

# International used electric vehicle trade: Enabling conditions and justice considerations

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## Article

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# Abstract

The international trade in used electric vehicles (EVs) is rapidly accelerating, yet little is known about what drives this emerging market or its implications for a just global energy transition. Combining a gravity-model analysis of bilateral trade flows across 177 importing countries and five major exporters (2015–2022) with 49 semi-structured interviews, we show that the used EV trade is structurally distinct from the long-studied used internal combustion engine (ICE) vehicle trade. We identify five enabling conditions—economic viability, infrastructure, trade and logistics, governance and legitimacy, and trusted bilateral networks—that jointly determine market entry and volume. These conditions are currently producing a ‘trickle-down energy transition,’ in which used EVs flow disproportionately to higher-income countries. This tiered diffusion pattern, combined with unresolved end-of-life and battery-recycling risks, raises pressing environmental justice concerns. We outline three policy priorities to support a more efficient and equitable global diffusion of used EVs.

## Introduction

The international trade in used electric vehicles (EVs) is rapidly accelerating: between 2017 and 2022, the trade increased sevenfold, with more than 240,000 used EVs flowing between countries (Fig. 1). Meanwhile, the parallel trade in used internal combustion engine (ICE) vehicles has slowed down (United Nations Environment Programme, 2024). This trend has major implications for the global energy transition in the transport sector and associated global environmental justice considerations. While used EVs could support an energy transition in importing countries, mitigating climate change and air pollution concerns, they also pose distinct risks as used EVs reach end of life and become waste. The relative advantages and burdens of the international used EV trade depend on the enabling conditions driving the flow, but those enabling conditions remain uncertain.

While a growing body of research explores the international trade in used vehicles, the vast majority centers on ICE vehicles. Research analyzing the drivers of the international ICE trade highlights three key enabling conditions: (1) economic viability, (2) governance, and (3) trade and logistics. First, trade in used ICEs is generally promoted through a cost-based framework that encompasses labor costs, fuel prices, repair and maintenance expenses, availability of spare parts, and transportation costs (Sen, 1962; Grubel, 1980; Navaretti et al., 2000; Davis and Kahn, 2010). As vehicles age, their market value declines while maintenance, compliance, and regulatory costs rise in high-income countries, creating strong economic incentives to export depreciated fleets to lower-income markets (Fuse et al., 2009). Second, stringent environmental regulations, safety standards, and inspection regimes in exporting countries tend to push older and higher-emitting vehicles out of domestic markets (United Nations Environment Programme, 2020). Conversely, unmet demand for affordable transportation in importing countries—combined with weaker regulatory enforcement and limited inspection capacity—pulls in these vehicles, even when they pose elevated environmental and safety risks (Ayeter et al., 2021; Boateng and Klopp, 2022). Third, well-established trade networks and logistics-oriented regulations further streamline this international trade.

When it comes to EVs, existing literature primarily focuses on new EV adoption in higher-income countries. Here, a frequent refrain is the importance of infrastructure, particularly charging infrastructure (Sierzechula et al., 2014). The expansion of charging infrastructure not only facilitates long-distance travel, but also improves consumer confidence in EV technology by addressing the issue of range anxiety (Egbue and Long, 2012). Other studies stress the importance of early adopters for building trust in EV technologies and establishing networks to facilitate EV adoption (Axsen and Kurani, 2012).

In this paper, we clarify the key enabling conditions for the international used EV trade and their justice implications through an approach that combines quantitative methods (econometric analyses) with qualitative methods (semi-structured interviews). Synthesizing findings from existing research on used ICE vehicles and new EVs, we identify five key enabling conditions for the international used EV trade: (1) economic viability, (2) infrastructure, (3) trade and logistics, (4) comprehensive governance and legitimacy, and (5) trusted bilateral networks. While our econometric analysis validates the enabling conditions, our interview analysis substantiates these conditions while revealing more detailed mechanisms that quantitative proxies cannot capture.

In addition to literature on used ICE vehicles and new EVs, this paper draws on existing research on environmental justice (Bullard, [1990] 2018; Pulido, 2000; Taylor, 2014). The transport sector has historically been a notable contributor to environmental injustices, with private ICE vehicles contributing to air pollution that often disproportionately harms low-income communities and people of color (Tessum et al., 2021). The ongoing electrification of the transport sector holds promise for mitigating air pollution and other harms related to ICE vehicles (Kendall et al., 2023). However, research in other contexts has revealed that clean energy transitions can reproduce and exacerbate existing inequities (Knuth et al., 2022). As the international trade in used EVs burgeons, it is crucial we understand its implications for environmental justice within and between countries.

This paper makes four significant contributions to literature on electric vehicles, energy transitions, and environmental justice. First, this is the first systematic mixed-method analysis of the international used EV trade. It demonstrates that the trade in used EVs is structurally distinct from used ICE vehicles and identifies five key enabling conditions that govern its flow. Second, we find that governance quality is positively associated with market entry, and the marginal effect of infrastructure depends on the governance environment—infrastructure matters most where institutions are weakest. Third, this paper clarifies the importance of trusted bilateral networks for the international used EV trade, an aspect particularly underexamined in relevant existing literature. Fourth, we find the five enabling conditions contribute to what we call a ‘trickle-down energy transition’: That is, used EVs reach higher-income countries first, with much less diffusion to lower-income countries. This tiered diffusion pattern presents significant implications for the global energy transition and justice considerations. While this study seeks to identify major enabling conditions and their explanations, these findings are neither mutually exclusive nor exhaustive. Instead, they are meant to indicate key trends and opportunities for targeted policy intervention in this emerging, fast-growing market.

## Results

We investigated the enabling conditions for the international used EV trade through a mixed-method approach, combining an econometric analysis of bilateral trade flows with 49 semi-structured interviews across exporting and importing countries (see Methods and Supplementary Information). The gravity model analysis draws on a panel of 177 importing countries and territories (of 208 economies in the raw UNEP database), five major exporters (European Union, Japan, South Korea, United Kingdom, and United States), and annual data from 2015 to 2022. Below, we present our findings organized around the five key enabling conditions identified in the literature.

## **1. The Used EV trade is structurally distinct from the used ICE trade**

We first tested whether the determinants of the used EV trade differ from those of the used ICE vehicle trade. A stacked PPML model interacting all covariates with an EV indicator allows a formal comparison of the two coefficient structures. A joint Wald test rejects the null that the ICE and EV coefficient vectors are equal (Supplementary Table 3), confirming that the used EV trade is governed by a structurally distinct set of determinants. Interview evidence reaffirms these enabling conditions while contributing further detail on specific mechanisms.

## **2. Infrastructure and economic viability**

Charging infrastructure is associated with the used EV trade through both market entry and trade volume. At the extensive margin, a one-unit increase in the log number of charging connectors is associated with a 1.4-percentage-point increase in the probability that a country pair trades used EVs (Supplementary Table 4). Consistent with this result, countries in the highest infrastructure quartile are approximately three times as likely to participate in the used EV trade as those in the lowest quartile (Fig. 2).

On the intensive margin, countries with denser charging networks tend to trade lower volumes of used EVs (Supplementary Table 4, col 2). This counterintuitive association does not imply that charging infrastructure reduces used EV imports. Rather, it appears to reflect differences between countries: markets with extensive charging networks are generally wealthy early-adopters that rely more heavily on new EVs. Two additional analyses are consistent with this interpretation. First, the within-between decomposition suggests that the negative association primarily reflects differences between countries, although both component estimates are imprecise (Mundlak, 1978; Supplementary Table 17). Second, after correcting for selection into the used EV trade, the charging connector effect is positive and significant (Heckman, 1979; Supplementary Table 7).

Notably, GDP per capita exhibits a sign reversal across the two margins: wealthier countries are more likely to enter the used EV trade (Supplementary Table 4, col 1), but among active traders, higher GDP per capita is associated with lower volumes (Supplementary Table 4, col 2), suggesting richer countries relying relatively more on new EVs rather than the used EV trade.

Interview evidence supports and further explains the key role of infrastructure as an enabling condition. Many major importing countries of used ICEs lack sufficient charging infrastructure for widespread used EV adoption (Interviewee 2, 3, 13). Moreover, as used EVs age and reach their end of life, additional

downstream infrastructure—including vehicle maintenance, battery management, and recycling systems—is required. A current lack of recycling infrastructure was a major concern in many countries, posing significant implications for sustainability, security, and environmental justice (Interviewee 10, 14, 15, 28).

Economic viability was another major concern with interviewees, with many highlighting the central importance of household-level cost considerations for used EV adoption (Interviewee 30). While used EVs are generally more expensive than used ICEs (Interviewee 18), buyers are attracted by the lower running cost of EVs (Interviewee 12). State policies in both exporting and importing countries also strongly affect the economic viability of used EVs. Some exporting countries have policies supporting domestic new EV adoption, which incentivizes individuals to sell their used EVs (Interviewee 4). Some importing countries employ fiscal incentives such as subsidies for purchasing EVs, including used EVs, as well as reductions or exemptions from import tariffs (Interviewee 20, 21, 42). However, multiple interviewees reported issues with subsidy programs, including instances where subsidies were too small, and difficulties with subsidy inconsistency over time (Interviewee 12, 19, 20). As these examples demonstrate, the economic viability of a used EV extends well beyond the vehicle purchase price, with factors such as running cost, repair cost, and state intervention all playing a major role in steering EV adoption.

### **3. Trade and logistics**

Import bans on used vehicles tend to reduce the flow of used EVs but do not eliminate it. In cross-sectional models where the UNEP regulatory categories can be directly estimated, import bans have a negative and statistically significant coefficient across all four specifications: moderate for total and ICE trade but substantially larger for EVs (Supplementary Table 5). Yet countries with bans still exhibit a 21% market entry rate (Fig. 3). This divergence between formal bans and observed trade flows may reflect EV-specific exemptions and uneven enforcement across countries.

Geographic distance is negatively associated with both used ICE and used EV trade (Supplementary Table 2). For used EVs, greater distance is associated with both a lower probability of trade and, among trading country pairs, lower trade volumes (Supplementary Table 4). The clearest EV–ICE contrast occurs at the extensive margin: the share of country pairs with positive used EV trade declines more steeply with distance than the corresponding share for used ICE trade (Supplementary Fig. 4). This pattern suggests the used EV trade may be more sensitive to transport costs and battery-related shipping frictions.

Interview evidence on trade and logistics shows that, in part, the inertia of the existing used ICE trade does play a role in the development of a used EV trade. Many countries that receive noteworthy numbers of used EVs have also historically received (and often still receive) large numbers of used ICEs from the same exporting country (Interviewee 16). However, the lithium-ion batteries inside EVs also lead to significant differences in used EV logistics when compared with used ICEs, including some export and import restrictions. These constraints may increase transport costs for used EVs and result in a stronger distance-decay effect. Lithium-ion batteries pose multiple risks during transport, such as the possibility of battery fires. Battery risks have contributed to export and import restrictions on used EVs and used lithium-ion batteries, as well as increased shipping regulations (Interviewee 3, 10). Among other frictions,

these difficulties exacerbate the problem of spent lithium-ion batteries piling up in used EV importing countries, as individuals and companies struggle to export them for recycling (Interviewee 31). Interviewees also noted that the valuable critical minerals inside lithium-ion batteries could lead exporting countries to restrict used EV exports in pursuit of mineral security (Interviewee 7, 9, 15, 25, 40). In both instances, the material particularities of used EVs intensify the equity concerns associated with their international trade.

#### **4. Comprehensive governance and legitimacy**

Governance quality is positively associated with both market entry and trade volumes. Better governance is associated with a higher probability of bilateral used EV trade. Its association with trade volume is positive but not significant in the PPML model (Supplementary Table 4), whereas it is significant after correcting for trade selection in the Heckman model (Supplementary Table 7). In income-stratified analyses, governance is the only covariate that remains significant across all subsamples (Supplementary Table 6 and Supplementary Fig. 4a).

The governance coefficient increases with income, suggesting that governance may serve different institutional functions across development levels. In lower-income countries, governance may provide the basic reliability needed for trade, including contract enforcement, efficient customs processing, and corruption control. In wealthier countries, it may instead capture regulatory capacity that supports EV adoption.

Infrastructure and governance are jointly associated with the used EV trade. In the baseline specification, the interaction between charging connectors and governance is negative and significant, indicating that the association between charging infrastructure and trade weakens as governance improves (Supplementary Table 2). The marginal association is positive at one standard deviation below the mean level of governance but strongly negative at one standard deviation above it, suggesting that charging infrastructure is most important where institutions are weaker (Fig. 4b). This pattern is particularly pronounced in middle- and low-income countries, where the connector coefficient is positive and its interaction with governance is strongly negative (Supplementary Table 6).

Our interviews similarly found that governments play a major role in steering the used EV trade, and their impact can extend well beyond financial levers. Sustainability is an explicit motive for some governments working to support used EV imports, though many regulations to streamline the trade remain underdeveloped (Interviewee 15, 25, 28). Interviewees noted a lack of harmonized standards for determining battery state of health before export, as well as at times weak registration and deregistration systems for tracking vehicles throughout their lifecycle (Interviewee 28, 31).

Several countries have undergone what we call a 'once bitten, twice shy' experience with used EVs: miscalculated government support leads to an early negative experience with used EVs, which creates backlash that hinders longer-term used EV adoption. For instance, beginning in 2015, the government of Fiji implemented a range of incentives to support hybrids and battery electric vehicles (Republic of Fiji, 2018). The incentives resulted in a large influx of used hybrids from Japan, though without sufficient

mechanisms to judge those batteries' state of health, leading to the import of some vehicles near their end of life. This negative experience apparently contributed to distrust of battery-containing vehicles and associated government support, hindering EV adoption (Interviewee 10).

## 5. Trusted bilateral networks

Common language is a strong bilateral predictor of the used EV trade. In the baseline PPML model estimated separately for used ICE vehicles and used EVs, the common-language coefficient is large, positive, and significant for used EVs (Supplementary Table 2), suggesting an important role for shared language in this emerging market. Consistent with this result, the extensive-margin model shows that common language is associated with a significantly higher probability of bilateral used EV trade (Supplementary Table 4).

The common-language effect is driven largely by the UK–Commonwealth channel: excluding the United Kingdom as an exporter removes much of the variation that identifies the language coefficient. However, a Brexit interaction model confirms that this effect persists even in the post-2020 period when UK trade reporting was absent (Supplementary Methods 9 and Supplementary Tables 18–19).

The quantitative common-language coefficient captures a broader sociopolitical mechanism. Shared language proxies for transnational networks, established dealer channels, regulatory familiarity, and post-colonial market integration—all of which lower the perceived risk of transacting in an unfamiliar product category.

Interview evidence helps to explain the quantitative proxy (common language) as a demonstration of the broader importance of trusted bilateral networks. Given the frequent lack of comprehensive regulation for the used EV trade within and between countries, trusted bilateral networks play a particularly important role in facilitating this trade. Often, these networks build on and extend existing trade relations, such as between the UK and other English-speaking countries in the Commonwealth (Interviewee 18, 22, 36). At other times, trust networks are built across languages, at times via intermediaries working between importing and exporting countries. For instance, New Zealand's used EV imports from Japan are in part supported by New Zealand intermediary logistics agencies, who facilitate the exchange between Japan-based auction houses and New Zealand-based vehicle dealerships (Interviewee 11). Existing trade relations also facilitate and are facilitated by shared infrastructure practices, such as driving on the same side of the road, which highlights the entanglements of the five enabling conditions (Interviewee 15). For an early-stage industry like the international used EV trade, trusted bilateral networks help to overcome regulatory nascency and other frictions.

## Discussion

This paper is the first to systematically analyze the enabling conditions for the international used EV trade. We find that the used EV market has its own gravity and is fundamentally different from the used ICE trade. In particular, we validate five key enabling conditions for the used EV trade. Our quantitative analysis highlights the noticeable importance of governance quality, charging infrastructure, and common

language, while our qualitative analysis helps to corroborate and expand on the findings from the quantitative analysis. By combining quantitative and qualitative analyses, we can capture both the broad-scale drivers of the used EV trade and the complexities underlying those drivers.

This paper's findings clarify the significant justice implications of the international used EV trade. In particular, we identify the used EV trade as an example of a 'trickle-down energy transition.' Rather than seeing widespread, equitable diffusion of used EVs, we instead see used EVs flowing primarily to higher-income importing countries. This flow could represent the early stages of a longer-term tiered diffusion pattern, with flows to lower-income countries increasing over time. However, without targeted intervention, the tiered pattern could become self-reinforcing rather than transitional. Lower-income countries could continue to receive used ICE imports (which might be more efficient recent models, bringing some environmental benefit) without being included in the transition to electric vehicles. This ambiguity in the present flow leads us to name it after the similarly ambiguous 'trickle-down' economic model.

Our analysis also reveals key justice considerations associated with individual enabling conditions. Among these, the most prominent are used EV end-of-life and recycling concerns. Multiple interviewees stressed problems already occurring at used EV end of life, including spent batteries piling up in repair shops or thrown into mangrove forests in importing countries (Interviewee 10, 14). Even as the used EV trade presents opportunities to mitigate certain environmental dangers, such as climate change and local air pollution, it could exacerbate others in inequitable ways.

Drawing on our findings, we identify three focused policy implications that could support a more efficient and equitable used EV trade. These are: (1) infrastructure investment, (2) regulatory cohesion, and (3) standard harmonization. First, our analysis finds that the marginal effect of infrastructure is largest where governance is weakest. This indicates that infrastructure programs might yield the highest returns in institutionally challenged environments, precisely where they are hardest to deliver. Interview evidence on insufficiencies in charging and recycling infrastructure support this finding.

Second, furthering regulatory cohesion within countries is key to facilitating the used EV trade. Used EVs often sit in a regulatory gray area: In some instances, they are grouped with used vehicles more generally and so face import restrictions. In other instances, they are excluded from policy support for new EVs. Policymakers and other stakeholders would benefit from identifying used EVs as a distinct vehicle category, with a set of advantages and constraints that is different from both used ICEs and new EVs. More targeted, coherent regulations for the used EV trade might help governments avoid a 'once bitten, twice shy' experience. They might also make it easier for governments to more efficiently foster the five enabling conditions for used EVs to support their trade.

Third, standard harmonization across countries would significantly improve the international used EV trade. At the moment, we see varying regulations for inspecting used EVs, including EV batteries' state of health, as well as for shipping used EVs between countries. We also see diverse charging infrastructure standards across countries, which creates additional friction in the international used EV trade. By harmonizing standards for inspecting, shipping, and using EVs across exporting and importing countries,

the flow could be streamlined and risks of injustice—such as spent battery waste piling up in importing countries—could be mitigated.

Future research should test whether the tiered diffusion pattern identified here narrows as prices fall and battery diagnostics improve, or instead becomes self-reinforcing. Expanding exporter coverage, especially to China, would clarify whether these enabling conditions generalize beyond the current exporter set. Better data on battery health, dealer networks, and informal trade channels could sharpen measures of vehicle quality and trust. Finally, policy-shock designs could estimate how import rules, tariff exemptions, and charging-infrastructure programs affect both the efficiency and equity of the used EV trade.

## Methods

### Quantitative methods

#### Data sources and sample construction

We analyze international used vehicle trade using the United Nations Environment Programme (UNEP) Used Vehicles Database, which compiles customs records of used-vehicle exports from the European Union, Japan, the Republic of Korea, the United Kingdom and the United States over 2015–2022. This data was provided by the Sustainable Mobility Unit of the United Nations Environment Programme, author of the 2020 report “Used Vehicles and the Environment” and ensuing updates (United Nations Environment Programme, 2020; United Nations Environment Programme, 2021; United Nations Environment Programme, 2024). The database separates used electric vehicles (EVs; battery-electric and plug-in hybrid vehicles) from used internal-combustion-engine (ICE) vehicles. Used EV flows are reported from 2017 onward and are not disaggregated for the United States; US exports therefore enter the total-vehicle and ICE models but are excluded from EV-specific models. The United Kingdom reported through European Union customs frameworks until the end of 2019 and is unobserved thereafter; we examine this reporting break in a Brexit diagnostic (Supplementary Methods 9 and Supplementary Tables 18–19).

The raw merged panel contains 7,696 importer-exporter-year observations. We exclude 1,147 observations in which the importer is one of the exporting jurisdictions or, for the European Union exporter, one of the 27 European Union member states, because the empirical question concerns diffusion from major exporting markets to importing countries rather than trade within the exporter group. The resulting restricted analysis panel contains 6,549 observations and 177 importer jurisdictions. EV-specific models use the 2017–2022, non-US-exporter subset. Descriptive statistics are reported in Supplementary Table 1, and the data-construction audit is reported in Supplementary Note 1 and Supplementary Table 8.

#### Covariates

Each importer-year is matched to covariates capturing economic capacity, governance, environmental conditions and charging infrastructure. GDP per capita in purchasing-power-parity terms, total population, electricity access and the fossil-fuel share of electricity generation are taken from the World Bank World Development Indicators. Government effectiveness is taken from the Worldwide Governance Indicators,

and CO<sub>2</sub> emissions per capita from the Global Carbon Budget series compiled by Our World in Data. Public charging infrastructure is measured as  $\ln(\text{connectors} + 1)$ , using country-year counts of public charging connectors from the BloombergNEF Global Public Charging Infrastructure Dashboard (15 January 2026 release). BloombergNEF does not report every importer-year: 48.1% of raw importer-year cells and 56.5% of restricted-panel importer-year cells have no direct entry and are coded as zero, consistent with BloombergNEF reporting conventions. We test sensitivity to this treatment by restricting to directly observed BloombergNEF countries (Supplementary Methods 4 and Supplementary Table 14).

Bilateral trade-cost and relationship variables are taken from the CEPII GeoDist database: population-weighted distance, contiguity, common official language and post-1945 colonial relationship. Importer regulatory policy toward used-vehicle imports is taken from the UNEP Used Vehicles Regulatory Ranking (2021 release) and entered as four indicators (Banned, Weak, Good and Very Good), with Very Weak as the reference category.

### Variable construction

Trade flows enter the main models in levels because the Poisson pseudo-maximum-likelihood estimator operates on untransformed non-negative counts. Continuous covariates that enter interaction terms are mean-centred before interaction construction, so their main effects are interpreted at the sample mean. The principal specification includes three two-way interactions: GDP per capita  $\times$  connectors, GDP per capita  $\times$  government effectiveness and connectors  $\times$  government effectiveness. The UNEP regulatory indicators are time invariant in the panel and are therefore absorbed by importer fixed effects in the main panel models; auxiliary cross-sectional specifications recover their descriptive associations (Supplementary Table 5).

### Gravity-model estimator

We estimate gravity models of bilateral used-vehicle trade with Poisson pseudo-maximum likelihood (PPML), which is standard for trade-flow data with heteroskedasticity and many zero observations. PPML avoids the sample loss and retransformation problems that arise when zero trade flows are logged, and we implement it with high-dimensional fixed effects using `ppmlhdfe` (Silva and Tenreyro, 2006; Yotov et al., 2016; Correia et al., 2020).

Let  $Y_{ijt}$  denote the number of used vehicles exported from exporter  $j$  to importer  $i$  in year  $t$ , and let  $r(i)$  denote importer  $i$ 's UNEP region. The baseline conditional mean is

$$E[Y_{ijt} | X_{ijt}, \gamma_{jt}, \delta_i, \theta_{r(i)t}] = \exp(\beta'X_{ijt} + \gamma_{jt} + \delta_i + \theta_{r(i)t}). \quad (1)$$

Here  $X_{ijt}$  is the vector of importer and bilateral covariates described above;  $\beta$  is the corresponding coefficient vector;  $\gamma_{jt}$  is an exporter-year fixed effect;  $\delta_i$  is an importer fixed effect; and  $\theta_{r(i)t}$  is a UNEP-region-year fixed effect. The exporter-year effect absorbs supply-side shocks and reporting changes, the importer effect absorbs time-invariant importer characteristics, and the region-year effect absorbs region-specific shocks while preserving within-region comparisons. Standard errors are clustered by importer, the

level at which the main country-year covariates vary. Equation (1) is estimated separately for total used vehicles, used ICE vehicles and used EVs.

Covariates are introduced sequentially in six steps: gravity and market-size variables; government effectiveness; charging connectors; UNEP regulatory indicators; environmental controls; and the three centred interactions. This sequence is motivated by correlations among the main development indicators: GDP per capita and government effectiveness are strongly correlated ( $r = 0.78$ ), while their correlations with charging connectors are moderate ( $r = 0.46-0.52$ ) in the current EV panel. We report the sixth step as the principal specification and use the earlier steps as coefficient-stability checks (Supplementary Table 9).

### Extensive- and intensive-margin models

Most potential used EV trading relationships are inactive. We therefore separate the extensive margin, whether a pair trades at all, from the intensive margin, trade volume conditional on positive trade. The extensive margin is estimated with a probit model:

$$Pr(Y^{EV}_{ijt} > 0 \mid Z_{ijt}, \gamma_{jt}, \theta_{r(i)t}) = \Phi(\alpha'Z_{ijt} + \gamma_{jt} + \theta_{r(i)t}). \quad (2)$$

$\Phi$  is the standard normal cumulative distribution function,  $Z_{ijt}$  is the probit covariate vector and  $\alpha$  is its coefficient vector. The probit includes exporter-year and region-year fixed effects as factor variables but omits importer fixed effects to avoid the incidental-parameters problem in a short nonlinear panel (Greene, 2004). The intensive margin is estimated by PPML on the subsample with strictly positive used EV flows (Supplementary Table 4).

### Stacked ICE-EV comparison

To test whether used EV and used ICE trade follow the same coefficient structure, we estimate a stacked PPML in which each importer-exporter-year cell appears once as a used ICE observation and once as a used EV observation. Let  $k$  index vehicle type and  $D^{EV}_k$  equal one for the EV row. The stacked conditional mean is

$$E[Y_{ijkt} \mid X_{ijt}, D^{EV}_k, \gamma_{jtk}, \delta_{ik}, \theta_{r(i)tk}] = \exp(\beta'X_{ijt} + \varphi'(D^{EV}_k \times X_{ijt}) + \gamma_{jtk} + \delta_{ik} + \theta_{r(i)tk}). \quad (3)$$

The vector  $\varphi$  captures how covariate associations differ for EV flows relative to ICE flows, and the joint Wald test  $H_0: \varphi = 0$  evaluates whether the two vehicle trades share a common structure. We report a parsimonious stacked model with six interacted covariates and an expanded model that enters the full covariate set, yielding eight identified interactions after collinear terms are absorbed (Supplementary Table 3).

### Identification and sensitivity analyses

We interpret the estimates as conditional associations rather than causal effects. The fixed-effects design controls for persistent differences between importers, exporter-specific annual shocks and region-specific

annual shocks. However, the panel is short, and several covariates change only modestly within countries over time. As a result, the estimates reflect a combination of cross-country differences and within-country changes, rather than the causal effect of changing any single enabling condition. We therefore interpret the models as evidence on conditional patterns in the used EV trade, rather than as causal estimates of the effect of any single enabling condition.

We examine three sources of potential bias. First, charging infrastructure may be built in response to used EV imports rather than preceding them. To address this timing concern, we re-estimate the model using one- and two-year lagged connector measures; the results show the same qualitative pattern (Supplementary Table 10). Second, importer fixed effects absorb characteristics that do not vary over time, including the UNEP regulatory categories and logistics indicators. We therefore estimate auxiliary cross-sectional models to describe how these variables are associated with the used EV trade across countries (Supplementary Table 5). Third, countries that trade used EVs may differ systematically from those that do not. We assess this selection issue using Heckman two-step and maximum-likelihood models, with prior ICE-trade relationships and the number of other EV-exporter partners used to predict trade participation but not trade volume (Supplementary Table 7).<sup>5</sup>

Sensitivity is evaluated across alternative model specifications, inference choices and samples. The charging connector coefficient cannot be separately estimated in the most saturated importer-year fixed-effects model, and it becomes positive but statistically insignificant when bilateral-pair fixed effects are used, indicating that the main negative estimate should not be interpreted as a within-pair causal effect (Supplementary Table 11). The main inference is similar when standard errors are clustered by importer or by importer and year; clustering by exporter is unreliable because there are only four EV exporters, and pair-level clustering produces a singular variance-covariance matrix (Supplementary Table 12). The negative connector coefficient is also similar when charging infrastructure is transformed using the inverse hyperbolic sine rather than  $\ln(\text{connectors} + 1)$ . By contrast, OLS on  $\ln(\text{used EVs} + 1)$  produces a smaller estimate, as expected for sparse and heteroskedastic trade data (Supplementary Table 13). Further checks restrict the sample to countries with directly observed BloombergNEF data, remove banned-import countries and outliers, test for post-2020 changes, separate within- and between-importer variation (Supplementary Methods 4–9 and Supplementary Tables 14–19).

## Qualitative methods

The quantitative analysis is complemented by 49 semi-structured interviews conducted between 21 June 2024 and 15 August 2025. Participants were selected purposively and through snowball sampling to capture perspectives from actors involved in the used EV trade, regulation, infrastructure, development and environmental governance (Table 1; see also Supplementary Tables 20 and 21). Interviewees included local and national government agencies, non-governmental and civil-society organizations, international organizations, academic institutions, industry associations, vehicle manufacturers, exporters, charging-infrastructure providers and other private-sector actors across exporting and importing regions. Additional details on recruitment, participant categories, and geographic coverage are provided in Supplementary Note 2.

Table 1: Interviewees by number, industry type, and country/region of focus

| <b>Interviewee #</b> | <b>Industry type</b>                       | <b>Country/<br/>region of<br/>Focus</b> | <b>Interviewee #</b> | <b>Industry type</b>                       | <b>Country/<br/>region of<br/>Focus</b> |
|----------------------|--------------------------------------------|-----------------------------------------|----------------------|--------------------------------------------|-----------------------------------------|
| 1                    | Government                                 | Europe                                  | 26                   | Government                                 | New Zealand                             |
| 2                    | International/<br>regional<br>organization | Mongolia                                | 27                   | Academia                                   | International                           |
| 3                    | International/<br>regional<br>organization | International                           | 28                   | International/<br>regional<br>organization | International                           |
| 4                    | Academia                                   | International                           | 29                   | Private sector                             | Japan                                   |
| 5                    | Private sector                             | Mongolia                                | 30                   | Private sector                             | Kenya                                   |
| 6                    | International/<br>regional<br>organization | International                           | 31                   | International/<br>regional<br>organization | Tunisia                                 |
| 7                    | Academia                                   | International                           | 32                   | Academia                                   | Mongolia                                |
| 8                    | International/<br>regional<br>organization | International                           | 33                   | Academia                                   | Mexico                                  |
| 9                    | Academia                                   | Tunisia                                 | 34                   | Academia                                   | Mongolia                                |
| 10                   | International/<br>regional<br>organization | Fiji                                    | 35                   | International/<br>regional<br>organization | International                           |
| 11                   | Private sector                             | New Zealand                             | 36                   | Private sector                             | New Zealand                             |
| 12                   | Academia                                   | New Zealand                             | 37                   | Private sector                             | Australia                               |
| 13                   | Academia                                   | Mexico                                  | 38                   | Academia                                   | United States                           |
| 14                   | Government                                 | Mongolia                                | 39                   | International/<br>regional<br>organization | International                           |
| 15                   | Academia                                   | Mexico                                  | 40                   | International/<br>regional<br>organization | International                           |

|    |                                        |               |    |                                            |          |
|----|----------------------------------------|---------------|----|--------------------------------------------|----------|
|    |                                        |               |    | regional<br>organization                   |          |
| 16 | Government                             | New Zealand   | 41 | Government                                 | Nigeria  |
| 17 | Government                             | New Zealand   | 42 | International/<br>regional<br>organization | Zambia   |
| 18 | Academia                               | New Zealand   | 43 | NGO                                        | Kenya    |
| 19 | Private sector                         | New Zealand   | 44 | International/<br>regional<br>organization | Zambia   |
| 20 | Academia                               | New Zealand   | 45 | Private sector                             | Kenya    |
| 21 | International/regional<br>organization | United States | 46 | NGO                                        | Ethiopia |
| 22 | Private sector                         | New Zealand   | 47 | NGO                                        | Brazil   |
| 23 | Private sector                         | New Zealand   | 48 | Private sector                             | Tanzania |
| 24 | Private sector                         | New Zealand   | 49 | NGO                                        | Kenya    |
| 25 | Academia                               | International |    |                                            |          |

Interviews were conducted remotely using Zoom or Microsoft Teams by at least one member of the author team with a semi-structured interview guide (Supplementary Note 3). Follow-up questions were adapted to each participant's expertise and geographic context. Interviews were audio-recorded with participant consent, transcribed, and reviewed for accuracy. Data collection continued until code saturation and meaning saturation were reached.

Transcripts were analyzed in NVivo 15 using inductive thematic analysis. A trained research assistant conducted initial coding under author supervision, and the coding framework was iteratively reviewed and refined by the research team. The process yielded 43 preliminary first-order themes, which were grouped into broader analytical categories used to interpret and contextualize the econometric findings. Interview evidence is used to explain mechanisms, institutional context, and stakeholder reasoning; it is not interpreted as a representative estimate of stakeholder prevalence.

## Declarations

Ethics, inclusion, and reporting

All interview participants provided informed consent before participation. To preserve confidentiality, participants are identified by stakeholder category and general organizational type rather than by name or specific institution. The study received ethics approval from Tufts University. The research design aimed to include perspectives from both exporting and importing regions and from public, private, civil-society and research organizations; remaining gaps in geographic and stakeholder representation are documented in the Supplementary Information.

#### Software and reproducibility

Quantitative analyses were run in Stata 18; replication requires Stata 17 or later and the `ppmlhdfc` and `reghdfc` packages. Qualitative coding was conducted in NVivo 15.

#### Data availability

UNEP, World Bank, CEPII, Worldwide Governance Indicators and Global Carbon Budget data are publicly available from their respective providers. BloombergNEF charging-infrastructure data are proprietary and cannot be redistributed in raw form. Raw interview transcripts are restricted to protect participant confidentiality.

#### Code availability

The Stata code and documentation are available to editors and reviewers through an anonymized OSF view-only link:

[https://osf.io/zdsaf/overview?view\\_only=1b4a19f0df4e479cb5fc477d01c68365](https://osf.io/zdsaf/overview?view_only=1b4a19f0df4e479cb5fc477d01c68365)

The repository will be made public under the MIT License upon publication.

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## Figures

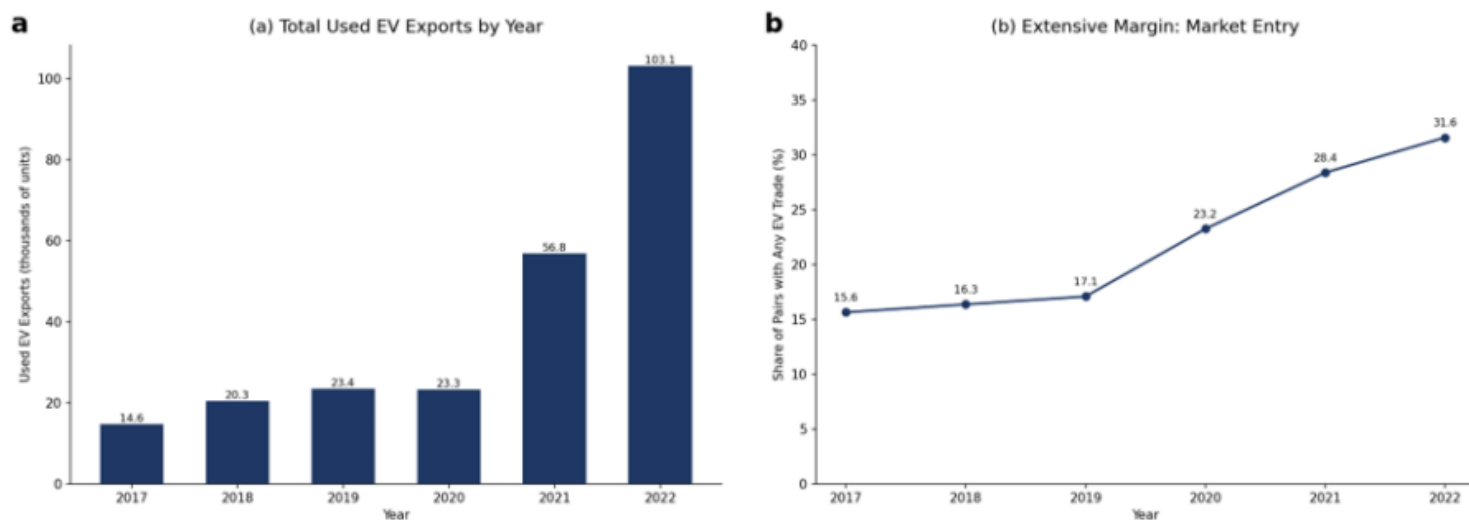


**Figure 1**

Growth of the international used EV trade, 2017–2022. (a) Aggregate trade volume; (b) market-entry rate, the share of importer–exporter pairs with positive used EV trade.

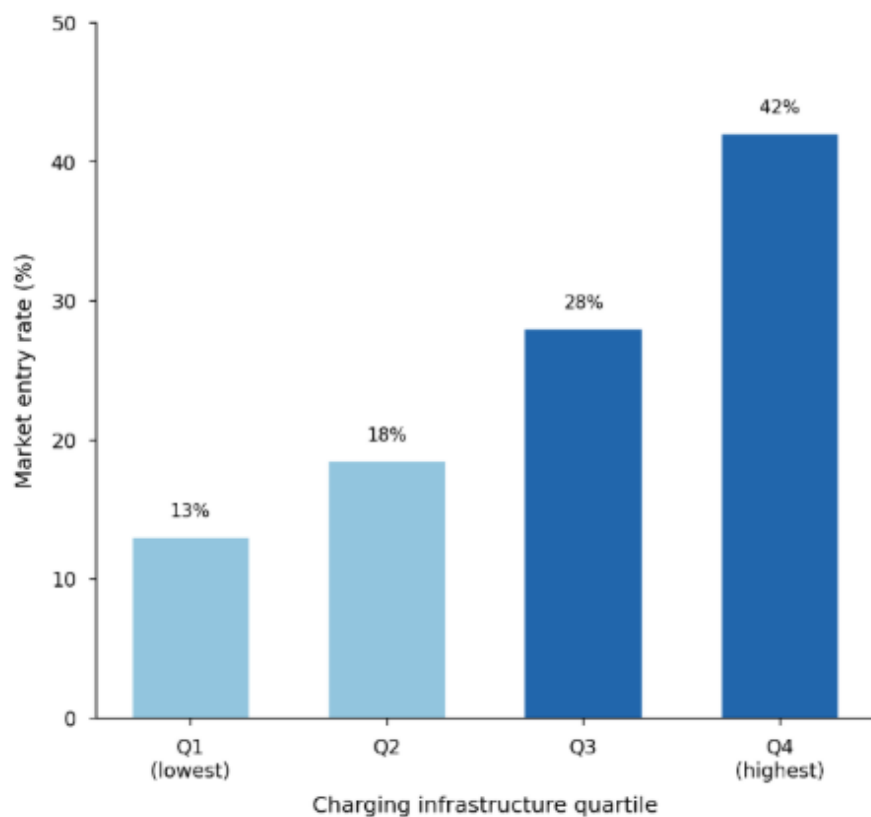


**Figure 2**

Charging infrastructure and used EV market entry

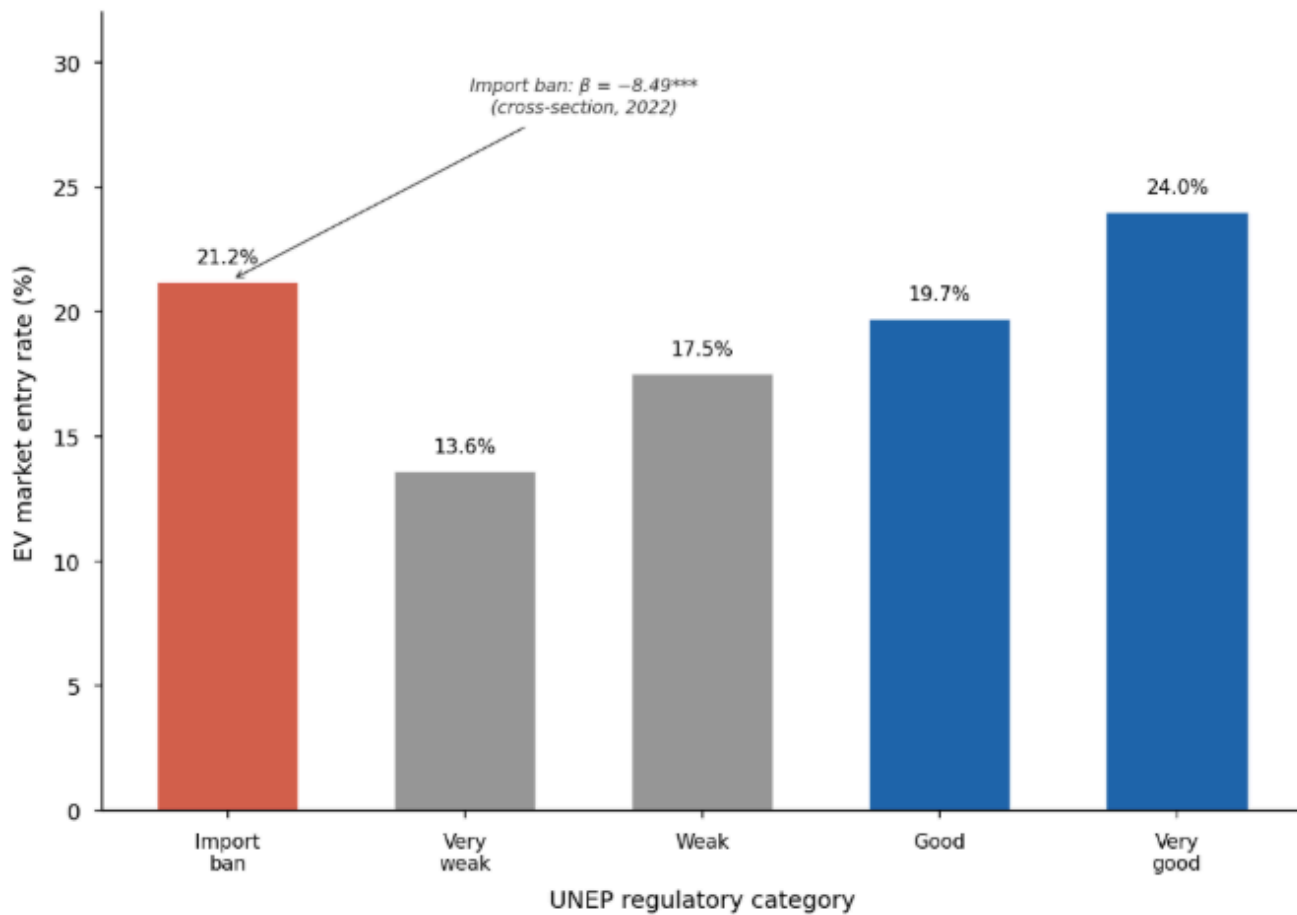


Figure 3

UNEP regulation

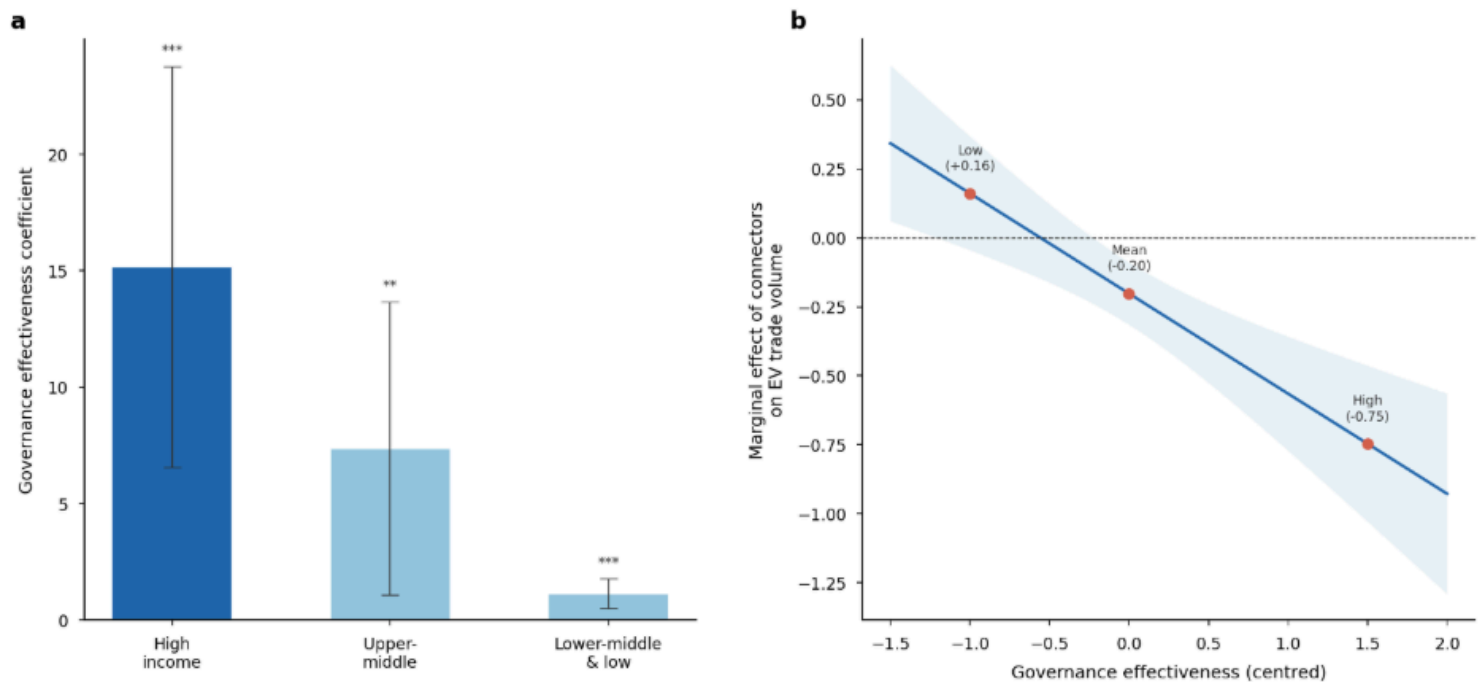


Figure 4

## Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [InternationalUsedElectricVehicleTradeSupplementaryInformation.docx](#)