Optimal road taxation for electric cars in Europe

Daniele De Santis[1*], Alejandro Tirachini[2]

[1] Department of Computer, Control and Management Engineering, Sapienza University of Rome, Italy

[2] Department of Civil Engineering and Management, University of Twente, Enschede, the Netherlands, and Department of Civil Engineering, Universidad de Chile, Chile.

SHORT SUMMARY

This paper determines the optimal kilometer tax (or subsidy) for electric vehicles (EVs) in 30 European countries, for both urban and rural areas. The analysis uses a second-best spatial equilibrium model, considering a market where gasoline and diesel cars are still in use. We analyze how interactions with the broader fiscal system affect the definition of this tax and its implications. Moreover, for each country, we show how the km-tax on EVs should be adjusted as the electric market share changes. Our study addresses an open question in the literature, exploring why different studies found taxing EVs to be optimal rather than subsidizing them in rural areas. We demonstrate this outcome is due to limited externalities' impact in rural areas, which reduces the weight of the corrective component of the km-tax. Consequently, the fiscal interaction effect – positive when EVs' share approaches zero – dominates, making taxation the optimal policy.

Keywords: Road pricing; Kilometer tax; Pricing and capacity optimization; Environmental impacts on transport; Transport economics and policy

1. INTRODUCTION

The issue of internalizing the negative externalities caused by market imperfections has been a central topic in economic theory since the work of Pigou (1920). Pigou's principle advocates for the use of corrective taxes to ensure that the marginal private cost of an activity equal to its marginal social cost. In the context of road transport, the external costs are associated with congestion, air pollution, climate change, habitat damage, well-to-tank emissions, noise, and accident-related risks.

One of the most influential contributions to road transport pricing is the model proposed by Parry & Small, 2005)on optimal fuel taxation. With our paper we extend the Parry and Small (2005) model to calculate optimal kilometer tax EVs across several European countries. This paper adopts a second-best spatial pricing model for road pricing. The second-best approach is preferable to the first-best – which involves pricing individual roads based on exact marginal costs – because it balances economic efficiency with practical implementation, avoiding the complexity and high costs of achieving perfect marginal cost pricing (Rouwendal & Verhoef, 2006).

In recent years, the literature has increasingly focused on how optimal road taxation evolves as EVs begin to penetrate the private automobile market. Hirte and Tscharaktschiew (2013) analyze the German private transport sector in urban and suburban areas – in a market with both EVs and internal combustion engine vehicles (ICEVs) – to determine the optimal electricity tax. Using a spatial general equilibrium model, the authors find that EVs should be taxed rather than subsidized – even if this may slow down the market penetration of EVs – since they produce negative externalities. Tscharaktschiew (2015) and Wangsness (2018) present similar studies based on the

framework of Parry and Small (2005). Tscharaktschiew (2015) seeks to the define the optimal gasoline tax for the German market, where diesel, gasoline and electric cars are present. Wangsness (2018) focuses on the benefits of a distance-based tax over a fuel/electricity tax, defining the optimal kilometer tax for ICEVs and EVs in Norway. Tscharaktschiew (2015) concludes that optimal gasoline taxes should decline as the share of EVs increases while Wangsness (2018) finds that EVs should be taxed rather than subsidized; in rural areas, he even suggests that the EV kilometer tax should exceed ICEVs kilometer tax.
The paper by Börjesson et al. (2023) provides a first-best pricing approach. It relies on the SamPers model to estimate traffic flows for each segment of the road network in the Mälardalen region (Sweden). This study offers a forward-looking analysis, assuming a future scenario where EVs account for the entire market share of private vehicles. The authors find that the optimal kilometer tax would primarily target urban areas with high congestion, instead of rural areas where externalities' impact is limited.

Our study makes the following contributions to the literature on road transport taxation. First, it calculates, for the first time, the optimal kilometer tax levels for EVs across 30 countries in Europe, which has striking differences in current EV adoption levels. By incorporating new, official, country-specific data on externalities, our results provide a comprehensive understanding of taxation needs across the continent. Second, our analysis search through the components of taxation, illustrating how the interaction between externality correction and fiscal needs leads to different results (tax or subsidy) in different areas (urban or rural). Finally, we demonstrate how optimal taxation should evolve as the market share of EVs changes.

2. METHODOLOGY

The utility function of a representative traveler is

$$U = u(m_G, n_G, m_D, n_D, m_P, n_P, X, l, T, E) \tag{1}$$

All variables are expressed on a per capita basis, with a bar indicating economy-wide variables that travelers perceive as exogenous. The utility function $u(.)$ is quasi-concave and it's increasing with respect to the following arguments: m_j, the kilometers driven per vehicle of energy type j ($j = G$ for gasoline, $j = D$ for diesel, and $j = P$ for electricity); n_j, the number of vehicles of type j; general consumption X; and leisure l. Conversely, utility decreases with respect to T, the aggregate travel time spent in cars, and E, an index capturing non-congestion-related externalities. Total yearly travel time for agent i is defined as:

$$T_i = \pi(\bar{M})M \tag{2}$$

Where π represents the (average) travel time per kilometer and it depends on the aggregate vehicle kilometrage $\bar{M}$, that it is assumed as exogenous by the agent ($\pi' > 0$). M represents the aggregate distance traveled by the representative household using each energy type, namely:

$$M = M_G + M_D + M_P = m_G n_G + m_D n_D + m_P n_P \tag{3}$$

The household's monetary budget constraint, which equates expenditures on travel activities and general consumption with net income, can be expressed as follows:

$$\sum_{j=G,D,P} \left\{ \left[\left(r_j + \tau_j \right) \tilde{j} + c_j^d \right] m_j + \tau_{m_j} m_j + c(\tilde{j}) + \varphi_j \right\} n_j + P_X X = (1 - \tau_L) wL \tag{4}$$

Where: r_j is the pre-tax consumer price per unit of energy type j; τ_j is the tax value per unit of energy type j; $\tilde{j}$ represents the energy intensity for cars of technology j; c_j^d denotes the other distance-dependent costs; τ_{m_j} is the kilometer tax; $c(\tilde{j})$ denotes the other costs of owning a car, dependent on energy intensity; φ_j represents the sum of the annual ownership tax and the annuity of the purchase tax for vehicle type; P_X is the average price of other consumption goods; τ_L is the labour tax; w is the average hourly wage; L represents the hours spent working.
The relationship between fuel use, energy intensity and kilometers driven is given by:

$$G = \tilde{g}M_G = \tilde{g}m_G n_G \quad (5)$$

$$D = \tilde{d}M_D = \tilde{d}m_D n_D \quad (6)$$

$$P = \tilde{p}M_P = \tilde{p}m_P n_P \quad (7)$$

In this model, households allocate their time across three main activities: working, commuting for work, and leisure. Therefore, the household's time constraint is:

$$L + l + \pi(\bar{M})M = \bar{L} \quad (8)$$

Where $\bar{L}$ is the available time, distributed between labor activities, leisure and car travel.
The government budget constraint, equating fixed public expenditure (GOV) to net revenue, is:

$$GOV = \sum_{j=G,D,P} \left(\tau_j j + \tau_{m_j} m_j n_j + \varphi_j n_j\right) + \tau_L wL \quad (9)$$

This relationship ensures that the government's fiscal policy remains balanced, with public spending fully covered by the available net revenue.
In this framework, firms under perfect competition use constant returns to scale production with labor as the sole input, generating no pure profits. Producer prices and the marginal product of labor, which equals workers' gross wages, remain fixed. Households are assumed to maximize their utility function specified in Equation (1), with respect to the decision variables $\mathrm{m_G}, n_G, \tilde{G}, \mathrm{m_D}, n_D, \tilde{D}, \mathrm{m_P}, n_P, X$ and l. Their choices are subject to the constraints defined by Equations (4) and (7).
To solve the optimization problem, the Lagrangian problem is formulated, where μ denotes the Lagrange multiplier associated with the household's comprehensive economic budget constraint. The household's indirect utility function can be expressed in terms of the following set of parameters: $\Omega = \{\tau_G, \tau_D, \tau_P, \tau_{m_G}, \tau_{m_D}, \tau_{m_P}, \varphi_G, \varphi_D, \varphi_P, \pi, E\}$. These parameters are treated as exogenous by households. The government's objective is to maximize the household's indirect utility function by strategically adjusting policy variables within the road pricing scheme.

$$\begin{aligned} V(\Omega) \equiv \max_{\mathrm{m_G}, n_G, \tilde{G}, \mathrm{m_D}, n_D, \tilde{D}, \mathrm{m_P}, n_P, \tilde{P}, X, l} & u(m_G, n_G, m_D, n_D, m_P, n_P, X, l, T, E) \\ & - \mu \left\{ \sum_{j=G,D,P} \left\{ \left[(r_j + \tau_j)\tilde{j} + c_j^d \right] m_j + \tau_{m_j} m_j + c(\tilde{j}) + \varphi_j \right\} n_j + P_X X \right. \\ & \left. - (1 - \tau_L) w (\bar{L} - l - \pi(\bar{M})M) \right\} \end{aligned} \quad (10)$$

We conduct an analytical exercise to derive the optimal tax on electric vehicle kilometers (τ_{m_P}). After some calculations, we arrive at the following expression for the optimal tax:

$$\tau^*_{m_P} = \tau^C_{m_P} + \tau^{RR}_{m_P} + \tau^{(TI)}_{m_P} + \tau^{CF}_{m_P} \tag{11}$$

The first component formulation is:

$$\tau^C_{m_P} = \sum_{j=G,D,P} (e_j\chi_j) + \left(e^{nc}_{m_G} + e^c_m(M)\right)\eta_G + \left(e^{nc}_{m_D} + e^c_m(M)\right)\eta_D + e^{nc}_{m_P} + e^c_m(M) \tag{12}$$

And it is the corrective – or Pigouvian – tax, that is set equal to the marginal cost of negative externalities. This tax addresses externalities by internalizing marginal external costs, ensuring private costs align with social costs. In Eq. (12), the parameter e_j represents the marginal external cost (MEC) associated with the consumption of fuel/power j. The marginal external cost of driving 1 kilometer, which contributes to traffic congestion, is denoted as $e^c_m(M)$. This parameter increases with traffic volume, reflecting the congestion externality's dependence on aggregate driving activity. Similarly, the parameters $e^{nc}_{m_j}$ capture the non-congestion-related MEC per kilometer driven by cars of technology j. The parameters χ_j represent how the consumptions of fuels/power of technology j changes in response to variations in τ_{m_P}. Similarly, the parameters η_G and η_D indicate how the distance traveled with a gasoline car and a diesel car, respectively, responds to changes in τ_{m_P}.
The second component of Eq. (11) is the revenue recycling component:

$$\tau^{RR}_{m_P} = \Omega_{\tau_L}\left(\frac{R_P\tilde{P} + c^d_P + \tau_{m_P}}{-\varepsilon_{M_P}} - \tau_{m_P}\right) \tag{13}$$

This term comprises the product of the marginal cost of public funds Ω_{τ_L} and the net tax revenue generated by marginally increasing the EV-kilometer tax. The parameter ε_{M_P} represents the own-price elasticity of EV kilometers. This component depends on the elasticity of demand for the taxed activity, such as EV kilometers traveled. When demand is less elastic, revenue remains more consistent and can be recycled more effectively.

The third term in Eq. (11) is the tax interaction effect, excluding congestion feedbacks. This component accounts for how changes in the EV-kilometer tax interact with pre-existing distortions in the economy, such as labor market inefficiencies. Its formulation is the following:

$$\begin{aligned}\tau^{(TI)}_{m_P} = -\left(1 + \Omega_{\tau_L}\right)\Bigg[&\left(\frac{\tau_L(R_P\tilde{P} + c^d_P + \tau_{m_P})(\varepsilon^c_{MI} + \varepsilon_{LI})}{-\varepsilon_{M_P}(1-\tau_L)}\right) + \tau_{m_G}\eta_G + \tau_{m_D}\eta_D \\ &+ \sum_{j=G,D,P}(\tau_j\chi_j) + \tau_P\tilde{P} + \sum_{j=G,D,P}(Z_j\kappa_j)\Bigg]\end{aligned} \tag{14}$$

Where the parameters $Z_j = \tau_{m_j}m_j + \tau_j\tilde{j}m_j + \varphi_j$ denote the annual per-vehicle tax revenue derived from technology j. The parameter κ_j reflects how the number of vehicles of technology j adjusts in response to changes in τ_{m_P}. ε^c_{MI} represents the income elasticity of vehicle kilometers, while ε_{LI} is the compensated income elasticity of vehicle kilometers.
The fourth term is the congestion feedback component:

$$\tau_{m_P}^{CF} = \left(1 + \Omega_{\tau_L}\right) \frac{\tau_L}{1 - \tau_L} (\varepsilon_{LI}(1 - \varepsilon_{MI})\varepsilon_{LL}^c) e_m^c(M)(1 + \eta_G + \eta_D) \qquad (15)$$

The congestion feedback component reflects the welfare benefits of reduced traffic congestion.

The dataset construction draws on multiple sources. Externalities are based on the Externalities Handbook by the European Commission (2019), refined through further analysis. Elasticities were derived from prior studies by Tscharaktschiew (2015), Wasgnessen (2018), and Fridstrøm and Østli (2021). Vehicle numbers and household shares across countries rely on the report by Acea (2024). Country-specific data on taxation levels, including fuels and labor, come from the Tax Foundation (2024a, 2024b). For fuel and power prices, as well as efficiency metrics, we used country-specific datasets such as Cargopedia (2024) and Eurostat (2024). For other car taxations (e.g., ownership) or EV subsidies we relied on the report by Transport Environment (2022).

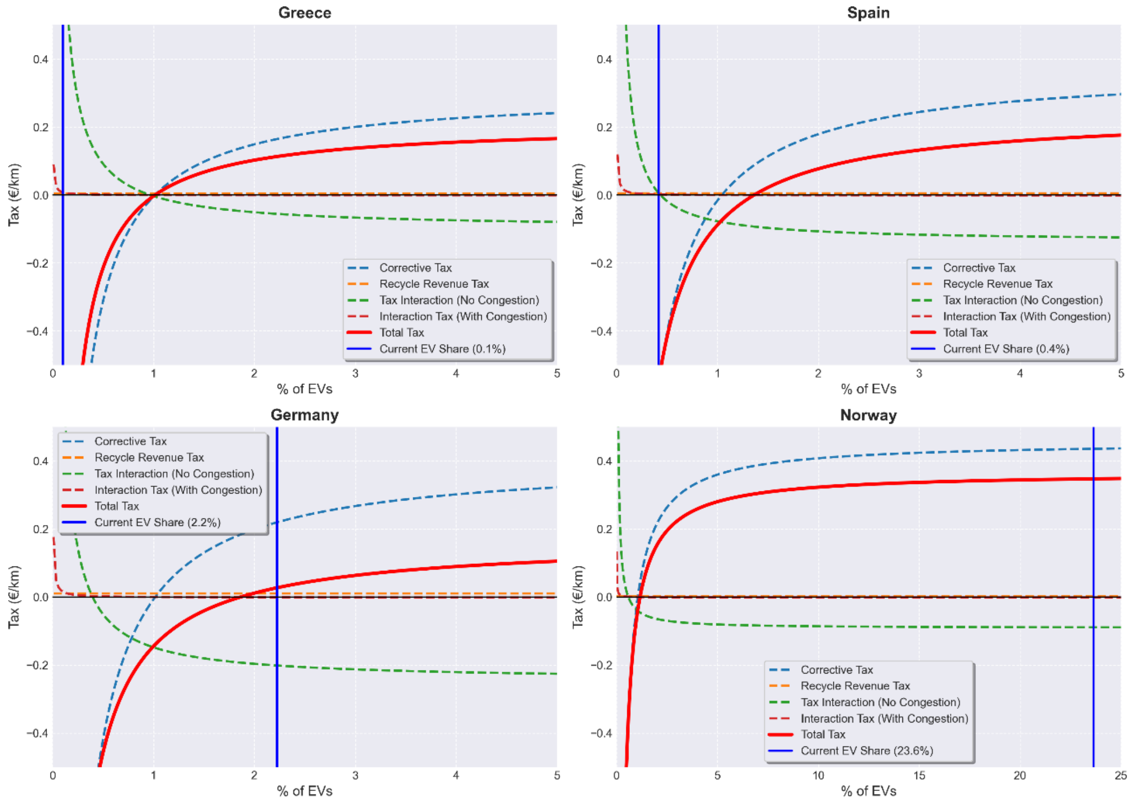
3. RESULTS AND DISCUSSION

Before analyzing the results regarding the optimal kilometer tax for EVs in each European country, it is crucial to understand the dynamics that determine whether taxation should be negative (i.e., a subsidy) or not, at every level of the share of EVs in the market. This analysis assumes a constant number of total cars per household and a constant ratio between gasoline and diesel vehicles. Figure 1 illustrates these dynamics for four European countries within their respective urban areas, while Figure 2 presents the same analysis for rural areas. The selected countries represent different stages of EV adoption: Greece, that is the country with the lowest EV adoption rate; Spain, representing the first tercile; Germany, representing the second tercile; and Norway, the country with the highest EV adoption rate. The graphs include all four components previously introduced.

It is evident from the graph that the behavior of several components diverges as the EV share approaches zero, and that the trends of the total tax differs between urban and rural areas. To explain these differences, it is necessary to analyze the specific role of each component that exhibits divergent behavior.

When $n_P \to 0$, the corrective component diverges to$-\infty$. The corrective components suggest to heavily subsidize electric vehicles when their market share is minimal, incentivizing their adoption and ensuring their presence in the market. Electric cars produce fewer negative externalities than diesel or gasoline cars, and subsidies can support their introduction, accelerating the decarbonization process by reducing reliance on more polluting alternatives.

Figure 1: Tax Components Sensitivity to EVs share, Urban Area



Regarding the fiscal interaction component, it diverges towards $+\infty$ when $n_P \rightarrow 0$. In order to explain this result it is important to understand what is the relationship between the km-taxes and the other taxes included in this framework. Taxes on conventional fuels (diesel and gasoline, τ_G and τ_D) and vehicle ownership costs for traditional vehicles (φ_G and φ_D) have a positive interaction with τ_{m_P}. This means that any revenue lost from these existing taxes due to the migration of users toward electric vehicles must be compensated, increasing the fiscal interaction component of τ_{m_P}. The total revenue lost due to the adoption of electric vehicles must still be compensated to maintain fiscal balance, namely in order to satisfy the government budget constraint expressed in Eq. (9). The interaction with labor taxes (τ_L) further increase this effect through the marginal cost of public funds (Ω_{τ_L}), which measures the economic distortion caused by raising additional revenue through labor taxation. To avoid increasing τ_L, which would impose additional distortions on the labor market, the government shifts the compensatory fiscal burden onto τ_{m_P}. Moreover, although both φ_P and τ_P interact negatively with τ_{m_P}, their ability to balance the divergence is fundamentally limited when n_p is small. All these three taxes depend on the same user base. As $n_P \rightarrow 0$, the revenue-generating capacity of φ_P and τ_P diminishes proportionally, forcing τ_{m_P} to take on most of the compensatory fiscal burden. This is amplified by the dominance of positive interactions, as the revenue losses from fuel taxes and the inefficiency of labor taxes create stronger upward pressure on τ_{m_P}.

The congestion feedback component represents the potential increase in traffic caused by the introduction of a new electric vehicle. Therefore, it diverges to $+\infty$ because, if the tax were to act as a subsidy instead, it would encourage the introduction of additional vehicles, leading to traffic increase.

Ultimately, the total tax will diverge to $+\infty$ if the fiscal interaction component outweighs the corrective tax – and this is the case of rural areas; otherwise, it will tend toward $-\infty$, as it does for urban areas.

Figure 2: Tax Components Sensitivity to EVs share, Rural Area

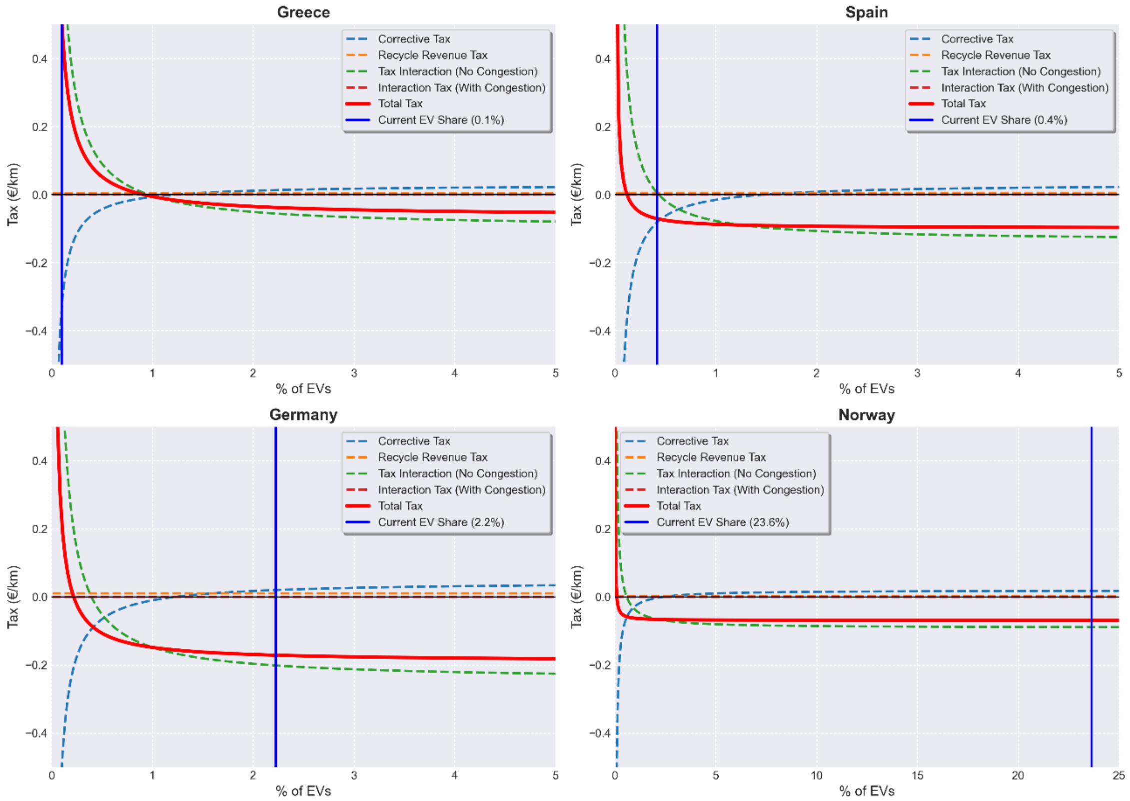
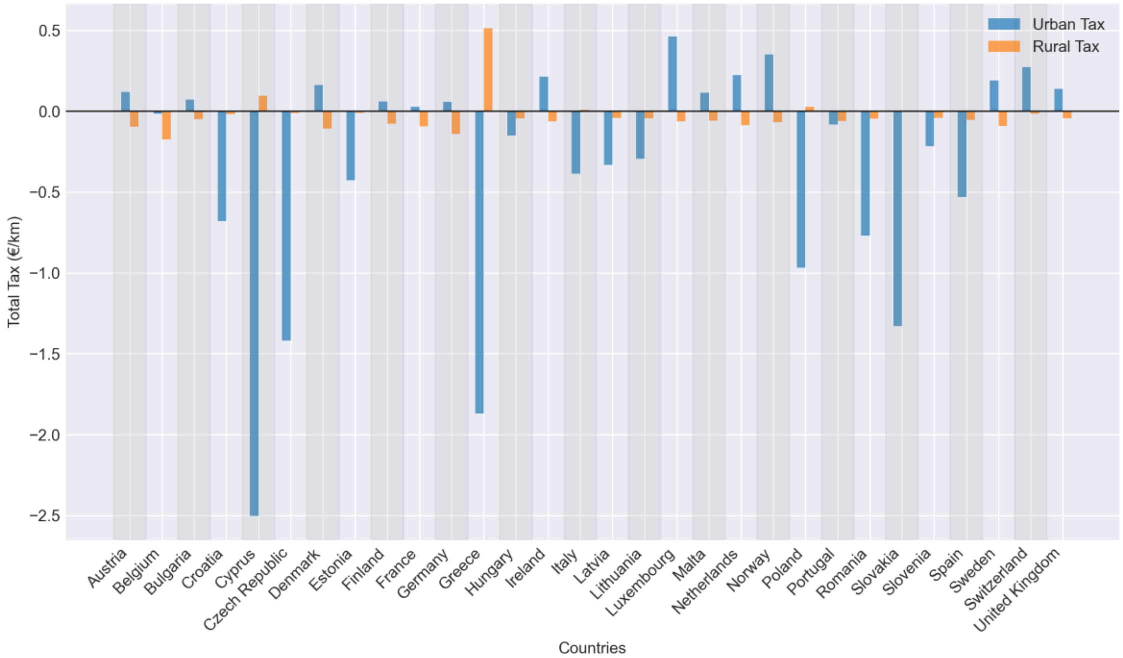


Figure 3 shows the optimal tax or subsidy per kilometer for EVs across all European countries, with the current EV adoption levels, distinguishing between urban and rural areas. The results can be explained by the previous analysis. In countries where EVs are not yet widespread (e.g., Cyprus, Czech Republic, Greece), urban areas typically have high subsidies, while rural areas often face higher taxes. In contrast, in countries with high EV adoption, subsidies in urban areas are more moderate, and in some cases, electric vehicles are taxed (e.g., Luxemburg, the Netherlands, Norway) due to the negative externalities they generate.

Figure 3: Urban and Rural km-tax for EVs



The results show that the EV-kilometer tax levels vary significantly across European countries due to differences in the market share of electric vehicles. In the early stages of market penetration, tax levels change rapidly but tend to stabilize as the share of electric vehicles increases.

4. CONCLUSIONS

This work demonstrates that, depending on the magnitude of the externalities produced, the total tax can take highly positive or highly negative values at very low levels ofEV presence). For example, due to fiscal interactions, maximizing welfare does not justify subsidizing EVs in rural areas when their market presence is still low; it is more effective to introduce subsidies at a later stage. While this approach might slow the adoption of EVs and, consequently, the ecological transition in the transportation sector, it ensures welfare maximization because pollution is not a sufficiently critical issue in rural areas. To make subsidies feasible in rural areas– when the market penetration of EVs is still in its early stages – the costs associated with environmental negative externalities would need to be increased.

5. REFERENCES

Acea. (2024). *Vehicles in use in Europe*.

Börjesson, M., Asplund, D., & Hamilton, C. (2023). Optimal kilometre tax for electric vehicles. *Transport Policy*, *134*, 52–64. https://doi.org/10.1016/j.tranpol.2023.01.019

Cargopedia. (2024). *European Fuel Prices*.

European Commission. (2019). *Handbook on the external costs of transport*.

Eurostat. (2024). *Electricity price statistics*.

Fridstrøm, L., & Østli, V. (2021). Direct and cross price elasticities of demand for gasoline, diesel, hybrid and battery electric cars: the case of Norway. *European Transport Research Review*, *13*(1), 3. https://doi.org/10.1186/s12544-020-00454-2

Hirte, G., & Tscharaktschiew, S. (2013). The optimal subsidy on electric vehicles in German metropolitan areas: A spatial general equilibrium analysis. *Energy Economics*, *40*, 515–528. https://doi.org/10.1016/j.eneco.2013.08.001

Parry, I. W. H., & Small, K. A. (2005). Does Britain or the United States Have the Right Gasoline Tax? *American Economic Review*, *95*(4), 1276–1289. https://doi.org/10.1257/0002828054825510

Pigou, A. C. (1920). *Economics of Welfare* (1st ed.).

Rouwendal, J., & Verhoef, E. T. (2006). Basic economic principles of road pricing: From theory to applications. *Transport Policy*, *13*(2), 106–114. https://doi.org/10.1016/j.tranpol.2005.11.007

Tax Foundation. (2024a). *Diesel and Gas Tax in Europe*.

Tax Foundation. (2024b). *Tax Burden on Labor in Europe*.

Transport Environment. (2022). *The good tax guide: A comparison of car taxation in Europe*.

Tscharaktschiew, S. (2015). How much should gasoline be taxed when electric vehicles conquer the market? An analysis of the mismatch between efficient and existing gasoline taxes under emerging electric mobility. *Transportation Research Part D: Transport and Environment*, *39*, 89–113. https://doi.org/10.1016/j.trd.2015.06.007

Wangsness, P. B. (2018). How to road price in a world with electric vehicles and government budget constraints. *Transportation Research Part D: Transport and Environment*, *65*, 635–657. https://doi.org/10.1016/j.trd.2018.10.002