to the net physical energy delivered by the EV fleet. The charging and discharging decisions also determine the physical state-of-charge evolution of each battery. Let $soc_{t,n} \in [0, E_n]$ denote the state of charge of EV n at time t, expressed in kWh. Where E_n is the battery capacity in kWh. The SOC evolves according to:

$$soc_{t+1,n} = soc_{t,n} + (\eta_c x_{t,n} - \frac{y_{t,n}}{\eta_d})\Delta t - kwh_{driving,t,n}, \quad \forall t, n. \tag{2}$$

The integrated-aggregator's problem can therefore be expressed in terms of physical charging and discharging decisions that maximizes expected profit from wholesale market trading and contractual payments exchanged with EV owners:

$$\max_{\{x_{t,n}, y_{t,n}\}} \sum_{t \in \mathcal{T}} \left[\sum_{m \in \mathcal{M}} \mathbb{E}[p_{t,m}] q_{t,m} + \sum_{n \in \mathcal{N}} \left(\pi_t \frac{x_{t,n}}{\eta_c} \Delta t - \rho_t \eta_d y_{t,n} \Delta t - \gamma_t a_{t,n} - F_{t,n} \right) \right], \tag{3}$$

subject to:

$$\underline{s}_{t,n} \leq soc_{t,n} \leq 1 \quad \forall t, n, \tag{4}$$

$$0 \leq x_{t,n} \leq \overline{x}_{t,n} \quad \forall t, n, \tag{5}$$

$$0 \leq y_{t,n} \leq \overline{y}_{t,n} \quad \forall t, n. \tag{6}$$

In this expression, $\mathbb{E}[p_{t,m}]$ denotes the expected wholesale price in market m for delivery period t. The parameters π_t and ρ_t denote the contractual volumetric tariffs applied to EV charging and discharging, respectively. These tariffs are specified ex ante in the service agreement between the EV owner and the Integrated-Aggregator and determine the price paid by the EV owner for charging and the remuneration received for discharging. They are independent of wholesale market prices and may differ across business models.

The variable $a_{t,n} \in \{0,1\}$ denotes the availability of EV n during period t, taking the value 1 if the vehicle is connected and 0 otherwise. The parameter γ_t denotes the contractual remuneration for vehicle availability, while $F_{t,n}$ represents any direct monetary transfer from the Integrated-Aggregator to the EV owner.

The lower bound $\underline{s}_{t,n}$ captures minimum energy requirements, including mobility needs, while $\overline{x}_{t,n}$ and $\overline{y}_{t,n}$ denote the maximum charging and discharging power capacities of the EVSE. Given the SOC constraints, the feasible charging and discharging bounds at each time step are:

$$x_{t,n}^{\max} = \min\left\{\overline{x}_{t,n},\ \frac{(1 - soc_{t,n})}{\eta_c \Delta t}\right\}, \tag{7}$$

$$y_{t,n}^{\max} = \min\left\{\overline{y}_{t,n},\ \frac{(soc_{t,n} - \underline{s}_{t,n})\eta_d}{\Delta t}\right\}. \tag{8}$$

5.2 EV owner's monthly electricity bill

Let π_t and ρ_t denote the contractual energy tariffs applied to charging and discharging, respectively. To accommodate the different billing approaches with and without net-metering, let $\mathcal{R}(\cdot)$ denote the monthly billing function that determines the network charges and taxes applied to the EV owner's energy exchanges with the grid.

The monthly electricity bill of EV owner n is therefore given by

$$B_n = \sum_{t \in \mathcal{T}} \left(\pi_t \frac{x_{t,n}}{\eta_c}\Delta t - \rho_t \eta_d y_{t,n}\Delta t - \gamma_t a_{t,n}\right) + \mathcal{R}(\{x_{t,n}, y_{t,n}\}_{t\in\mathcal{T}}) - F_n, \tag{9}$$

where γ_t denotes the contractual remuneration for vehicle availability and F_n represents any fixed monthly transfer or subscription rebate paid by the Aggregator.

In particular, For billing systems without net-metering,

$$\mathcal{R} = \sum_{t \in \mathcal{T}} \left(\lambda_t^c \frac{x_{t,n}}{\eta_c}\Delta t - \lambda_t^d \eta_d y_{t,n}\Delta t + \kappa_t^c \frac{x_{t,n}}{\eta_c}\Delta t - \kappa_t^d \eta_d y_{t,n}\Delta t\right), \tag{10}$$

where λ_t^d and λ_t^d denote network charges applied to electricity withdrawals and injections, respectively, while κ_t^c and κ_t^d represent the corresponding taxes.

For billing systems based on monthly net-metering, the same network charges and taxes are applied, but on the net monthly energy exchange rather than separately to electricity withdrawals and injections. Accordingly,

$$\mathcal{R}^* = \sum_{t \in \mathcal{T}} (\lambda_t^c + \kappa_t^c)\left(\frac{x_{t,n}}{\eta_c} - \eta_d y_{t,n}\right)\Delta t. \tag{11}$$

5.3 Incentive-compatibility constraint

The incentive-compatible condition evaluates whether an additional discharge–recharge cycle is financially neutral or beneficial for the EV owner. Thus, if one assume, that an additional unit of V2G discharging must be replenished through a later charging event, the resulting marginal bill variation of a discharge from the EV owner perspective is therefore

$$-\frac{\partial B_n}{\partial y_{t,n}} = \widetilde{\delta}_t \eta_d \Delta t - \widetilde{\tau}_{t'} \frac{1}{\eta_c} \Delta t, \tag{12}$$

Here, $\widetilde{\delta}$ is the effective discharge remuneration and $\widetilde{\tau}$ is the effective recharge cost, including applicable tariffs, taxes, and network charges. If battery degradation is non-negative, a necessary condition for incentive compatibility is that the financial margin of the cycle is non-negative before degradation is considered.

If one assumes that an additional discharge-charge cycle might impose an additional (non-negative) cost on the EV owner from battery degradation, a minimum condition for incentive compatibility is obtained by assuming the extreme case of zero marginal degradation cost. Under this considers, a minimum incentive-compatible V2G contract must at least guarantee that the net marginal bill variation associated with one discharge-recharge cycle complies with the following condition:

$$\widetilde{\delta}_t \eta_d \Delta t - \widetilde{\tau}_{t'} \frac{1}{\eta_c} \Delta t \geq 0, \quad \forall t, n. \tag{13}$$

Any positive marginal battery degradation cost further strengthens this condition.

5.4 Calibration of the minimum incentive-compatible condition

We now calibrate the minimum incentive-compatible condition derived in the previous subsection using the contractual tariff structures of the V2G business models presented in Table 1 and the network tariffs and taxes presented in Table 2.

For each business model, we compute the minimum incentive-compatibility margin as

$$IC = \widetilde{\delta} \eta_d - \frac{\widetilde{\tau}}{\eta_c}, \tag{14}$$

Throughout the calibration, we use the following assumptions for the charging and discharging efficiencies $\eta_c = 0.92$ and $\eta_d = 0.77$ (Apostolaki-Iosifidou et al., 2017).

A positive value of IC indicates that the marginal discharge–recharge cycle is financially beneficial for the EV owner before battery degradation. A negative value means that additional contractual compensation, lower cycling, or recharge-cost credits are required.

Table 3 shows that Hegg is the only business model that can satisfy this minimum condition under the calibrated tariffs, because both charging and discharging are indexed to market prices and Dutch net metering eliminates repeated volumetric charges. In the other business models, marginal recharge costs exceed marginal discharge benefits, either because discharge remuneration is low or absent, or because taxes and network charges are added to the EV owner bill.

In contrast for the other four business models, the effective marginal cost of charging is higher than the effective marginal benefit of discharging. This is partly due to low or non-existent discharge remuneration, efficiency losses and also due to regulated volumetric

charges: for example, the Octopus UK offer has a zero contractual energy tariff, but the IC margin becomes negative once network charges and taxes are included.

This finding is calculated from only one factor, and thus does not imply that the other business models fail to create value for EV owners. It simply shows that the fees for charging are greater than the credits for discharging, that is, the discharge–recharge cycles alone are not beneficial for the EV owner. The overall attractiveness of a V2G contract therefore depends on additional remuneration mechanisms: those could include retail tariffs better than for non-V2G customers or availability payments, as well as on the charging and discharging strategy implemented by the integrated retailer–aggregator.

Table 3: Calibration of the minimum incentive-compatible condition

Business model	**Effective charging** $\widetilde{\tau}$	**Effective discharge** $\widetilde{\delta}$	**IC margin** $\widetilde{\delta}\eta_d - \widetilde{\tau}/\eta_c$
Mobilize (FR)	0.157–0.307	0–0.054	-0.334 to -0.129
Octopus (UK)	0.031–0.102	0	-0.111 to -0.034
Octopus–Ford (DE)	0.261	0	-0.284
E.ON / BMW (DE)	0.310	0.353	-0.065
Hegg (NL)	$p + 0.007$	$p + m - 0.007$	$0.770m - 0.317p - 0.013$[a]

Notes: Values are expressed in €/kWh and exclude VAT. The calibration assumes $\eta_c = 0.92$ and $\eta_d = 0.77$. The IC margin is computed as $\widetilde{\delta}\eta_d - \widetilde{\tau}/\eta_c$. For Mobilize, $\widetilde{\tau} = 0.121 + \lambda^c + 0.025$, with $\lambda^c \in [0.011, 0.161]$, and $\widetilde{\delta} = 0.054$ only during the export-credit period and zero otherwise. For Germany, $\widetilde{\tau}$ includes the charging energy tariff, the network tariff (€0.047/kWh), and other volumetric taxes (€0.064/kWh). Availability and connection bonuses are excluded because they are not marginal per-kWh incentives.For the UK, $\widetilde{\tau} = \lambda^c + 0.030$, with $\lambda^c \in [0.001, 0.072]$.

[a] The Hegg contract spread of €0.014/kWh is divided symmetrically around the market price: the charging tariff is $p + 0.007$ and the discharge tariff is $p + m - 0.007$. Requiring the IC margin to be non-negative gives

$$m \geq \frac{p + 0.007}{\eta_c \eta_d} - p + 0.007.$$

6 Simulation framework

Figure 1 presents the overall simulation framework, which is structured into four sequential modules. Module 1 simulates the EV mobility system, capturing driving behavior and the evolution of the battery SOC. Module 2 models the retailer–aggregator's forecast process on electricity market prices. Module 3 optimizes charging and discharging decisions based on these forecasts. This optimization module models alternative business model scenarios considered and the independent-aggregator policy scenario. Finally, Module 4 computes the electricity bills for EV owners and the profits of the aggregator.

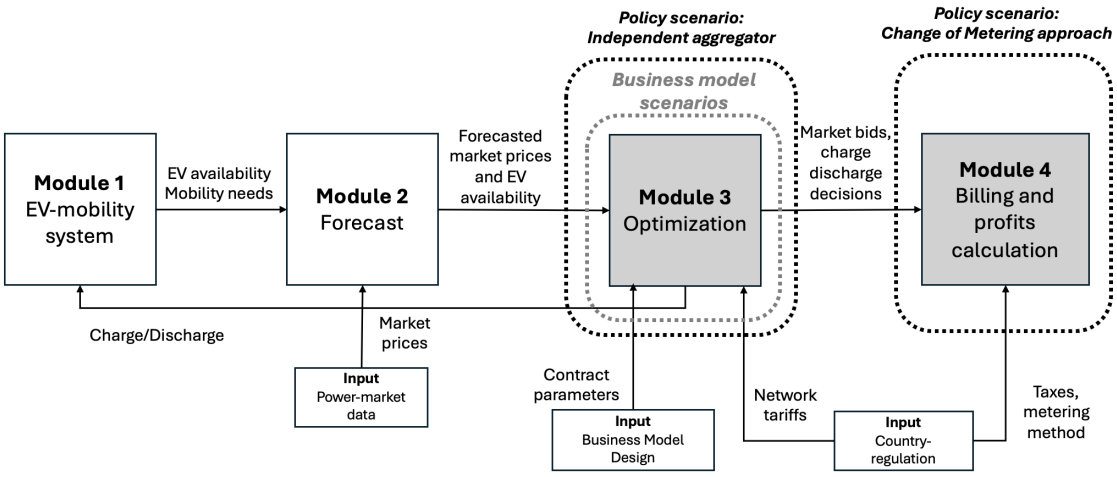


Figure 1: Simulation Framework

6.1 EV-mobility system module

The evolution of SOC dynamics follows equation 2; where the charge and discharge decisions are an outcome of the aggregator profit-maximization process which controls the EV, as stated in equation 3. The time-step of the simulation is 15-min to follow the actual market minimum granularity.

Mobility patterns, home-connection times, and EVSE availability are calibrated using the dataset from Gaete-Morales et al. (2021). The sample contains 200 EV users, allowing us to represent heterogeneity in kilometres driven, home-connection time, and daytime versus nighttime availability. Figure 2 summarizes these driver characteristics.

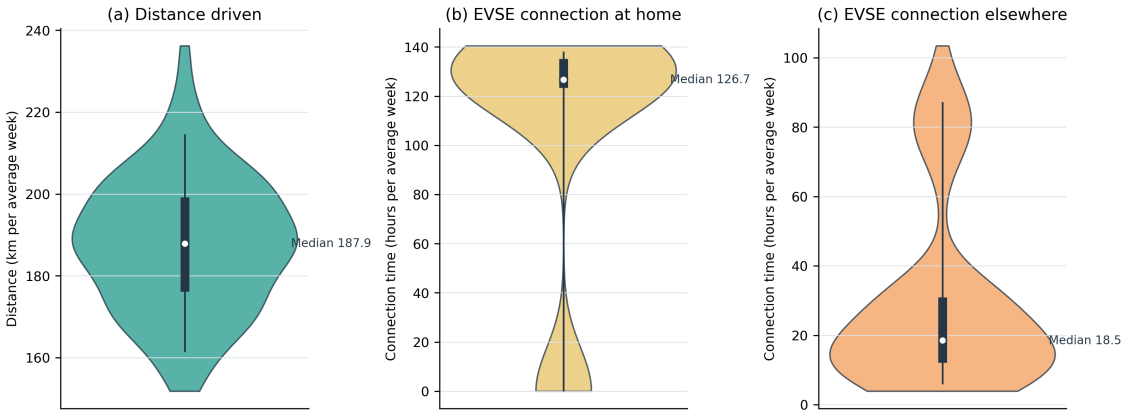


Figure 2: Distribution of EV driver-characteristics (data from Gaete-Morales et al., 2021).

We replace the default "home" charging configuration in the dataset of Gaete-Morales et al. (2021) with EV and EVSE characteristics that reflect the specifications of current market offers for V2G business models. Table 4 presents the battery size and EVSE capacity used in the simulation for each case. For the baseline scenario we assume that the EV owner has a standard electricity contract that does not consider controlled charge, as we will describe in more detail in module 4.

Table 4: EV and EVSE assumptions across business models

Business Model	EVSE Power - (Current)	Usable battery capacity (kWh)
Mobilize	11 kW (AC)	55
Octopus (UK)	11.5 kW (AC)	60.5
Octopus (DE)	11 kW (AC)	79
E.ON	7.4 kW (DC)	108.7
Hegg	11 kW (AC)	55
Baseline	7.4 kW (AC)	39

Table 5: Wholesale-market bidding sequence implemented in the simulation

Market	Decision time	First delivery	Lead time	Horizon	Time step
DA	12:00, $D-1$	00:00, D	12 h	24 h	15 min
IDA1	15:00, $D-1$	00:00, D	9 h	24 h	15 min
IDA2	22:00, $D-1$	00:00, D	2 h	24 h	15 min
IDA3	10:00, D	12:00, D	2 h	12 h	15 min
CID	Every 15 min	Next interval	15 min	15 min	15 min

Notes: D denotes the delivery day and auction times are CET/CEST. Lead times and horizons reproduce the values passed to the optimization. The IDA schedule and 0.1-MW volume increment follow the EPEX SPOT 2025 product description. A 0.1-MW position maintained for 15 minutes equals 25 kWh. Actual CID gate closure can vary by bidding-zone border; the simulation applies a common 15-minute lead time. Each market updates the position inherited from the preceding market. Unrounded EV-level positions are aggregated and rounded away from zero to the next 0.1-MW increment for the market-feasibility profit calculation.
Sources: EPEX SPOT, *Trading at EPEX SPOT*; CACM Annual Report 2024.

In addition, we use the same charging and discharging efficiency assumptions adopted in the calibration of the incentive-compatibility assessment in Section 5.4, based on the estimates proposed by Apostolaki-Iosifidou et al. (2017).

6.2 Power markets and price forecasts

Due to data availability, the market dataset covers a six-month period from January to June 2025. In France, Germany, and the Netherlands, the Aggregator can sequentially revise its market position across five trading stages: the day-ahead market (DA), three intraday auctions (IDA1–IDA3), and the continuous intraday market (CID). For the UK, only day-ahead market data are included due to data availability.

All market prices are represented on a common 15-minute time grid. EV resources are aggregated at the fleet level before market settlement and traded in increments of 0.1 MW, equivalent to 25 kWh over a 15-minute delivery interval. The complete calibration of market timing, lead times, optimization horizons, and data sources is reported in Tables 5 and 6.

For continental Europe, spot-market prices are obtained from EPEX SPOT, while upward and downward imbalance prices are obtained from the ENTSO-E Transparency

Table 6: Wholesale-price calibration and data coverage

Country	Area	Sources	Observed market series
France	FR	EPEX SPOT; ENTSO-E[a]	DA, IDA1, IDA2, IDA3, CID, and imbalance prices
Germany	DE–LU	EPEX SPOT; ENTSO-E[a]	DA, IDA1, IDA2, IDA3, CID, and imbalance prices
Netherlands	NL	EPEX SPOT; ENTSO-E[a]	DA, IDA1, IDA2, IDA3, CID, and imbalance prices
United Kingdom	GB	Nord Pool N2EX[b]	DA only; intraday fields are missing and imbalance fields are zero placeholders

[a] EPEX SPOT supplies spot-market observations. Upward and downward imbalance prices (`pBUP` and `pBDO`) are obtained from the ENTSO-E Transparency Platform, Article 17(1)(g).
[b] N2EX is a standalone GB day-ahead auction for delivery on $D+1$ and closes at 09:50 GMT/BST. See Nord Pool, About the N2EX Day Ahead Auction.
Notes: The calibration window is January–June 2025. Continental SDAC day-ahead prices had a 60-minute market time unit during this period; the 15-minute SDAC transition occurred on 1 October 2025. Source prices are divided by 1,000 for conversion from currency/MWh to currency/kWh. Hourly DA prices are repeated over four 15-minute intervals. Missing values are forward- and backward-filled; missing Dutch CID values use pIDA-N.

Platform for the corresponding balancing areas. Hourly day-ahead prices are repeated across the four corresponding 15-minute simulation intervals, whereas intraday prices retain their original temporal resolution. For the UK, day-ahead prices are obtained from Nord Pool.

Figures 3 summarize the observed price variation across markets and trading stages.

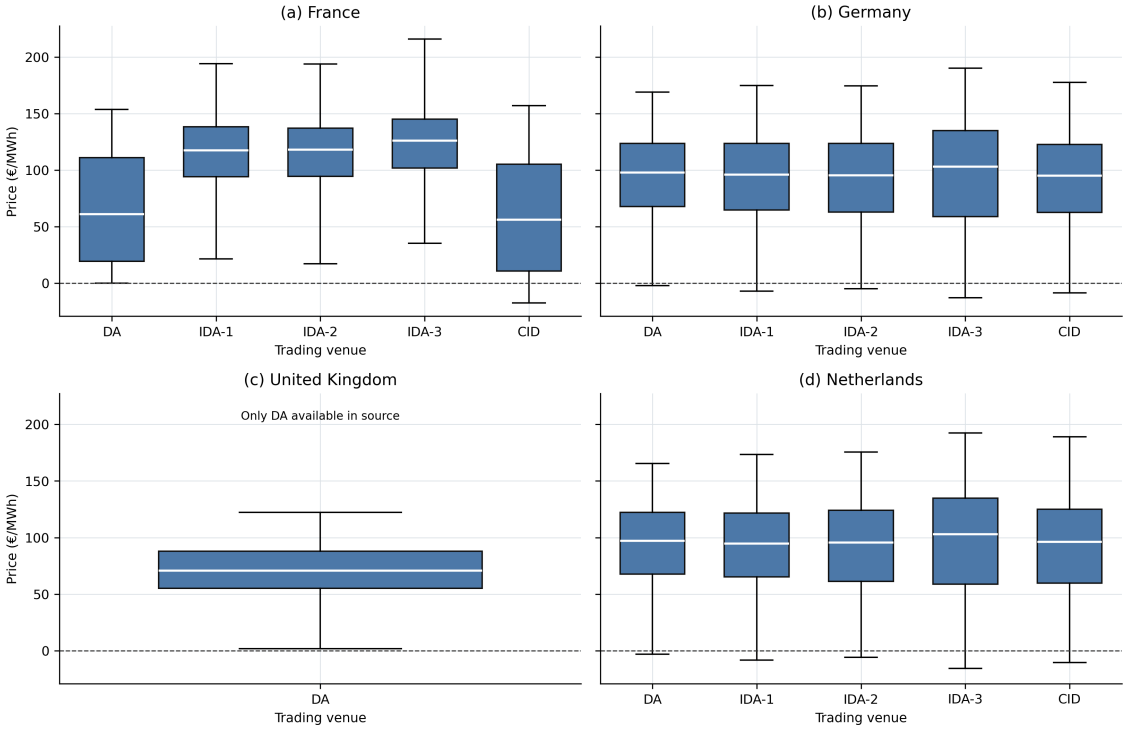


Figure 3: Wholesale spot-price distributions, January–June 2025.

After the final trading stage, any difference between the Aggregator's contracted market position and its realized physical delivery results in an imbalance. This deviation is settled at the applicable imbalance price, meaning that the Aggregator may either pay for or receive remuneration for the deviation depending on the direction of its imbalance and the corresponding settlement price. Figure 4 reports the observed distributions of upward and downward imbalance prices. While most of the imbalance prices are positive. The resulting cash flow depends on the direction and magnitude of the imbalance, and the state of the balancing system. For example, an EV fleet may be unable to match the minimum tradable bid size exactly, creating a gap between its market position and physical delivery. A deviation that supports system balancing may be remunerated, whereas one that aggravates the system imbalance may generate a cost, thereby reducing or even eliminating the Aggregator's arbitrage margin.

For the UK, the available dataset does not include the corresponding balancing-price series. We therefore exclude imbalance settlement from the UK market calibration.

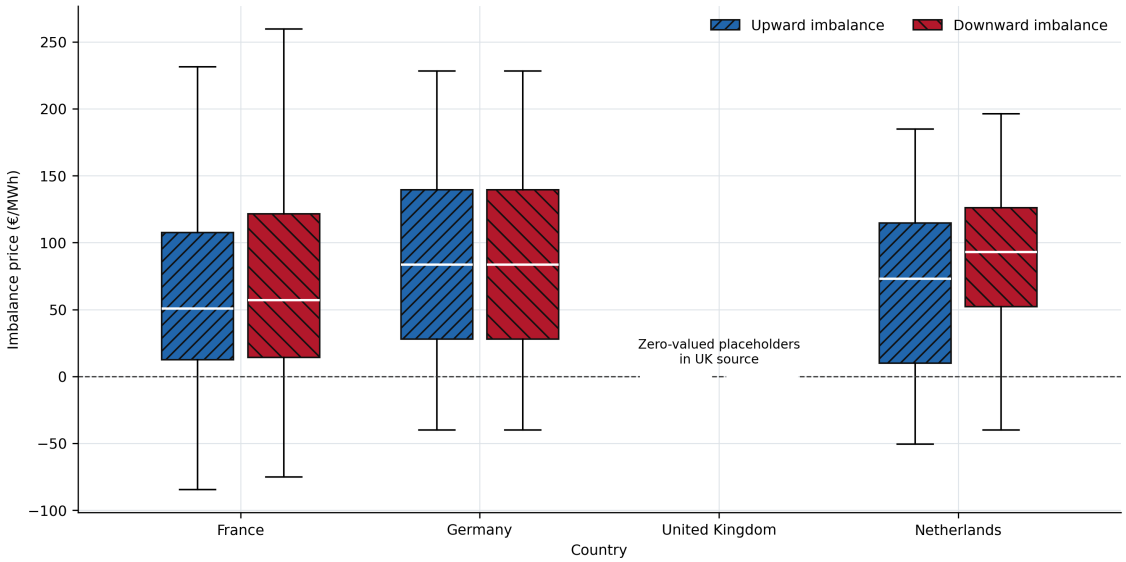


Figure 4: Upward and downward imbalance-price distributions, January–June 2025.

At each market event, the optimizer observes a noisy forecast of the relevant market price. Same-market forecasts equal the realized price plus a normally distributed error with standard deviation 5 currency/MWh. Forecasts of the next sequential market use a standard deviation of 10 currency/MWh. Errors are zero-mean, so forecasts are unbiased by construction. In contrast, mobility is treated as perfectly forecast: the aggregator knows each EV's connection status, driving-energy requirement, and next departure over the planning horizon. This assumption isolates contractual and regulatory incentives from mobility-forecast error.

6.3 Optimization module

Consistent with the decision framework in Section 5.1, at each market update k, the Aggregator solves a linear program over a 36-hour planning horizon to account for the lead-time on day-ahead markets. Where, optimal charging and discharging schedules are obtained using a rolling linear optimization solved with Gurobi at each market update. Because, markets are sequential the positions established in earlier markets can be adjusted as subsequent markets become available.

6.4 EV-owner bills and Aggregator profit

For each simulated EV-owner-month, the electricity bill follows the contractual structures summarized in Section 3. In addition, aggregator profitability is evaluated at three accounting levels to distinguish the effects of market granularity and imbalance exposure. First, Π^{cont} values the unrounded energy positions selected by the optimizer before minimum-volume restrictions are imposed. Second, Π^{25} rounds the aggregate market position away from zero to the next 25-kWh block, corresponding to a 0.1-MW minimum bid increment over a 15-minute product.

Third, realized profit includes imbalance settlement:

$$\Pi^{\text{imb}} = \Pi^{25} + R^{\text{imb}}, \tag{15}$$

where R^{imb} values the difference between the rounded market position and realized physical delivery using the corresponding upward or downward imbalance price.

6.5 Simulation scenarios

We consider three dimensions to perform several rounds of simulation-scenarios. First, a No-V2G benchmark against which EV-owner savings are measured. Second, each commercial V2G business model is evaluated under alternative optimization logics and minimum cycling margins. Third, we modify selected regulatory conditions to assess the sensitivity of the results to alternative policy designs.

No-V2G benchmark The no-V2G benchmark represents unmanaged charging under a standard national retail tariff: the EV charges at maximum available power whenever connected until the battery is full or the vehicle disconnects.

Business model design scenarios Because public offers do not reveal the providers' dispatch rules, these scenarios should be interpreted as sensibility analysis for the business-model designs. Each commercial V2G offer described in Section 3 is simulated under two unobserved business model responses: restricting cycling through a minimum arbitrage margin and reallocating surplus through discharge credits.

Table 7: Energy tariffs used for the no-V2G dumb-charging benchmark

Country	Retail provider	Retail tariff	Energy tariff €/kWh
France	EDF	Tariff Bleu – réglementaire	0.134
Germany	E.ON	ZukunftsStrom Home Charging	0.300
United Kingdom	Octopus	Fixed tariff	0.204
Netherlands	Vattenfall	Groen uit Nederland	0.198

Minimum cycling margin. The first scenario introduces a minimum arbitrage margin m that each charging–discharging cycle must satisfy before being scheduled. This is implemented by modifying the objective function in Equation 3 as

$$\max_{\{x_{t,n},y_{t,n}\}} \sum_{t\in\mathcal{T}} \left[\sum_{m\in\mathcal{M}} \mathbb{E}[p_{t,m}] q_{t,m} + \sum_{n\in\mathcal{N}} \left(\pi_t \frac{x_{t,n}}{\eta_c} \Delta t - (\rho_t + m)\eta_d y_{t,n} \Delta t - \gamma_t a_{t,n} - F_{t,n} \right) \right]. \tag{16}$$

Increasing m restricts cycling to periods with higher expected arbitrage value, reducing throughput and the EV owner's exposure to recharge costs, taxes, and network charges. We evaluate the simulation under the following minimum cycling margins of 0.10, 0.20, 0.30, and 0.40 €/kWh.

Discharge credits. The second scenario introduces a discharge credit that effectively reduces the recharge energy (in kWh) or cost otherwise billed to the EV owner. This credit could be accomplished by policy, for example, NEM, or by a payment drawn from the value captured from V2G operation. A partial credit can be calibrated as the minimum compensation needed to satisfy the incentive-compatible condition.

Let c_t denote the amount of per-kWh discharging credit to the customer. The effective charging cost faced by the EV owner becomes

$$\widetilde{\tau}_t^{\,c} = \max\{\widetilde{\tau}_t - c_t, 0\}.$$

The incentive-compatible condition is therefore modified to

$$\widetilde{\delta}_t \eta_d - \frac{\widetilde{\tau}_t^{\,c}}{\eta_c} \geq 0.$$

A full charging credit corresponds to $c_t = \widetilde{\tau}_t$, so that the EV owner does not bear any marginal recharging cost from V2G operation. Our partial credit case calculates the minimum compensation required to satisfy the incentive-compatible condition:

$$c_t \geq \widetilde{\tau}_t - \eta_c \eta_d \widetilde{\delta}_t.$$

This scenario considers that the integrated retailer–aggregator may apply the credit to

any charging undertaken by the EV owner as a mechanism for sharing the value generated by V2G operations. We evaluate a range of credit levels, from no credit to the maximum amount that can be transferred to the EV owner while leaving the Aggregator at its break-even point. The credit offsets the EV owner's charging costs, including energy costs, taxes, and network charges, and therefore measures how much V2G value can be redistributed without making the business model unprofitable.

6.5.1 Policy scenarios

Having evaluated the commercial business models under current market and regulatory conditions, we consider two policy dimensions that may affect the allocation of V2G value: the institutional separation of retail supply and aggregation, and the billing treatment of bidirectional electricity flows.

Retailer–bid minimization. In the retailer–bid minimization scenario, dispatch minimizes the EV-owner bill using the applicable charge and discharge tariffs, taxes, and network charges, rather than optimizing wholesale-market revenues.

Metering policy. Each V2G business model is also evaluated under net billing-tariff (NBT) and net metering or net energy metering (NEM)(California Public Utilities Commission, 2023). Under net billing-tariff, charging and discharging flows are settled separately, such that electricity withdrawn into the EV and subsequently injected into the grid may face separate charges and credits. Under net metering, the relevant consumption-based energy, tax, and network components are applied to net quantities over the billing period. This comparison captures how the billing treatment of storage cycles affects EV-owner bills and the allocation of value among EV owners, retailers, and aggregators.

7 Analysis

We organize the analysis of quantitateive results into four subsections. First, we examine EV-owner electricity bills under V2G relative to the unmanaged-charging (non-V2G) baseline for each country. Second, we analyse the same scenarios from the perspective of the integrated retail–aggregator. Third, we investigate the scope for ex-post value redistribution between EV owners and the integrated retail–aggregator by comparing outcomes with and without discharge credits. Finally, we assess the impact of the policy scenarios.

7.1 EV-owner bills under V2G

Figure 5 presents the distribution across the 200 simulated EV owners of the monthly electricity bills (€/EV-month) for each business model under different scenarios on the minimum arbitrage margin. A negative bill implies that the EV owner is credited that

amount for the month (that is, their V2G earnings were greater than their premises electric consumption cost).

The results highlights two main findings. First, when the minimum margin required by the retail–aggregator to perform energy arbitrage is low, as shown in the first V2G column of the figure, the operation generally increases battery cycling and leads to a wider distribution of outcomes. This effect is particularly pronounced for Mobilize and Octopus Energy Germany, where consumer remuneration relies primarily on charging conditions and availability payments rather than volumetric discharge remuneration. Second, as the minimum arbitrage margin increases, as shown in the columns to the right with higher margins, charging and discharging are restricted to periods with larger market-price spreads, reducing battery throughput and shifting the distribution of EV-owner bills downward across most business models. At the highest arbitrage margin, average bills relative to the corresponding country-specific unmanaged charging baseline by approximately 64 % for Mobilize, 65 % for E.ON/BMW, 66 % for Octopus Energy Germany, 54 % for Octopus Energy UK, and 38 % for g. In addition, the lower tails of several distributions extend below zero, indicating that a small number of EV owners receive a net credit or payment for participating in V2G.

Second, business models respond differently to changes in the minimum arbitrage margin depending on their remuneration structure. Hegg and Octopus Energy UK exhibit relatively small changes across margin scenarios because their consumer remuneration is directly linked to dynamic electricity prices or to zero retail charging costs. These pricing structures better align the incentives of EV owners with wholesale-market conditions, reducing the risk that additional battery cycling translates into higher consumer costs. In the case of Octopus Energy UK, the absence of charging-energy costs means that the remaining increase in EV-owner bills at low margins is driven primarily by taxes and network charges associated with additional charging, rather than by the retail electricity tariff itself.

Table 8 decomposes EV-owner bills into their main components: charging-energy costs, discharge remuneration, availability payments, monthly subscription charges, taxes, network costs, and charging throughput. The table show that the primary driver of differences across business models is the product of battery throughput and volumetric charging costs, particularly taxes and network charges. For Mobilize, increasing the minimum arbitrage margin from 0.1 to 0.4 €/kWh reduces monthly charging throughput from 1,132 to 168 kWh/EV. This reduction in battery cycling decreases taxes from 88 to 9 €/EV-month and network costs from 67 to 11 €/EV-month, while Mobilize's fixed availability payment of 36 €/EV-month remains unchanged. A similar mechanism is observed for Octopus Energy Germany. At a 0.1 €/kWh margin, intensive battery cycling results in taxes of 127 €/EV-month and network costs of 56 €/EV-month, leading to an average bill of 332 €/EV-month. Increasing the arbitrage margin substantially reduces battery throughput and the associated volumetric charges, lowering the average bill to 33 €/EV-month.

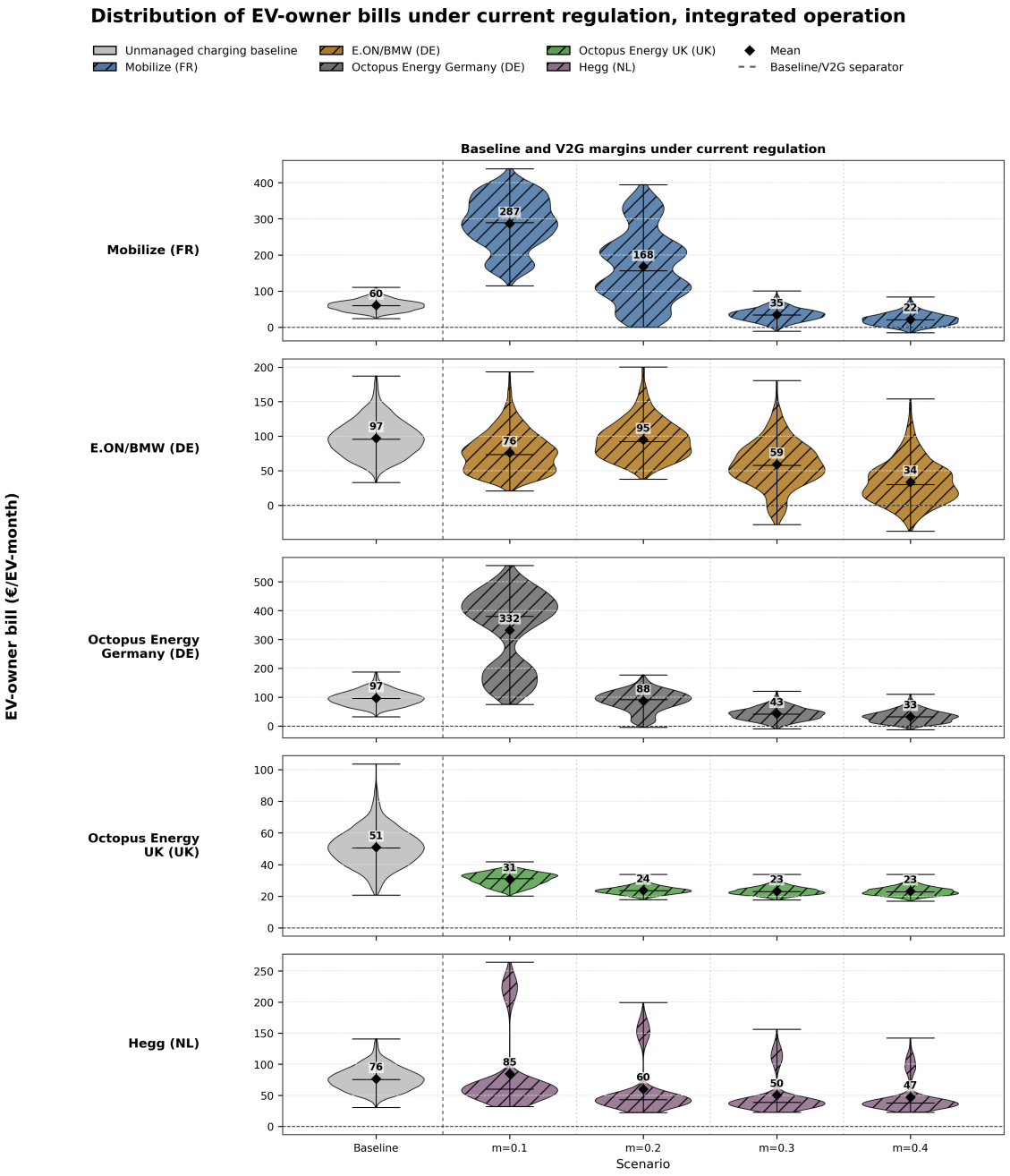


Figure 5: Distribution of EV-owner bills under current regulation ("Baseline") in the first column, and under four programs with integrated V2G operation in the four subsequent columns. Left to right, programs discharge only when there is a more favorable margin of discharge credit to charging cost. Diamonds denote means.

Table 8 also illustrates how different remuneration mechanisms influence the allocation of V2G value. E.ON/BMW combines discharge remuneration with availability payments, allowing EV owners to recover a large share of the costs associated with V2G participation. At a 0.4 €/kWh margin, the average discharge remuneration (70 €/EV-month) plus availability payments (60 €/EV-month) more than offset charging costs, taxes, and network charges, reducing the average bill to 34 €/EV-month. At lower margins, however, the increase in battery throughput also increases taxes and network charges, partially offsetting these consumer benefits. By contrast, Octopus Energy UK and Hegg follow different remuneration logics. Octopus Energy UK eliminates retail charging costs, leaving taxes and network charges as the primary costs associated with additional battery cycling. Hegg combines dynamic pricing with net metering, which largely removes the additional charging costs associated with repeated charge–discharge cycles.

Table 8: Average EV-owner bill components and throughput under integrated V2G operation

Business model	Margin (€/kWh)	Charge costs (€/EV-month)	Discharge rem. (€/EV-month)	Monthly subscription (€/EV-month)	Availability payment (€/EV-month)	Taxes (€/EV-month)	Network costs (€/EV-month)	Charge throughput (kWh/EV-month)	Discharge throughput (kWh/EV-month)	EV-owner bill (€/EV-month)
Baseline (FR)	–	23.1	0.0	14.0	0.0	15.6	9.6	142.4	0.0	60.4
Mobilize (FR)	0.1	165.2	0.0	14.0	-36.0	88.1	67.4	1131.6	979.6	287.2
	0.2	104.6	0.0	14.0	-36.0	52.1	38.9	716.1	563.8	167.6
	0.3	32.3	0.0	14.0	-36.0	12.5	13.0	221.1	68.7	34.7
	0.4	24.5	0.0	14.0	-36.0	8.6	11.5	167.9	15.4	21.9
Baseline (DE)	–	51.4	0.0	12.9	0.0	26.2	8.1	142.1	0.0	97.1
E.ON/BMW (DE)	0.1	220.8	-262.1	11.4	-60.0	501.6	52.4	918.2	742.4	76.0
	0.2	278.5	-346.7	11.4	-60.0	549.4	66.0	1158.1	982.1	94.8
	0.3	168.8	-185.5	11.4	-60.0	231.4	40.0	701.6	525.6	59.2
	0.4	89.7	-69.5	11.4	-60.0	49.3	21.3	373.1	196.9	33.5
Octopus Energy Germany (DE)	0.1	179.3	0.0	9.5	-30.0	126.6	56.4	1112.7	948.0	332.4
	0.2	56.5	0.0	9.5	-30.0	36.4	17.8	350.7	186.0	88.0
	0.3	33.6	0.0	9.5	-30.0	19.7	10.6	208.8	44.0	42.5
	0.4	28.8	0.0	9.5	-30.0	16.2	9.1	178.9	14.1	32.9
Baseline (UK)	–	27.2	0.0	14.9	0.0	6.4	2.5	110.6	0.0	50.9
Octopus Energy UK (UK)	0.1	0.0	0.0	14.9	0.0	11.0	5.1	303.7	161.5	30.7
	0.2	0.0	0.0	14.9	0.0	6.2	2.7	161.8	13.6	23.7
	0.3	0.0	0.0	14.9	0.0	5.9	2.6	153.2	5.1	23.3
	0.4	0.0	0.0	14.9	0.0	5.8	2.6	149.9	1.8	23.2
Baseline (NL)	–	33.9	0.0	14.8	0.0	27.7	0.0	142.1	0.0	76.5
Hegg (NL)	0.1	52.9	-19.9	15.4	0.0	36.0	0.0	1467.5	1322.2	84.5
	0.2	25.7	-7.3	15.4	0.0	26.3	0.0	505.1	353.6	60.2
	0.3	14.5	-2.8	15.4	0.0	23.0	0.0	245.2	93.5	50.1
	0.4	11.0	-1.6	15.4	0.0	22.1	0.0	194.5	42.8	47.1

Notes: Discharge remuneration and availability payments are reported with a negative sign because they reduce the EV-owner bill.

7.2 Integrated Retail-Aggregator marginal value per EV

Figure 6 reports the corresponding distribution of unrounded-position aggregator profits (i.e.,without considering minimum bid-size nor imbalances, thus their is not losses from not fulfilling exactly the bid-size) in €/EV-month. The figure shows that low margins can create high unrounded-position value for Mobilize, Octopus Energy Germany and Hegg, but as expected this value falls as the margin increases. Octopus Energy UK remains positive across margins because the contract has low no remuneration for the EV owner. E.ON/BMW is negative across all margins in unrounded terms; the discharge and availability payments transferred to EV owners exceed the wholesale and retail value captured by the aggregator.

Table 9 decomposes average aggregator value into wholesale-market revenues, retail revenues, EV discharge remuneration, subscription revenues, availability payments, and profits under alternative accounting assumptions. The unrounded-profit measure represents the economic value captured before accounting for minimum bid-size constraints and imbalance settlement.

The results highlight the trade-off between battery cycling and value allocation. Mobilize illustrates this pattern clearly: unrounded profit decreases from 194 to −6 €/EV-month as the minimum arbitrage margin increases from 0.1 to 0.4 €/kWh. Lower battery throughput reduces wholesale-market revenues to the point where they might create lossess for the aggregator. A similar, but more pronounced, pattern is observed for Octopus Energy Germany, where unrounded profit declines from 254 to only 1 €/EV-month over the same range of arbitrage margins. By contrast, Hegg remains profitable across all scenarios, with unrounded profits declining from 149 to 25 €/EV-month.

Table 9 reports profits after accounting for 25-kWh minimum bid-size requirements and imbalance settlement, together with bid volumes and physical energy deliveries. These results show that residential V2G requires sufficient aggregation to participate efficiently in wholesale markets. For example, although Hegg generates a unrounded profit of 25 €/EV-month at a 0.4 €/kWh margin, imbalance settlement reduces this value to −20 €/EV-month. The deterioration reflects the cost of translating many small and uncertain household flexibility positions into tradable wholesale-market products.

E.ON/BMW exhibits a different mechanism. Unlike the other business models, profitability is negative even before market-access constraints are considered. At a 0.4 €/kWh margin, wholesale-market and retail revenues amount to approximately 100 €/EV-month, whereas discharge remuneration and availability payments together exceed 130 €/EV-month, resulting in a unrounded loss of 18 €/EV-month.

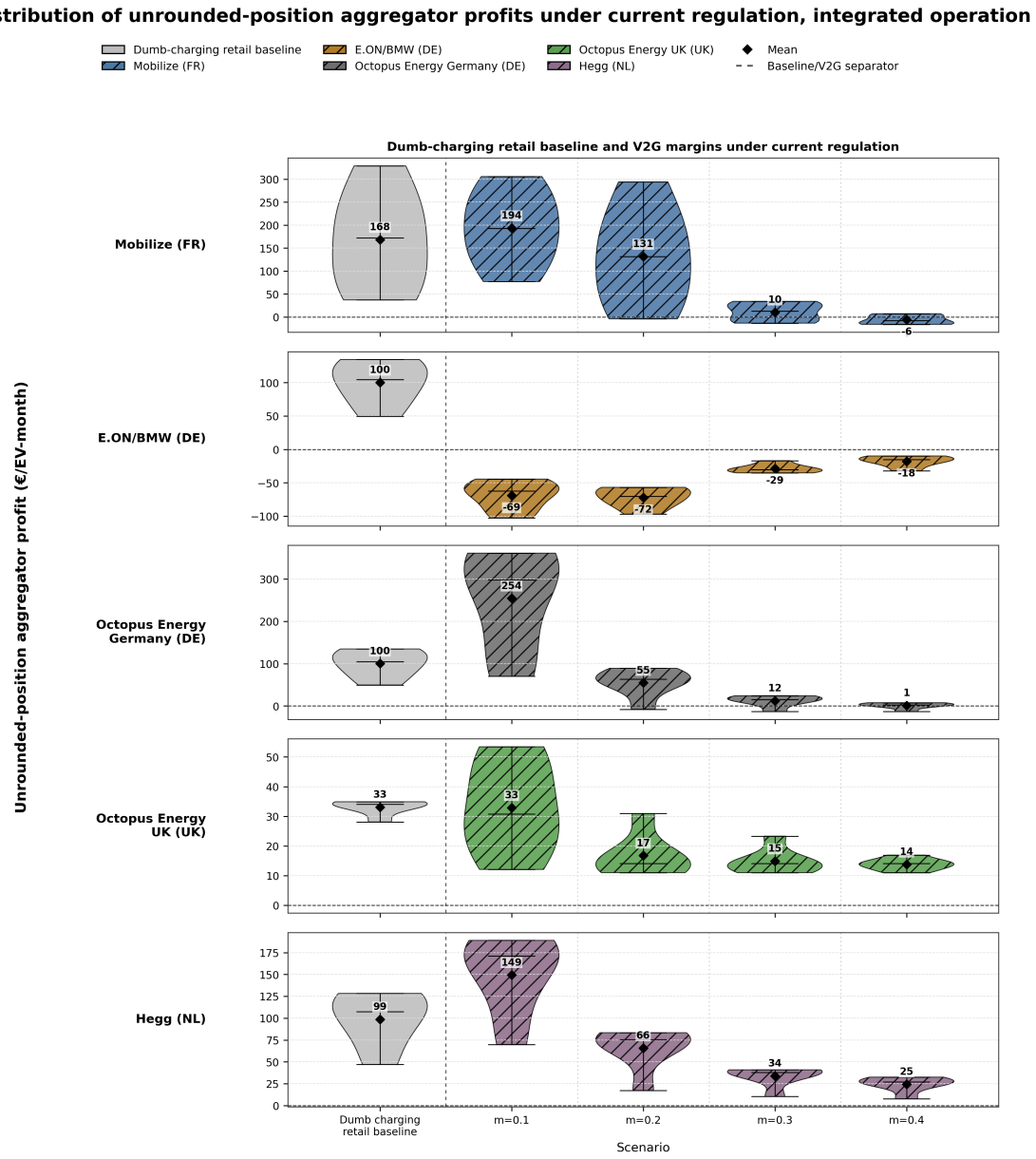


Figure 6: Distribution of unrounded aggregator profits under current regulation and integrated V2G operation. The baseline reports unrounded retailer–aggregator profit under unmanaged charging. Diamonds denote means.

Table 9: Average aggregator profit components and market positions under integrated V2G operation

Business model	Margin (€/kWh)	Wholesale value (€/EV-month)	Retail revenue (€/EV-month)	EV discharge rem. (€/EV-month)	Subscription revenue (€/EV-month)	Availability payment (€/EV-month)	Unrounded profit (€/EV-month)	25-kWh profit (€/EV-month)	Imbalance profit (€/EV-month)	Bid volume (MWh/month)	Physical delivery (MWh/month)
Baseline (FR)	–	131.3	23.1	0.0	14.0	0.0	168.4	147.7	114.0	108.9	34.4
Mobilize (FR)	0.1	50.3	165.2	0.0	14.0	-36.0	193.5	187.0	169.4	210.6	148.3
	0.2	48.9	104.6	0.0	14.0	-36.0	131.5	115.9	92.8	168.8	101.0
	0.3	-0.1	32.3	0.0	14.0	-36.0	10.2	-12.7	-38.0	117.2	44.6
	0.4	-8.4	24.5	0.0	14.0	-36.0	-5.9	-29.2	-54.4	110.9	38.6
Baseline (DE)	–	35.9	51.4	0.0	12.9	0.0	100.2	68.7	31.6	102.2	34.3
E.ON/BMW (DE)	0.1	20.8	220.8	-262.1	11.4	-60.0	-69.0	-69.4	-78.9	108.2	73.3
	0.2	44.8	278.5	-346.7	11.4	-60.0	-71.9	-83.2	-102.9	132.5	83.4
	0.3	36.8	168.8	-185.5	11.4	-60.0	-28.6	-57.9	-93.3	139.1	64.4
	0.4	10.6	89.7	-69.5	11.4	-60.0	-17.7	-55.6	-98.5	141.8	50.8
Octopus Energy Germany (DE)	0.1	95.4	179.3	0.0	9.5	-30.0	254.2	242.4	225.6	94.6	49.5
	0.2	18.6	56.5	0.0	9.5	-30.0	54.6	32.9	7.6	103.3	38.2
	0.3	-0.8	33.6	0.0	9.5	-30.0	12.4	-10.5	-37.1	103.3	36.1
	0.4	-7.4	28.8	0.0	9.5	-30.0	0.9	-22.1	-48.6	103.1	35.6
Baseline (UK)	–	-9.0	27.2	0.0	14.9	0.0	33.1	21.1	21.1	62.3	26.7
Octopus Energy UK (UK)	0.1	18.0	0.0	0.0	14.9	0.0	32.9	30.7	30.7	46.3	33.0
	0.2	1.9	0.0	0.0	14.9	0.0	16.7	13.1	13.1	47.3	32.0
	0.3	0.0	0.0	0.0	14.9	0.0	14.9	11.2	11.2	47.2	31.9
	0.4	-1.1	0.0	0.0	14.9	0.0	13.8	10.0	10.0	47.1	31.9
Baseline (NL)	–	50.0	33.9	0.0	14.8	0.0	98.8	69.0	30.4	99.4	34.3
Hegg (NL)	0.1	100.9	52.9	-19.9	15.4	0.0	149.4	146.6	132.4	79.3	50.9
	0.2	32.0	25.7	-7.3	15.4	0.0	65.8	49.2	24.1	87.7	37.8
	0.3	6.8	14.5	-2.8	15.4	0.0	34.0	15.6	-10.3	86.6	34.0
	0.4	-0.4	11.0	-1.6	15.4	0.0	24.5	5.8	-19.8	86.3	33.2

Notes: EV discharge remuneration and availability payments are reported with a negative sign because they reduce aggregator profit.

7.3 Ex-post value allocation with discharge credits

The ex-post simulation is used to estimate the maximum V2G payment that the integrated retailer–aggregator could settle on the customer's monthly bill. In practice, this payment could be implemented as additional remuneration for each meterd kWh discharged, or as an equivalent performance-based credit, without identifying which subsequent charging interval replaces the discharged energy. In the model, the feasible payment is capped by the lower of the Aggregator's positive unrounded-position profit and the EV owner's net charging-energy cost after discharge remuneration, ensuring that the transfer does not make the Aggregator unprofitable. Network charges and consumption taxes are treated separately through the net-metering counterfactual: imports and exports are netter over the monthly billing period, and these charges are applied only to any residual net withdrawal.

Figure 7 compares the average value created for EV owners with the unrounded-position profit captured by the aggregator across all business-model and arbitrage-margin scenarios. The vertical axis reports the EV-owner value of V2G, defined as the difference between the the customer's bill with unmanaged-charging baseline versus with V2G. Positive values indicate that participation in the V2G program reduces the EV owner's electricity bill relative to unmanaged charging. The horizontal axis reports the aggregator's unrounded-position profit per EV before accounting for minimum bid-size requirements and imbalance settlement. Filled circles represent the initial outcomes reported before, whereas open squares show the best outcome from the perspective of the EV owner after applying the feasible discharge credit. The arrows therefore represent a pure redistribution of value from the aggregator to the EV owner: every euro transferred through discharge credits increases EV-owner value by one euro while reducing aggregator profit. Labels identify the corresponding business model and minimum arbitrage margin.

A feasible configuration of business model requires two satisfy two conditions simultaneously: the aggregator earns positive unrounded-position profit, and the EV owner faces lower net charging costs after discharge remuneration. Figure 7 shows that several iterations of Hegg illustrates this case. At a 0.1 margin, the credit shifts EV-owner value from -8 to 25 €/EV-month while preserving 116 €/EV-month of continuous aggregator profit. This makes Hegg the closest case to an incentive-compatible allocation in which both sides retain positive value. By contrast, E.ON/BMW cannot finance a credit because unrounded-position aggregator profit is negative in every margin scenario. Octopus Energy UK also shows no credit movement because the EV owner's net charging-energy cost after discharge remuneration is already zero. The scenarios closest to a balanced outcome are therefore not those with the largest original aggregator profit, but those where positive surplus can be reallocated without making the aggregator unprofitable.

The figure 7 also shows that several low-margin scenarios create substantial unrounded-position aggregator profit while increasing the EV owner's bill relative to unmanaged charging despite of discharge credits. For example, Mobilize at a 0.1 margin generates 194 €/EV-month of unrounded-position aggregator profit, but the EV-owner value is -227 €/EV-month. After the feasible charging credit, aggregator profit falls to 28 €/EV-

month and EV-owner value improves to -62 €/EV-month. The contract still does not outperform unmanaged charging for the average EV owner, but the credit substantially reduces the misalignment. A similar pattern appears for Octopus Energy Germany at a 0.1 margin: the original outcome combines 254 €/EV-month of aggregator profit with -235 €/EV-month of EV-owner value; after the credit, the allocation becomes 75 €/EV-month for the aggregator and -56 €/EV-month for the EV owner.

Table 10 reports the calculation underlying these transitions for an average EV-owner per month. In practice, the credit would be applied individually to each EV owner under a common remuneration rule specified in advance and based on that owner's metered V2G activity. The values reported in the table are averages across tehse individual customer outcomes. The table therefore measures the average amount of V2G-related charging costs that the Aggregator could offset without making its unrounded-position profit negative. For Mobilize at a 0.1 margin, the aggregator could finance a 165 €/EV-month credit, reducing the average EV-owner bill from 287 to 122 €/EV-month while retaining 28 €/EV-month of unrounded-position profit. For Octopus Energy Germany at the same margin, the feasible credit is 179 €/EV-month, reducing the bill from 332 to 153 €/EV-month and leaving 75 €/EV-month of unrounded-position profit. These cases demonstrate the average capacity for value sharing per month sometimes are not sufficient whenever the original bill increase is larger than the redistributable surplus. E.ON/BMW and Octopus Energy UK illustrate the two limiting cases: the former has no feasible credit because aggregator profit is negative, while the latter has no credit need under this definition because the EV owner's net charging-energy cost is already zero.

Table 10: Feasible charging credit financed from unrounded-position aggregator profit

Business model	Margin (€/kWh)	Net charge after discharge	Unrounded profit	Feasible credit	Bill after credit	Profit after credit
			(€/EV-month)			
Mobilize (FR)	0.1	165.2	193.5	165.2	122.0	28.3
	0.2	104.6	131.5	104.6	63.1	26.9
	0.3	32.3	10.2	10.2	24.5	0.0
	0.4	24.5	-5.9	0.0	21.9	-5.9
E.ON/BMW (DE)	0.1	0.0	-69.0	0.0	76.0	-69.0
	0.2	0.0	-71.9	0.0	94.8	-71.9
	0.3	0.0	-28.6	0.0	59.2	-28.6
	0.4	20.2	-17.7	0.0	33.5	-17.7
Octopus Energy Germany (DE)	0.1	179.3	254.2	179.3	153.0	74.9
	0.2	56.5	54.6	54.6	33.4	0.0
	0.3	33.6	12.4	12.4	30.2	0.0
	0.4	28.8	0.9	0.9	32.0	0.0
Octopus Energy UK (UK)	0.1	0.0	32.9	0.0	30.7	32.9
	0.2	0.0	16.7	0.0	23.7	16.7
	0.3	0.0	14.9	0.0	23.3	14.9
	0.4	0.0	13.8	0.0	23.2	13.8
Hegg (NL)	0.1	33.0	149.4	33.0	51.5	116.3
	0.2	18.4	65.8	18.4	41.8	47.4
	0.3	11.7	34.0	11.7	38.4	22.3
	0.4	9.5	24.5	9.5	37.6	15.0

Notes: The feasible credit is calculated as $\min\{\max(\Pi^{\text{unr}}, 0), \max(C^{\text{charge}} - R^{\text{discharge}}, 0)\}$. It is therefore limited both by positive unrounded-position aggregator profit and by the EV owner's net charging-energy cost after discharge remuneration. Negative-profit scenarios have zero feasible credit.

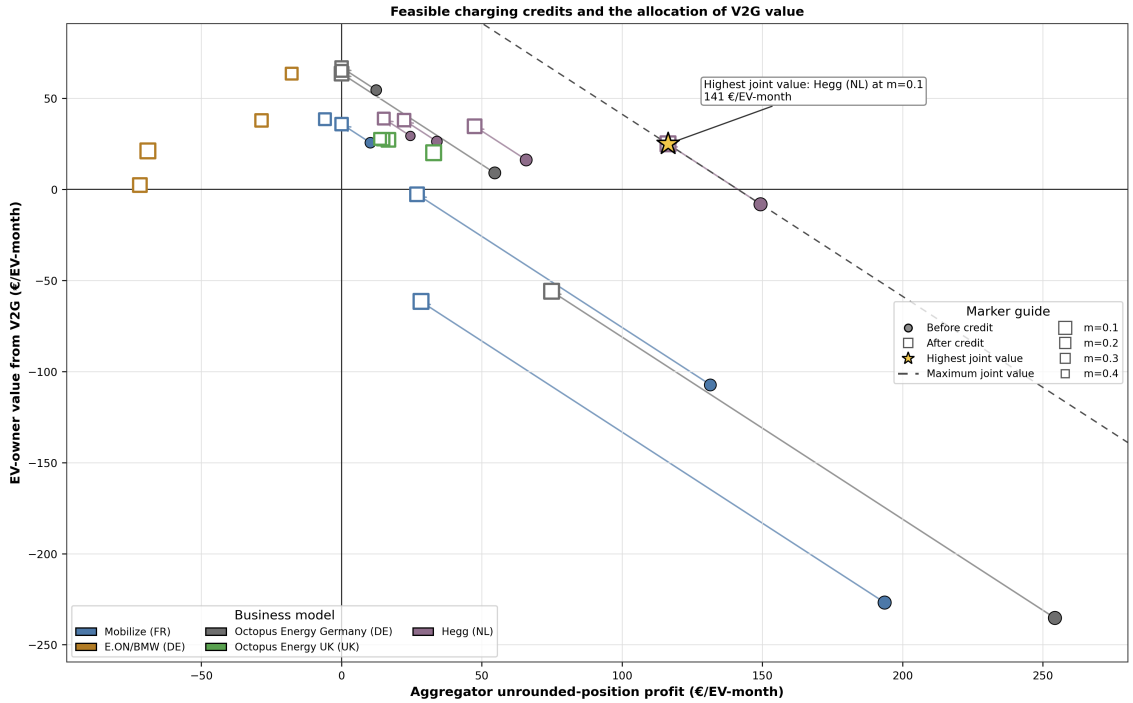


Figure 7: Transition in EV-owner value and unrounded-position aggregator profit after feasible charging credits. Filled circles show the original V2G contract outcome. Open squares show the outcome after applying the feasible charging credit. Labels identify the business-model code and cycling margin.

7.4 Policy-analysis

Figure 8 summarizes the distributional effect of the two policy scenarios across all integrated business-model margins. The metering comparison is defined relative to the current national arrangement. Which means net metering for France, Germany and the United Kingdom and net-metering for the Netherlands.

For France, Germany and the United Kingdom, negative values in the figure mean that net metering lowers EV-owner bills relative to current net billing. For Hegg, the interpretation is reversed because net metering is already the current Dutch arrangement; the figure therefore reports the net-billing counterfactual relative to current net metering. The independent-aggregator comparison is treated as an optional consumer benchmark. When, the gain is set to zero is because the independent aggregation would not reduce EV-owner bills.

Table 11 reports the same policy effects by margin and adds p10–p90 ranges to show who is most affected within the distribution. Metering reform matters most when throughput is high. For E.ON/BMW, net metering reduces bills by 47 €/EV-month at 0.1–0.2 margins, with p10–p90 reductions of approximately 22–75 €/EV-month. The effect remains material at a 0.4 margin, but falls to 20 €/EV-month. Octopus Energy Germany shows an even stronger low-margin effect: net metering reduces bills by 60 €/EV-month at a 0.1 margin, but by less than 1 €/EV-month at a 0.4 margin. Mobilize follows the same pattern, falling from a 16 €/EV-month reduction at a 0.1 margin to almost zero at a 0.4 margin. In the Netherlands, current net metering is especially valuable for Hegg at low margins: moving to net billing would increase bills by 138 €/EV-month on average at a 0.1 margin, with a p10–p90 range of 65–180 €/EV-month. At a 0.4 margin, this avoided increase falls to 5 €/EV-month.

Retailer–aggregator separation has a different distributional profile. It is largest when the integrated dispatch creates high consumer-facing costs. At a 0.1 margin, the optional independent-aggregator benchmark reduces bills by 300 €/EV-month for Octopus Energy Germany on average, with a p10–p90 range of 103–450 €/EV-month. Mobilize shows a 168 €/EV-month average reduction at the same margin. These effects collapse at higher margins because the integrated business model already limits cycling. For Octopus Energy UK, the independent-aggregator option has no incremental value in any margin scenario because the integrated contract already gives the EV owner a lower bill than the independent benchmark. Appendix A.2 provides descriptive correlation tables that help to interpret who is affected: high-mileage EV owners are more exposed when margins restrict arbitrage cycling, and for E.ON/BMW the metering-induced bill change is strongly related to kilometres driven, with a correlation of -0.52.

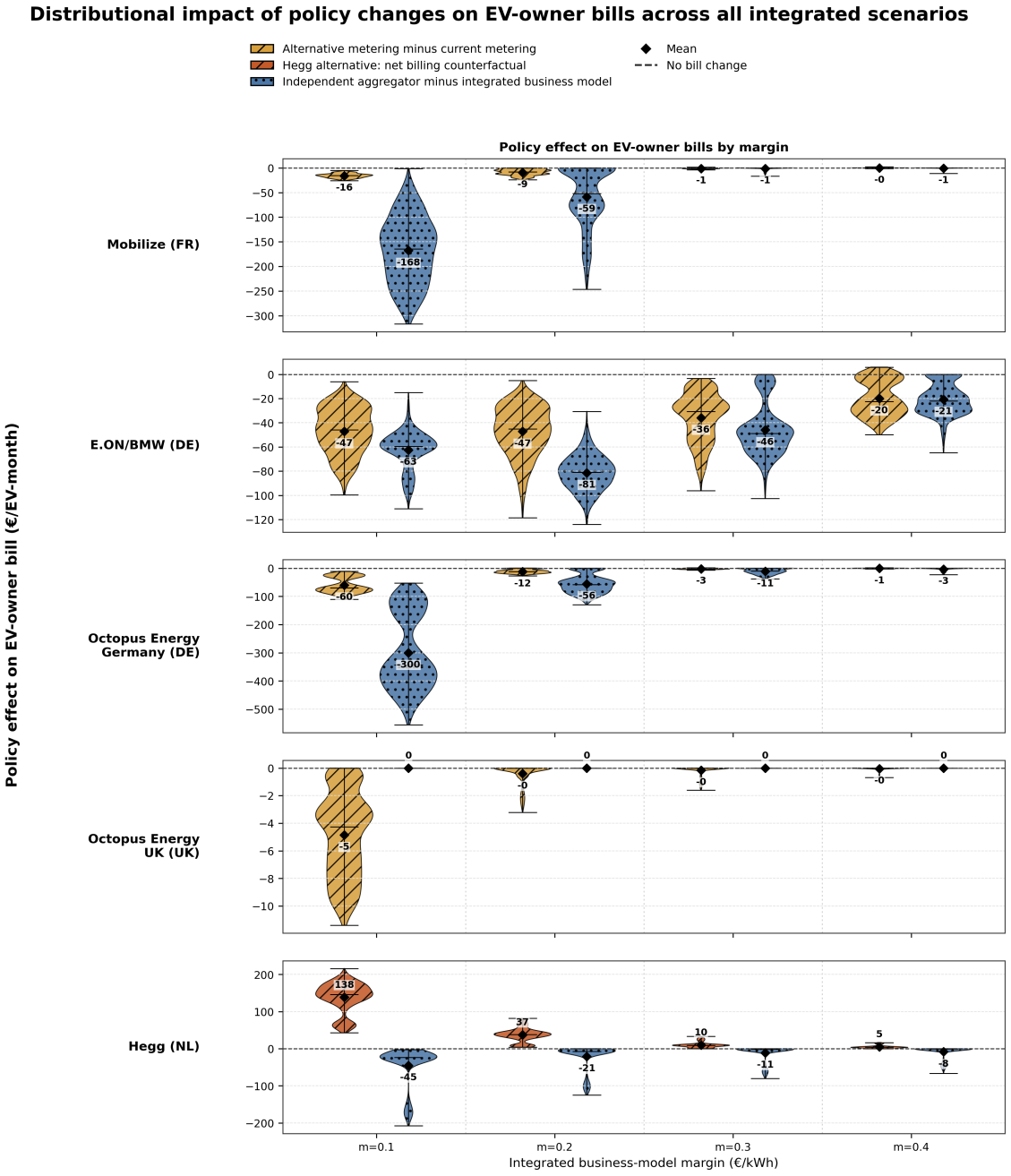


Figure 8: Distributional effect of policy counterfactuals on EV-owner bills across all integrated business-model margins. Yellow violins show the alternative metering rule minus current metering. The orange-red Hegg violins show the net-billing counterfactual because net metering is current regulation in the Netherlands. Blue violins show the optional independent-aggregator benchmark relative to the integrated business model, with positive bill differences capped at zero. Negative values reduce the EV-owner bill.

Table 11: EV-owner bill reductions from policy alternatives by margin

Business model	Margin (€/kWh)	Metering comparison	Metering mean	Metering p10–p90	Independent mean	Independent p10–p90
			Bill reduction (€/EV-month)			
Mobilize (FR)	0.1	Net metering vs current net billing	15.8	9.5–21.6	167.8	79.3–259.4
	0.2	Net metering vs current net billing	9.1	0.9–18.3	58.5	0.0–154.5
	0.3	Net metering vs current net billing	1.1	0.1–2.2	1.3	0.0–7.1
	0.4	Net metering vs current net billing	0.1	-0.1–0.7	0.6	0.0–3.2
E.ON/BMW (DE)	0.1	Net metering vs current net billing	47.0	22.6–74.6	62.6	46.9–88.3
	0.2	Net metering vs current net billing	47.2	22.2–75.4	81.4	63.4–100.4
	0.3	Net metering vs current net billing	35.8	10.3–63.9	46.0	7.8–68.2
	0.4	Net metering vs current net billing	19.9	0.2–38.0	20.8	0.0–34.7
Octopus Energy Germany (DE)	0.1	Net metering vs current net billing	60.5	21.5–90.4	299.9	103.2–449.9
	0.2	Net metering vs current net billing	11.9	1.4–20.2	56.0	1.2–95.9
	0.3	Net metering vs current net billing	2.8	0.0–5.0	11.5	0.0–25.6
	0.4	Net metering vs current net billing	0.8	0.0–2.0	3.4	0.0–12.7
Octopus Energy UK (UK)	0.1	Net metering vs current net billing	4.8	0.5–9.2	0.0	0.0–0.0
	0.2	Net metering vs current net billing	0.4	0.0–1.9	0.0	0.0–0.0
	0.3	Net metering vs current net billing	0.2	0.0–0.9	0.0	0.0–0.0
	0.4	Net metering vs current net billing	0.1	0.0–0.1	0.0	0.0–0.0
Hegg (NL)	0.1	Current net metering vs net billing	138.4	64.9–179.7	45.1	6.7–167.6
	0.2	Current net metering vs net billing	37.4	8.6–61.9	21.2	0.0–97.4
	0.3	Current net metering vs net billing	10.1	2.0–22.6	11.3	0.0–58.0
	0.4	Current net metering vs net billing	4.7	0.6–12.0	8.4	0.0–43.9

Notes: Positive values are bill reductions. For Hegg, net metering is the current Dutch arrangement, so the metering column reports the avoided bill increase relative to a net-billing counterfactual. Independent-aggregator gains are capped at zero when the option would increase the EV-owner bill.

8 Discussion

To explore the potential of V2G, previous research has predominantly relied on simulations of theoretical business models to evaluate how different policy and market designs influence the value of V2G services (Andersen & Powell, 2025; Hong et al., 2012; Signer et al., 2024). However, recent commercial V2G offers differ from the prior assumptions in this literature. These offers combine multiple remuneration mechanisms, retail tariffs, and contractual arrangements that have received limited attention in previous studies. Against this background, analyzing existing commercial offers through both an analytical framework and techno-economic simulations provides new insights into the incentive structures embedded in business-model design. This approach enables us to contribute to both the academic literature and policy-making, while also identifying important avenues for future research.

8.1 Contributions to the academic literature

This article's findings contribute to the literature on V2G business models by demonstrating that the commercial performance of V2G depends not only on the value created in electricity markets, but also on how that value is distributed between EV owners and aggregators. Whereas previous studies have primarily evaluated V2G from technical, market, or system perspectives, this paper develops an EV-owner perspective that explicitly incorporates the incentives created by business-model design. From this perspective, commercial contracts are not merely implementation details, but key determinants of the allocation efficiency and long-term viability of the V2G industry.

A first theoretical contribution is the introduction of an incentive-compatibility framework for evaluating V2G business models. Existing studies generally assess V2G according to the value generated through wholesale-market participation or the effects of specific regulatory instruments, such as double taxation. In contrast, the proposed framework evaluates whether sufficient value is transferred to EV owners to compensate for additional V2G participation costs to them, including charging costs, battery degradation, taxes, and network charges. The analysis demonstrates that differing business models can create markedly different incentives for EV owners. Incentive compatibility therefore provides a complementary criterion for assessing both the commercial sustainability of V2G business models and their exposure to moral-hazard problems.

A second contribution is to distinguish between V2G value creation and value allocation. Lower arbitrage margins increase the total value generated through wholesale-market participation by encouraging more intensive battery cycling. However, this additional value is not necessarily transferred to EV owners. Instead, it may be absorbed through higher charging costs, taxes, and network charges, leading to higher electricity bills. Conversely, increasing the minimum arbitrage margin reduces battery cycling and improves consumer outcomes while reducing aggregator profits. The commercial challenge is therefore not simply to maximize wholesale-market revenues, but to design contractual arrangements

that allocate the value created by V2G in a manner that provides sustainable incentives for both EV owners and aggregators.

Finally, the paper contributes to the literature on the organization of electricity markets by showing that integrating electricity retail and aggregation changes the incentives of performing V2G. Because integrated retailer–aggregators internalize both wholesale-market revenues and retail-billing revenues, they can redistribute value through multiple contractual channels rather than solely through explicit discharge remuneration. The comparison between E.ON/BMW, Octopus UK, and Hegg illustrates that dynamic pricing, retail tariffs, discharge remuneration, and availability payments represent alternative mechanisms for transferring value to EV owners, but create substantially different incentives for battery cycling and aggregator profitability. Moreover, the discharge-credit analysis demonstrates that integrated retailer–aggregators can further redistribute value ex post by offsetting charging costs rather than increasing discharge remuneration. Together, these findings suggest that business-model design should be considered alongside market design as a fundamental analytical dimension for understanding the commercial development of flexibility services in electricity systems.

8.2 Policy-related contributions

The policy analysis demonstrates that the effectiveness of regulatory interventions depends on their interaction with V2G business models. Net metering substantially reduces EV-owner bills when net billing repeatedly applies volumetric charges to electricity that is subsequently discharged to the grid. Consequently, the largest consumer benefits are observed in high-throughput scenarios where battery cycling is intensive. As the minimum arbitrage margin increases and battery throughput declines, the incremental benefit of net metering becomes considerably smaller. Conversely, in the Netherlands, where net metering already constitutes the regulatory baseline, the counterfactual net-billing scenario increases EV-owner bills, particularly under high-throughput operating conditions.

These findings indicate that eliminating double charging is a necessary, but not sufficient, condition for consumer-oriented V2G. While net metering reduces the additional costs associated with repeated charging and discharging cycles, it cannot resolve incentive problems created by business-model design. Contracts that encourage excessive battery cycling continue to generate relatively high EV-owner bills even under a net-metering arrangement. Metering reform and business-model design should therefore be viewed as complementary instruments rather than substitutes.

The independent-aggregator benchmark provides a complementary perspective by isolating the role of vertical integration. In many scenarios, separating retail supply from aggregation reduces EV-owner bills because dispatch decisions no longer internalize retail revenues. However, these benefits disappear when integrated business modelsare more lucrative, and if they transfer sufficient value to consumers through favourable retail tariffs or alternative remuneration mechanisms. Retailer–aggregator separation should therefore not be interpreted as a universally superior institutional arrangement. Instead,

its effectiveness depends on the underlying contractual design and the incentives created by the business model. In this sense, independent aggregation should be regarded as one possible governance mechanism for improving consumer outcomes rather than as a universal policy solution.

Finally, the comparison between unrounded-position and scalable market participation highlights the importance of wholesale-market design for residential V2G. Several business models remain profitable under idealized unrounded-position participation but become less profitable once minimum bid sizes, aggregation requirements, and imbalance settlement are considered (Borne et al., 2018). These results suggest that commercial viability depends not only on the contractual relationship between EV owners and aggregators, but also on the ability to aggregate sufficient flexibility to participate efficiently in electricity markets. Aggregators relying exclusively on residential V2G may therefore require substantial scale or complementary flexible assets to dilute imbalance costs, satisfy minimum bid-size requirements, and maintain commercially viable operations. From a policy perspective, facilitating residential V2G requires coordinated attention to retail regulation, aggregation frameworks, and wholesale-market access conditions.

8.3 Limitations and future research

This study has several limitations that can be addressed in future research. First, the analysis assumes that aggregator profits are primarily derived from wholesale-energy-market arbitrage. As discussed in Section 2, however, integrated retailer–aggregators may simultaneously capture value from additional revenue streams, including balancing services, congestion management, local flexibility markets, capacity markets or equipment sales. These complementary activities may improve aggregator profitability and expand the contractual mechanisms used to remunerate EV owners. Future research should therefore investigate how multiple value streams can be stacked within consumer-oriented V2G business models and how remuneration schemes can be designed to maintain incentive compatibility when aggregators participate simultaneously in several flexibility markets.

Second, the simulations are based on a representative fleet of 200 EVs and assume that the Integrated Retail–Aggregator can accurately anticipate EV-owner behaviour under the contractual conditions considered. In practice, charging behaviour, vehicle availability, and participation decisions are subject to considerable uncertainty and may differ across consumer segments, and may be incentivized by fees or remunerations.. Moreover, commercial V2G programmes may attract specific groups of EV owners with heterogeneous mobility patterns, risk preferences, and valuations of battery degradation. Future research should therefore examine business-model performance with fully real-world behavioural data, including variable charging station availability, imperfect information, unplanned trips, and heterogeneous consumer preferences. Such analyses could also explore how aggregators design and manage EV portfolios that maximize profitability while maintaining reliable flexibility provision under uncertainty.

Third, the analysis assumes that the relevant metering point is located at the EVSE

rather than at the household connection and therefore excludes household electricity consumption from the settlement boundary. This deliberately narrow boundary is well suited to a V2G-specific analysis: it isolates the incremental energy flows generated by EV charging and discharging, permits the associated costs, revenues, taxes, and network charges to be attributed to V2G operation, and enables consistent comparisons across business-model designs without confounding the results with heterogeneous household load profiles. In practice, however, V2G may be settled through a household meter, in which case EV exchanges interact with household demand, onsite generation or storage, and electrical losses between the household meter and the EVSE. Determining which flows and costs are attributable to the EV, how they should be netted, and how the resulting value should be allocated between household consumption and V2G operation is an important accounting and regulatory problem that may generate different incentives and operating strategies. Future research should therefore examine alternative metering configurations and assess how household-level energy flows affect V2G profitability and value allocation.

9 Conclusions

This paper examined how business-model design and policy interact to shape the distribution of value in emerging consumer-oriented V2G services. Using an analytical framework and simulations of five commercial V2G offers operating in France, Germany, the Netherlands, and the United Kingdom, we analyzed EV-owner electricity bills, aggregator profitability, charging-credit capacity, and two policy scenarios—net metering and retailer–aggregator separation—under country-specific regulatory frameworks.

Three main conclusions emerge. First, the value created by V2G and the value captured by EV owners may not be correlated. Under the current business model design and policy framework, low minimum arbitrage margins increase battery cycling and wholesale-market revenues, but they do not improve consumer outcomes in all programs studied. Instead, repeated charging cycles can increase charging costs, taxes, and network charges (especially lacking NEM policy). Increasing the minimum arbitrage margin reduces market revenue but for the consumer reduces battery throughput and improves EV-owner outcomes, lowering average monthly bills to 22–47 €/EV-month depending on the business model.

Second, the allocation problem can be reduced, but not always eliminated, by business-model design. Discharge-credits can improve consumer outcomes by offsetting consumer charging costs when the aggregator has sufficient surplus. For Hegg at a 0.1 margin, the feasible credit raises EV-owner value from -8 to 25 €/EV-month while preserving 116 €/EV-month of aggregator profit. For Mobilize and Octopus Energy Germany at the same margin, credits reduce the misalignment substantially but do not make the average EV owner better off relative to unmanaged charging. For E.ON/BMW, no credit is feasible because unrounded-position aggregator profit is negative across all margins. This result reinforces the importance of incentive compatibility: a V2G contract can create market value while still failing to provide enough value to the consumer who supplies the battery.

Third, public policy has a fundamental effect on the results of differeing business-models. Net metering reduces EV-owner bills by up to 60 €/EV-month outside the Netherlands when net billing repeatedly applies volumetric charges to storage cycles; in the Netherlands, where net metering is already the current policy, it avoids a 138 €/EV-month bill increase for Hegg at low margins. Retailer–aggregator separation can reduce EV-owner bills by up to 300 €/EV-month when integrated dispatch creates high consumer-facing costs, although if integrated contracts already provide favourable remuneration mechanisms, retailer–aggregator separation add no further benefit. These results indicate that policies such as net metering or independent aggregation cannot be evaluated independently of the contractual incentives embedded in commercial V2G offers.

Future research should extend the proposed framework to additional flexibility services, including balancing, congestion management, and local flexibility markets, while incorporating behavioural uncertainty, heterogeneous EV-owner preferences, and more detailed battery-degradation models. As commercial V2G programmes continue to mature, empirical validation of the proposed incentive-compatibility framework will provide further insights into how contractual design influences the long-term adoption of consumer-oriented flexibility services.

A Appendix

A.1 Model Notation

Table 12 summarizes the main notation used in the analytical framework, simulation module, bill accounting and policy comparisons. The table distinguishes decision variables chosen by the optimization model, endogenous state variables updated through time, exogenous inputs and parameters, and accounting outcomes computed after dispatch. Retail-neutral optimization diagnostics and archived figure inventories are retained in the project folder, but they are not part of the paper appendix because the main empirical object is the integrated commercial business model.

Table 12: Main notation used in the analytical framework and simulation model

Object	Symbol	Type	Definition
Sets and indices			
Time interval	$t \in \mathcal{T}$	Index	Fifteen-minute simulation interval.
EV owner	$n \in \mathcal{N}$	Index	Individual EV owner in the simulated fleet.
Market stage	$m \in \mathcal{M}$	Index	Wholesale-market stage used by the sequential optimization module.
Country or offer	i	Index	Business-model and regulatory setting.
Optimization decision variables			
Charging quantity	$x_{t,n}$	Decision variable	Energy charged by EV n in interval t.
Discharging quantity	$y_{t,n}$	Decision variable	Energy discharged by EV n in interval t.
Market position	$q_{t,m}$	Decision variable	Aggregated energy position submitted or updated in market stage m.
Charging credit	c_t	Business-model decision	Per-kWh credit that reduces the marginal charging cost faced by the EV owner.
State variables and physical constraints			
State of charge	$soc_{t,n}$	Endogenous state	Battery state of charge of EV n after interval t.
Initial state of charge	$soc_{0,n}$	Initial condition	Battery state of charge at the beginning of the optimization horizon.
Battery capacity	E_n	Technical parameter	Usable battery capacity of EV n.
Charging efficiency	η_c	Technical parameter	Efficiency applied to electricity withdrawn from the grid and stored in the battery.
Discharging efficiency	η_d	Technical parameter	Efficiency applied to electricity discharged from the battery and delivered to the grid.
Charging-power limit	$\overline{x}_{t,n}$	Technical parameter	Maximum charging power available to EV n in interval t.
Discharging-power limit	$\overline{y}_{t,n}$	Technical parameter	Maximum discharging power available to EV n in interval t.
Connection status	$a_{t,n}$	Exogenous input	Indicator equal to one when EV n is connected to a charger at home.
Mobility reserve	$\underline{s}_{t,n}$	Exogenous input	Minimum state of charge required to satisfy forecast mobility needs.
Interval duration	Δt	Parameter	Duration of each simulation interval.
Prices, tariffs and contract parameters			
Wholesale price	$p_{t,m}$	Exogenous input	Electricity-market price observed or forecast for interval t and market stage m.
Charging energy tariff	π_t	Contract parameter	Energy price charged to the EV owner for electricity withdrawn under the V2G contract.
Discharge remuneration	ρ_t	Contract parameter	Energy payment received by the EV owner for electricity discharged to the grid.
Effective charging cost	τ_t	Accounting variable	Marginal charging cost faced by the EV owner, including relevant energy charges, taxes and network charges.
Effective discharge value	δ_t	Accounting variable	Marginal discharge remuneration received by the EV owner, including discharge credits where applicable.
Network tariff on imports	λ_t^c	Regulatory parameter	Volumetric network charge applied to charging imports.
Network credit on exports	λ_t^d	Regulatory parameter	Network credit or charge applied to discharging exports.
Other volumetric taxes	κ_t	Regulatory parameter	Non-VAT volumetric taxes and levies applied to electricity flows.
Value-added tax	ν_i	Regulatory parameter	VAT rate applied in country or offer i.
Availability payment	γ_t	Contract parameter	Payment for keeping the vehicle connected and available for V2G operation.
Fixed payment or subscription	$F_{t,n}$	Contract parameter	Lump-sum transfer, subscription charge, or fixed monthly payment associated with the contract.
Minimum cycling margin	m	Scenario parameter	Minimum arbitrage margin imposed before additional V2G cycling is scheduled.
Bill, profit and value-allocation outcomes			
EV-owner bill	$B_{n,s}$	Accounting outcome	Monthly electricity bill of EV owner n under scenario s. Lower values indicate better consumer outcomes.
No-V2G baseline bill	B_n^0	Accounting outcome	Monthly bill of EV owner n under unmanaged charging without V2G.
EV-owner V2G value	$V_{n,s}^{EV}$	Accounting outcome	Difference between the no-V2G baseline bill and the V2G bill, $B_n^0 - B_{n,s}$. Positive values indicate that V2G lowers the EV-owner bill.
Unrounded-position aggregator profit	Π_s^{unr}	Accounting outcome	Aggregator profit using the unrounded market positions selected by the optimizer.
Rounded-position profit	Π_s^{25}	Accounting outcome	Aggregator profit after rounding aggregate market positions to the 25-kWh increment used to represent the 0.1-MW minimum bid size.
Profit with imbalances	Π_s^{imb}	Accounting outcome	Aggregator profit after minimum-bid rounding and imbalance settlement.
Imbalance settlement	R_s^{imb}	Accounting outcome	Revenue or cost from the difference between rounded market positions and physical delivery.
Feasible charging credit	C_s^{credit}	Accounting outcome	Maximum monthly charging-cost offset that can be financed from positive unrounded-position aggregator profit without making that profit negative.
Policy and heterogeneity variables			
Metering regime	g_s	Scenario indicator	Billing approach used in scenario s, either net billing or net metering.
Retailer–aggregator structure	r_s	Scenario indicator	Institutional setting in scenario s, either integrated retail–aggregation or independent aggregation.
Kilometres driven	km_n	Exogenous characteristic	Weekly-equivalent kilometres driven by EV owner n in the month.
Home connection time	h_n^{home}	Exogenous characteristic	Weekly-equivalent hours in which EV owner n is at home and connected to a charger.
Daytime home connection	h_n^{day}	Exogenous characteristic	Weekly-equivalent home connection hours between 07:00 and 22:00.
Nighttime home connection	h_n^{night}	Exogenous characteristic	Weekly-equivalent home connection hours between 22:00 and 07:00.

Notes: Decision variables are chosen inside the optimization problem. State variables evolve endogenously as a consequence of those decisions. Exogenous inputs and parameters are taken from mobility data, market data, technical assumptions, contracts or regulation. Accounting outcomes are calculated after dispatch and are used in the results tables and figures.

A.2 Correlation of EV owner bills with driver characteristic

Tables 13–15 report Pearson correlations between simulated outcomes and driver characteristics. For EV-owner bills, the unit of observation is the EV-owner-month. For aggregator profits, unrounded-position fleet-month profit per EV is assigned to each EV-owner-month in the corresponding month, yielding the same 1,200 observations per business-model margin as the EV-owner bill table. These aggregator correlations should therefore be interpreted as descriptive associations with the composition of the connected fleet rather than as individual-level causal profit estimates. For policy bill effects, the unit of observation is the policy-counterfactual EV-owner-month, pooling the four margins within each business model and policy comparison.

The mobility variables are measured as weekly-equivalent quantities within each month. Kilometres driven is expressed in km/week. Home connection is the number of hours per week in which the vehicle is at home and connected to an EVSE. Daytime home connection covers 07:00–22:00; nighttime home connection covers 22:00–07:00. Significance stars are based on two-sided Pearson correlation tests: $^{*}p < 0.10$, $^{**}p < 0.05$, and $^{***}p < 0.01$.

Table 13: Robustness: correlation between EV-owner bills and driver characteristics

Business model	Margin (€/kWh)	Obs.	Kilometres driven (km/week)	Home connection (h/week)	Day home connection (h/week)	Night home connection (h/week)
Mobilize (FR)	0.1	1200	0.02	0.01	0.02	0.00
	0.2	1200	0.06*	0.00	0.00	0.01
	0.3	1200	0.70***	0.00	0.04	0.04
	0.4	1200	0.77***	0.02	0.06**	0.04
E.ON/BMW (DE)	0.1	1200	0.72***	0.01	0.02	0.01
	0.2	1200	0.74***	0.02	0.03	0.01
	0.3	1200	0.71***	0.02	0.03	0.00
	0.4	1200	0.81***	0.02	0.04	0.01
Octopus Energy Germany (DE)	0.1	1200	0.03	0.00	0.02	0.02
	0.2	1200	0.39***	0.00	0.00	0.00
	0.3	1200	0.70***	0.01	0.04	0.02
	0.4	1200	0.76***	0.02	0.05*	0.01
Octopus Energy UK (UK)	0.1	1200	0.18***	0.00	0.01	0.02
	0.2	1200	0.56***	0.01	0.03	0.01
	0.3	1200	0.54***	0.01	0.03	0.01
	0.4	1200	0.52***	0.01	0.03	0.01
Hegg (NL)	0.1	1200	0.01	0.01	0.01	0.00
	0.2	1200	0.05	0.01	0.01	0.00
	0.3	1200	0.11***	0.01	0.02	0.00
	0.4	1200	0.16***	0.01	0.02	0.00

Notes: Entries are Pearson correlations for EV-owner-month observations. $^{*}p < 0.10$, $^{**}p < 0.05$, and $^{***}p < 0.01$. The dependent variable is the monthly EV-owner bill under the integrated business-model scenario.

Table 14: Robustness: correlation between unrounded-position aggregator profits and driver characteristics

Business model	Margin (€/kWh)	Obs.	Kilometres driven (km/week)	Home connection (h/week)	Day home connection (h/week)	Night home connection (h/week)
Mobilize (FR)	0.1	1200	0.04	0.00	0.00	0.00
	0.2	1200	0.03	0.00	0.00	0.00
	0.3	1200	0.05*	0.00	0.00	0.00
	0.4	1200	0.05	0.00	0.00	0.00
E.ON/BMW (DE)	0.1	1200	0.06*	0.00	0.00	0.00
	0.2	1200	0.05*	0.00	0.00	0.00
	0.3	1200	0.02	0.00	0.01	0.00
	0.4	1200	0.01	0.00	0.01	0.00
Octopus Energy Germany (DE)	0.1	1200	0.05*	0.00	0.00	0.00
	0.2	1200	0.04	0.00	0.01	0.00
	0.3	1200	0.00	0.00	0.01	0.00
	0.4	1200	0.01	0.00	0.00	0.00
Octopus Energy UK (UK)	0.1	1200	0.05*	0.00	0.00	0.00
	0.2	1200	0.04	0.00	0.00	0.00
	0.3	1200	0.05*	0.00	0.00	0.00
	0.4	1200	0.06**	0.00	0.00	0.00
Hegg (NL)	0.1	1200	0.04	0.00	0.00	0.00
	0.2	1200	0.03	0.00	0.00	0.00
	0.3	1200	0.01	0.00	0.00	0.00
	0.4	1200	0.00	0.00	0.01	0.00

Notes: Entries are Pearson correlations for EV-owner-month observations. $^{*}p < 0.10$, $^{**}p < 0.05$, and $^{***}p < 0.01$. The dependent variable is unrounded-position aggregator profit per EV, assigned to each EV-owner-month in the corresponding fleet month.

Table 15: Robustness: correlation between policy bill effects and driver characteristics

Business model	Policy comparison	Obs.	Kilometres driven (km/week)	Home connection (h/week)	Day home connection (h/week)	Night home connection (h/week)
Mobilize (FR)	Metering counterfactual	4800	0.04***	0.00	0.01	0.00
	Independent aggregator	4800	0.07***	0.01	0.01	0.00
E.ON/BMW (DE)	Metering counterfactual	4800	-0.52***	0.01	0.02	0.01
	Independent aggregator	4800	0.09***	0.00	0.01	0.01
Octopus Energy Germany (DE)	Metering counterfactual	4800	0.03*	0.00	0.01	0.00
	Independent aggregator	4800	0.03**	0.00	0.01	0.00
Octopus Energy UK (UK)	Metering counterfactual	4800	0.05***	0.00	0.01	0.01
	Independent aggregator	4800	–	–	–	–
Hegg (NL)	Metering counterfactual	4800	0.06***	0.00	0.01	0.01
	Independent aggregator	4800	0.07***	0.01	0.01	0.01

Notes: Entries are Pearson correlations for policy-counterfactual EV-owner-month observations. $^{*}p < 0.10$, $^{**}p < 0.05$, and $^{***}p < 0.01$. The dependent variable is the policy-induced bill change; negative values reduce EV-owner bills.

Reproducibility note

The numerical simulations were executed on Ruche, the Mésocentre high-performance computing cluster of CentraleSupélec and Université Paris-Saclay. The final simulation outputs were then downloaded into the local project repository for figure and table generation. The complete simulation campaign required several days of computation, because each business-model–policy scenario solves repeated rolling-horizon optimization problems for the EV fleet across the January–June 2025 sample period.

Upon publication, the cleaned input data, processing scripts, simulation outputs, and final figure/table generation scripts will be made available in an online repository.

Declaration of generative AI

During the preparation of this work, the authors used OpenAI Codex to improve the language, readability, and organization of author-written text; assist with reference formatting; and support software development, debugging and reproducibility checks. All AI-assisted text and code were reviewed, tested, and edited by the authors. The model formulation, data processing, calculations, references, results, interpretations, and conclusions were independently performed by the authors. The authors take full responsibility for the content of the published article.

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