BEV Adoption in the EU in Light of the 2035 Carbon Emitting Vehicles Ban

Lucy Kanias
Massachusetts Institute of Technology
BS Chemical Engineering

Loann Marquant
Harvard Kennedy School
MA Public Policy

Onur Talu
Massachusetts Institute of Technology
MS Technology and Policy

***Abstract*—In 2023, the European Union adopted legislation to ban new sales of small commercial and passenger vehicles running on non zero-emission fuels by 2035, in line with the EU 2050 net-zero greenhouse gas emissions target. This paper examines the feasibility of transitioning EU's light-duty vehicle fleet to zero emissions by 2035 using a fixed-effects panel regression analysis to analyze historical data, and logistic growth model to forecast countries' trends into the future. By clustering countries into two groups based on income and EV adoption metrics, the study assesses the universality of key adoption drivers across diverse economic contexts. The regression analysis identifies publicly available fast chargers as the consumer driver with the highest correlative power, and utilizes this logistic growth model to calculate the required growth targets for each country's charger network to reach 100% battery electric vehicle (BEV) sales across the EU. The paper concludes with potential policy implications of our findings to prevent the ban from being punitive on EU's less developed regions.**

I. Introduction

In 2022, the European Union introduced legislation requiring all new passenger cars and light commercial vehicles to run exclusively on CO2-neutral fuels by 2035, effectively banning the sales of all vehicles, except for zero-emission vehicles (ZEV). Prior to this EU Commission legislation, most countries in the EU had already passed national policies aimed at incentivising electric vehicle (EV) adoption by various future target dates, with diverse levels of commitment and policy types to achieve these goals [1].

In 2023, battery electric vehicles (BEVs) accounted for 15% of new light-duty vehicle sales and 1.7% of the active stock in the European Union 2023 [2], raising questions about the EU's ability to reach its 2035 goal. With domestic transport responsible for 23% of total emissions and light-duty vehicles contributing 60.8% of this share, the transport sector represents a critical area for achieving net-zero emissions by 2050 [2][3].

Extensive literature has examined the main factors influencing EV adoption compared with ICEs. First, the availability of charging infrastructure was identified early on as a key driver of adoption during periods of low uptake [4]. Subsequent studies emphasized that the location of charging points—at home, at work, and in public spaces—is equally significant for increasing adoption rates [5][6]. Furthermore, recent literature emphasizes that there's a strong correlation between income and charging network density indicating these markets are more mature in countries with high GDP per Capita [7].

Second, research shows that while EVs are associated with high purchase costs, they offer lower running, maintenance, and charging expenses [5]. Consequently, financial incentives that reduce upfront costs are strongly correlated with EV market shares, with an estimated 5-7% increase in relative sales share per €1,000 of financial incentive [8]. Given consumers' focus on short-term benefits, immediate grants and purchase tax exemptions have been shown to be more effective than income tax credits distributed annually. Additionally, consumer behavior patterns show that consumers have great sensitivity to gasoline prices, compared to electricity prices, in assessing the cost of ownership of their vehicles and in replacing their IC vehicles with BEV or PHEV alternatives [9][10].

EV sales and stock sizes changed rapidly over the last couple of years, and while the EV sales are projected to account for between 83% and 92% of new car sales by 2035 [1], we couldn't find any studies that evaluate how the different countries in the union performing so far and how likely they are to transition fully to ZEVs. While there is a wealth of literature that studies the impact of different factors for EV adoption, there is little evidence for how consumer preferences and behaviors are driving this transition, especially given the dependence of the market on consumer-decision. This study investigates the consumer drivers of BEV adoption using a fixed-effects panel regression method, with recent data on one-time financial incentives of vehicle ownership, the network of publicly available fast and slow chargers, as well as the gasoline and home electricity prices across the EU. It then forecasts the BEV sales share of the EU countries from 2024 to 2035 to determine how the various countries in the region are doing about meeting 100% BEV sales by 2035.

II. Methodology

Our methodology involved four steps. First, we tabulated panel data across EU countries for our variables of interest we identified in our literature review. Second, we clustered EU countries into two groups based on their income levels and shares of EV sales in the light-duty vehicle market. Third, we ran various fixed-effects panel regression models, to identify the contributions of the drivers of EV adoption. Finally, we used a logistic growth model to project the growth of BEV sales in each country to assess their likelihood of reaching 100% BEV sales share by 2035.

A. Parameter Selection and Data Collection

We selected the independent variables to include in our model following a literature review of determinants of electric vehicle adoption for consumers. To prevent over-fitting in our linear regression model, we focused on the parameters that were most often highlighted in our literature review, instead of considering many consumer-based variables and eliminating them through regularization. In total, we collected data from the 27 countries in the European Union, from 2010 to 2023. We utilized a publicly available dataset that the Munzel et al. paper collected for all information prior to 2017, and we collated our own dataset for 2018 onward, which are tabulated in Table I below.

As our output variable, we chose to use BEV sales, rather than the share of BEV sales because the former provides more informative insights across a range of market sizes. This approach captures the localized nature of BEV adoption in the EU, which is concentrated in urban areas in many countries, and reflects the early stage of market development in most national contexts [7]. For information regarding financial incentives, we only accounted for capital incentives for vehicle ownership, including registration tax breaks, value-added tax breaks and subsidies, due to data availability problems.

TABLE I
DATA AND SOURCES

Variable	Data	Source
X_1	One-time purchase incentives (Real)	ACEA[11] Munzel et.al[8]
X_2	Publicly available fast chargers	IEA[1] Munzel et.al[8]
X_3	Publicly available slow chargers	IEA[1] Munzel et.al[8]
X_4	Ratio of gas and home electricity prices	Statista Munzel et.al[8]
y	Annual BEV sales	IEA[1] Munzel et.al[8]

B. Clustering

We clustered our dataset from different countries into two groups, depending on the countries' income, and the share of BEV sales in light-duty vehicle markets. These factors influence the BEV adoption rates significantly across our panel [12][7], and in doing so enable us to draw conclusions about countries that are at various stages of BEV adoption and various income levels. This better highlights key differences and similarities across these countries in assessing the consumer drivers and in comparing the historical growth rates of their BEV adoption to forecast on. In order to prevent running into inconclusive or misleading results, we chose to have only two clusters.

C. Fixed Effects Panel Regression

The limited timeframe in which European countries have implemented EV incentives and introduced electric vehicles has resulted in sparse time series data for both independent and dependent variables. To address this, we used a fixed effects panel regression to pool data across the 27 countries studied over time. While this approach favors countries with more data and longer histories of EV investment, we assume that the key drivers of EV adoption are relatively uniform across countries and time under similar circumstances.

We include both time and country fixed-effects, to focus on the effects of our four selected parameters and control for unobservable trends that vary over time but not across country, as well as characteristics that are time-invariant, but change between different countries. We used the ordinary least squares (OLS) method to find the weights of our explanatory parameters in the annual sales of battery electric vehicles (BEV), using the Equation 1 below:

$$\begin{aligned} y_{\text{BEV Sales}} = {} & \beta_1 \cdot x_{it}^{\text{DC Chargers}} + \beta_2 \cdot x_{it}^{\text{AC Chargers}} \\ & + \beta_3 \cdot x_{it}^{\text{Incentives}} + \beta_4 \cdot x_{it}^{\text{Gas/Electricity Price}} \\ & + \alpha_i + \gamma_t \end{aligned} \tag{1}$$

where y is the dependent variable, BEV sales, X are the various independent variables, β are the weights of each independent variable, α is the time-invariant country fixed effect, and γ is the location-invariant, time fixed effect. Subscript i indicates the indices for different countries and t indicates the different years.

In total, we ran regressions on clusters and the complete dataset, starting with single-variable regressions to examine individual relationships between independent parameters and the output. These regressions informed the multi-variable panel analysis, helped assess model robustness, and refined the solution space. We then performed multi-variable regressions with four selected parameters on both clustered and complete datasets.

D. Projections

To evaluate pathways for the EU27 countries, we forecasted the growth of key independent variables and their influence on annual BEV sales and market share. Using a logistic growth model, we focused on variables with high predictive power—slow and fast charger numbers—while holding low predictive power variables, such as financial incentives and electricity-to-gas fuel prices, constant. This decision was based on regression results that identified chargers as the most critical factors for BEV adoption.

To address noise in annual car registrations, we calculated the maximum number of car registrations for each country using historical data and projected total car sales to reach this maximum by 2035. The logistic model assumed 100% BEV sales by 2035, starting with an initial growth rate that linearly decayed to 0%. We determined the necessary initial growth rate to achieve this target for each country and compared

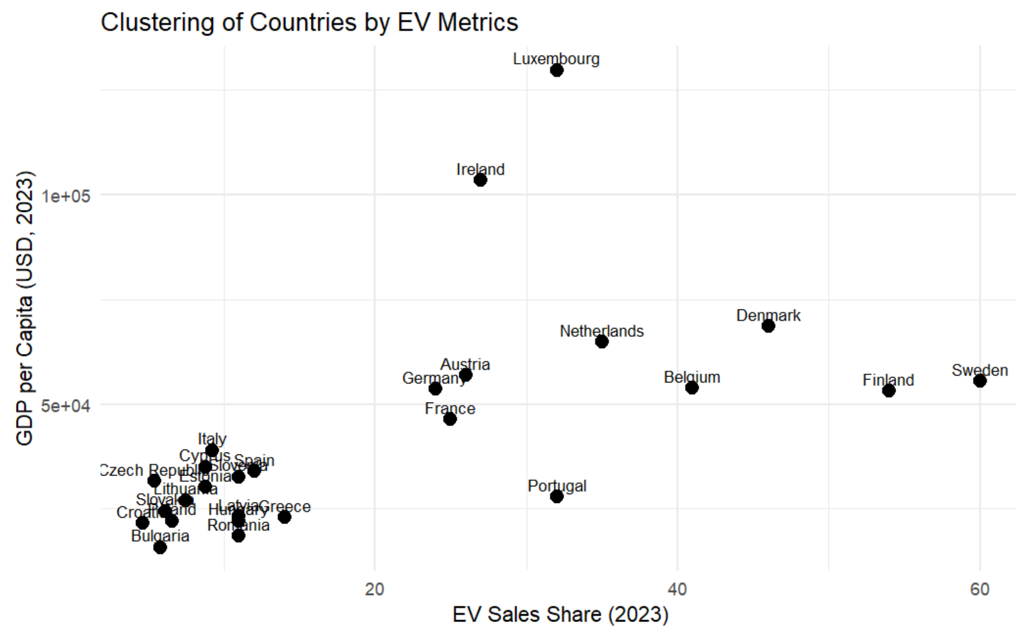

Fig. 1. Clustering of countries based on EV sales share and GDP per capita in 2023. Countries with higher EV sales shares generally exhibit higher GDP per capita, with two distinct clusters visible: Cluster 1 comprises countries with EV sales shares exceeding 20%, and Cluster 2 includes those with shares below 20%.

it against benchmarks, including the geometric averages of relevant variables over the past 5 and 3 years.

Due to data limitations, our forecasts covered 13 countries, including 9 in Cluster 1 (richer countries) and 4 in Cluster 2 (poorer countries), ensuring a reliable basis for projections.

III. Results

A. Clustering

As visible in Figure 1, by plotting the different countries' net median income per capita and the EV sales share of their light-duty vehicle markets, based on 2023 data, we can identify two distinct clusters. Cluster 1 consists countries with 2023 EV sales shares exceeding 20% while Cluster 2 consists of countries with EV sales shares below 20%. Cluster 2 countries generally exhibit a lower GDP per capita than Cluster 1 countries, except for Portugal. The tabulated list of these clusters are shown in Table II.

TABLE II
EU27 Clustered

Cluster 1	**Cluster 2**
Austria	Bulgaria
Belgium	Croatia
Denmark	Cyprus
Finland	Czech Republic
France	Estonia
Germany	Greece
Ireland	Hungary
Luxembourg	Italy
Netherlands	Latvia
Portugal	Lithuania
Sweden	Malta
	Poland
	Romania
	Slovakia
	Slovenia
	Spain

B. Cluster Regressions

Our results confirm that charging stations are good indicators of EV adoption. We regressed each independent variable against BEV sales, and Tables VI and VII summarize the results. BEV sales show a strong correlation with the number of publicly available fast chargers in Cluster 1 (richer) countries, while in Cluster 2 (poorer) countries, both fast and slow chargers strongly correlate with BEV sales.

Regressing all variables by cluster produced similar results. Tables VIII and IX show that the coefficient on fast chargers has a strong p-value (< 0.01) in Cluster 1 countries. However, in Cluster 2 countries, only slow chargers are significant, while fast chargers are not—contrary to the conclusions from single-variable regressions. This discrepancy likely arises from the collinearity of fast and slow charger networks in these countries. In Cluster 2's single-variable regression (2), the coefficient on fast chargers may partly reflect the effects of slow chargers. Furthermore, we had access to fewer/less data on chargers in Cluster 2 countries compared to Cluster 1 countries, which could explain the greater collinearity observed in the former.

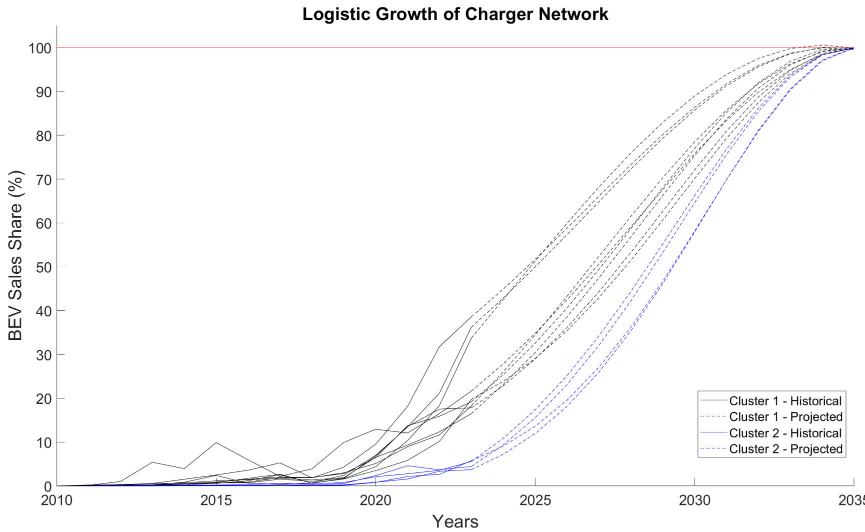

Fig. 2. Logistic growth of charger networks required to achieve 100% BEV sales share by 2035, displaying data for the 13 countries in 2 clusters. Growth rate required to reach 100% target by 2035 is starker for less developed countries than it is for more developed ones.

C. Full Panel Regressions

Running regressions on all 27 EU countries at once reveals the overall picture and confirms the results found in the clusters. As shown in Tables X and XI, the number of publicly available fast chargers explains the variation in BEV sales effectively in both single and multivariable regressions. The clustered analysis further clarifies why slow chargers have lower significance compared with fast chargers, due to collinearity and differences in data availability.

Overall, our linear regression model shows that fast chargers (DC) show strong correlation with BEV sales. As evidenced in the reviewed literature, the lack of charging infrastructure significantly limits EV adoption. In contrast, one-time purchase incentives and the price ratio of electricity to gas consistently fail to show a significant influence on consumer adoption in the regressions.

D. Forecast

As seen in Table III below, our forecasts indicate that 75% of Cluster 2 countries and 33% of Cluster 1 countries surveyed need maximum growth rates exceeding the 5-year average rates (5YA), which serve as our more conservative benchmark. Using the average of the last 3 years (3YA) as the benchmark, only Poland among the 13 countries falls short of meeting the 2035 target.

Given most Cluster 2 countries lack high enough growth rates, while most Cluster 1 countries achieve sufficient growth rates to meet their 2035 goals under the more conservative benchmark, shows that richer countries with greater progress in BEV adoption are more likely to be prepared for the 2035 ban.

TABLE III
LOGISTIC GROWTH FORECAST OF BEV SALES SHARES

Country	Cluster	Required	5YA	3YA
Austria	1	32%	26%	38%
Belgium	1	40%	41%	61%
Denmark	1	20%	53%	75%
Finland	1	15%	47%	90%
France	1	30%	38%	82%
Germany	1	35%	49%	50%
Greece	2	52%	34%	82%
Italy	2	43%	31%	47%
Netherlands	1	24%	22%	40%
Poland	2	52%	44%	30%
Portugal	1	20%	60%	80%
Spain	2	40%	61%	46%
Sweden	1	22%	19%	48%

Austria, the Netherlands, and Sweden require higher growth rates than their five year average, despite being leaders in charger network expansion and BEV adoption [1]. This could be due to a relative plateau in their growth rates in recent years, or an indication that the model doesn't have enough historical datapoints to forecast so far into the future. The higher rates in the last 3 years' average column, combined with the difference in their historical trajectories and required projections in Figure 2 above indicate that some countries may have only recently ramped up their investment in EV adoption. As a result, these elevated growth rates might not be sustainable in the long term. In general, while this forecast is helpful to make generalized claims about the different clusters and across the panel, it shouldn't be used to explain individual countries.

Overall, the forecasting method presented here is not suitable as a benchmark for determining whether countries will meet their targets. However, it can highlight trends, such as whether charger network growth aligns somewhat linearly with BEV sales. If the charger network becomes a limiting factor for adoption in the future, countries that have lagged in BEV adoption so far will face the greatest risk.

IV. Discussion

A. Charger Network

Charging infrastructure must be central to the EU's transportation decarbonization plans. Our findings, aligned with existing literature, confirm that fast (DC) public chargers strongly correlate with EV adoption, while slow chargers also play a crucial role in areas lacking home or workplace charging options [5]. To accelerate infrastructure deployment, governments should prioritize both market and non-market incentives [13].

Without adequate charging networks, the 2035 ban risks being punitive for less developed EU regions, potentially hindering rather than advancing decarbonization efforts [14]. To ensure the ban drives meaningful change, robust investments in charging infrastructure must pair with financial incentives to support the growth rates projected in our analysis. EU officials must also address the ban's distributional effects, as rising EV demand could strain electricity generation and transmission systems, jeopardizing consumer trust and adoption [15]. Overcoming these challenges is critical to achieving a smooth and equitable transition to zero-emission vehicles.

Finally, researchers widely agree that bans on carbon-emitting vehicles or fossil fuel use are ineffective without viable alternatives. Punitive measures alone fail to drive change unless adequate options exist to support the transition [16].

B. Financial Incentives

Our regression analysis found no statistically significant correlation between financial incentives and BEV registrations, with a high p-value suggesting inconclusive results. Inconsistent depth and quality of incentive data likely contributed to these findings, which diverge from prior studies. Normalizing or disaggregating incentives might clarify their impact, but interactions with factors like policy and GDP add complexity [17].

Notably, previous research, including Corradi et al.[18] and Munzel et al.[8] highlights a strong link between financial incentives and EV adoption, suggesting that removing incentives prematurely could hinder fleet electrification [19]. Maintaining financial incentives remains essential within a comprehensive policy strategy.

C. Projections

Our projections show that richer EU countries are on track to transition their car sales by 2035. However, EV adoption remains slow in poorer European countries, requiring further efforts to accelerate progress and meet the 2035 goal. Additionally, some recent protectionist regulations by the EU, like their recent decision to impose tariffs of up to 45% on Chinese EVs risk slowing adoption further by reducing competition among European EV manufacturers and driving up average EV prices [20].

V. Conclusion

Overall, our findings indicate that fast chargers show the greatest correlation with consumer adoption of BEVs. Looking ahead, this provides a good proxy for forecasting the growth rates necessary for BEV sales to reach 100% battery electric vehicle (BEV) sales across the EU by 2035. In order for the ban to provide the correct signals to consumers to replace their carbon-emitting vehicles with their BEV alternatives, instead of becoming punitive to the least developed and poorest parts of the union, the EU should invest in expanding the publicly available charger infrastructure, with an emphasis on access to fast (DC) chargers.

TABLE IV
SINGLE VARIABLE REGRESSION RESULTS FOR BEV SALES IN CLUSTER 1 †

Dependent Variable:	BEV sales			
Model:	(1)	(2)	(3)	(4)
Variables				
One-time purchase incentive	2.572			
	(3.046)			
Publicly available fast chargers		23.58***		
		(5.272)		
Publicly available slow chargers			2.115	
			(1.425)	
Ratio of gas and home electricity prices				237,038.7
				(261,061.5)
Fixed-effects				
Country	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Fit statistics				
Observations	152	142	142	153
R^2	0.52304	0.91559	0.69327	0.51756
Within R^2	0.02442	0.80953	0.30784	0.01117

Clustered (Country) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

†*Countries in Cluster 1: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Luxembourg, Netherlands, Portugal, Sweden*

TABLE V
SINGLE VARIABLE REGRESSION RESULTS FOR BEV SALES IN CLUSTER 2 †

Dependent Variable:	BEV sales			
Model:	(1)	(2)	(3)	(4)
Variables				
One-time purchase incentive	-0.6070			
	(0.9003)			
Publicly available fast chargers		6.963***		
		(0.7146)		
Publicly available slow chargers			1.746***	
			(0.2075)	
Ratio of gas and home electricity prices				27,354.4
				(41,247.0)
Fixed-effects				
Country	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Fit statistics				
Observations	216	152	152	210
R^2	0.45973	0.87321	0.91873	0.46252
Within R^2	0.01413	0.55594	0.71538	0.01363

Clustered (Country) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

†*Countries in Cluster 2: Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Greece, Hungary, Italy, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, Slovenia, Spain*

TABLE VI
SINGLE VARIABLE REGRESSION RESULTS FOR BEV SALES IN CLUSTER 1 †

Dependent Variable:	BEV sales			
Model:	(1)	(2)	(3)	(4)
Variables				
One-time purchase incentive	2.572 (3.046)			
Publicly available fast chargers		23.58*** (5.272)		
Publicly available slow chargers			2.115 (1.425)	
Ratio of gas and home electricity prices				237,038.7 (261,061.5)
Fixed-effects				
Country	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Fit statistics				
Observations	152	142	142	153
R^2	0.52304	0.91559	0.69327	0.51756
Within R^2	0.02442	0.80953	0.30784	0.01117

Clustered (Country) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

†*Countries in Cluster 1: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Luxembourg, Netherlands, Portugal, Sweden*

TABLE VII
SINGLE VARIABLE REGRESSION RESULTS FOR BEV SALES IN CLUSTER 2 †

Dependent Variable:	BEV sales			
Model:	(1)	(2)	(3)	(4)
Variables				
One-time purchase incentive	-0.6070 (0.9003)			
Publicly available fast chargers		6.963*** (0.7146)		
Publicly available slow chargers			1.746*** (0.2075)	
Ratio of gas and home electricity prices				27,354.4 (41,247.0)
Fixed-effects				
Country	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Fit statistics				
Observations	216	152	152	210
R^2	0.45973	0.87321	0.91873	0.46252
Within R^2	0.01413	0.55594	0.71538	0.01363

Clustered (Country) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

†*Countries in Cluster 2: Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Greece, Hungary, Italy, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, Slovenia, Spain*

TABLE VIII
MULTIVARIABLE REGRESSION RESULTS FOR BEV SALES IN CLUSTER 1 †

Dependent Variable:	BEV sales
Model:	(1)
Variables	
One-time purchase incentive	0.9527
	(0.7320)
Publicly available fast chargers	22.82***
	(5.906)
Publicly available slow chargers	0.1374
	(0.2871)
Ratio of gas and home electricity prices	-130,118.9
	(132,770.3)
Fixed-effects	
Country	Yes
Year	Yes
Fit statistics	
Observations	141
Adjusted R^2	0.89970
Within R^2	0.81753

Clustered (Country) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

†*Countries in Cluster 1: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Luxembourg, Netherlands, Portugal, Sweden*

TABLE IX
MULTIVARIABLE REGRESSION RESULTS FOR BEV SALES IN CLUSTER 2 †

Dependent Variable:	BEV sales
Model:	(1)
Variables	
One-time purchase incentive	-0.0830
	(0.4219)
Publicly available fast chargers	-0.1863
	(4.661)
Publicly available slow chargers	1.829**
	(0.7855)
Ratio of gas and home electricity prices	-20,288.7
	(16,472.2)
Fixed-effects	
Country	Yes
Year	Yes
Fit statistics	
Observations	152
Adjusted R^2	0.89897
Within R^2	0.72114

Clustered (Country) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

†*Countries in Cluster 2: Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Greece, Hungary, Italy, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, Slovenia, Spain*

TABLE X
SINGLE VARIABLE REGRESSION RESULTS FOR BEV SALES IN ALL EU COUNTRIES

Dependent Variable:	BEV sales			
Model:	(1)	(2)	(3)	(4)
Variables				
One-time purchase incentive	-0.8264			
	(1.509)			
Publicly available fast chargers		22.70^{***}		
		(4.948)		
Publicly available slow chargers			2.267^{*}	
			(1.308)	
Ratio of gas and home electricity prices				-6,144.3
				(79,305.3)
Fixed-effects				
Country	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Fit statistics				
Observations	368	294	294	363
R^2	0.42041	0.88884	0.70465	0.42463
Within R^2	0.00314	0.76266	0.36943	1.95×10^{-5}

Clustered (Country) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

TABLE XI
MULTIVARIABLE REGRESSION RESULTS FOR BEV SALES IN ALL EU COUNTRIES

Dependent Variable:	BEV sales
Model:	(1)
Variables	
One-time purchase incentive	0.2513
	(0.5437)
Publicly available fast chargers	20.99^{***}
	(5.918)
Publicly available slow chargers	0.3894
	(0.3269)
Ratio of gas and home electricity prices	-104,908.3
	(85,078.0)
Fixed-effects	
Country	Yes
Year	Yes
Fit statistics	
Observations	293
Adjusted R^2	0.87561
Within R^2	0.77428

Clustered (Country) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

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