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Energy Tax Spillovers and Energy Consumption: A Spatial Econometric Analysis of EU Countries

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This paper investigates the spatial impacts of energy taxation on energy consumption in 25 EU countries. For this purpose, we use spatial panel models. Our results reveal the presence of positive and significant energy consumption spillovers among neighbouring countries. Furthermore, energy taxes reduce consumption through both direct and indirect effects. These results underscore the need for policy coordination among countries to achieve EU decarbonization targets.

I. Introduction

In this paper, we examine the spatial effects of energy taxes on total energy consumption in 25 European Union (EU) countries. Our hypothesis is that energy taxation reduces energy consumption in both the domestic country and neighbouring countries. The energy tax serves as a Pigouvian tax by internalizing the negative externalities associated with energy consumption.

Testing this hypothesis is important because, over the past decade, the EU has adopted a range of policy instruments to reduce environmental degradation. Energy taxation has played a central role among these instruments. In highly integrated markets such as the EU, these impacts can transcend national borders. This creates cross-border policy externalities, whereby a tax change in one country influences neighbouring countries through different channels, including shared infrastructure and cross-border energy trade.

We employ panel data from 25 EU countries covering the period 1995–2020 and find that energy taxation has significant direct and indirect effects on energy consumption. The existing literature on energy consumption has predominantly concentrated on the domestic impacts of energy taxation (Bashir et al., 2021; Morley, 2012; Sackitey, 2023). Some studies also investigate spatial interaction effects in energy consumption across countries (Flores-Chamba et al., 2019; Jeetoo, 2022), but only a few address country-level interdependence through the impact of environmental taxes on renewable energy consumption (Shahnazi & Dehghan Shabani, 2020).

This study contributes to the literature in two important ways. First, it extends existing research beyond country-specific effects by identifying and quantifying spatial interdependence in energy consumption across EU member states. Using spatial econometric techniques, the analysis captures how changes in energy consumption and taxation in one country propagate through geographically connected economies. Second, the study decomposes the overall effect of energy taxation into direct and indirect components, thereby distinguishing its domestic impact from the cross-border spillovers transmitted to neighbouring countries. This distinction provides a more complete assessment of the effectiveness of energy taxation and offers new evidence on why coordinated policy action may be necessary in an economically integrated region such as the EU.

The remainder of the paper is organised as follows. Section II describes the data, specifies the baseline and spatial econometric models, and explains the construction of the spatial weight matrix. Section III presents the model-selection tests, discusses the estimated direct and spillover effects, and reports the robustness analyses. Section IV concludes by summarising the main findings, outlining their policy implications, and identifying directions for future research.

II. Data And Methodology

A. Data

This study uses annual panel data for 25 EU countries over the period 1995–2020, with Cyprus and Malta excluded. The sample period ends in 2020 because financial

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development (*FD*) data are unavailable after that year. Equation (1) presents the panel fixed-effects model:

$$lnEC_{it} = a_i + \beta_1 ETAX_{it} + \beta_2 lnGDPpc_{it} + \beta_3 TOP_{it} + \beta_4 lnUR_{it} + \beta_5 FD_{it} + \varepsilon_{it} \quad (1)$$

here, α_i denotes country-specific fixed effects. β_i are the coefficients of the explanatory variables. $lnEC$ is denotes energy consumption per capita. $ETAX$ denotes energy tax revenue as a share of GDP. Energy tax revenue comprises revenue exclusively from energy-related taxes. The model also includes $lnGDPpc$ (GDP per capita at constant 2015 prices), TOP (trade openness), $lnUR$ (urban population), and FD (the financial development index) as control variables. These control variables reflect the key factors influencing energy demand. In this context, $lnGDPpc$ is expected to increase energy consumption. The effects of TOP, UR, and FD could be positive or negative because of mechanisms such as economies of scale, clean-technology transfer, and efficiency gains. *ln* denotes the natural logarithm, and the it represents the panel-data dimensions (country i and time t). All variables are sourced from internationally standardised databases to ensure cross-country comparability. $lnEC$, $lnGDPpc$, TOP and UR are obtained from the World Bank. $ETAX$ is sourced from Eurostat, while the FD index is obtained from the IMF database.

Figure 1 shows energy consumption across EU countries in 2020. The figure reveals clear geographical clustering in energy-consumption patterns. This visible spatial correlation between neighbouring countries indicates that energy consumption is not solely a country-specific phenomenon but is also strongly influenced by regional proximity. Table 1 presents descriptive statistics that demonstrate substantial variation in the energy and economic profiles of EU member states.

B. Methodology

This study employs a fixed-effects spatial autoregressive (SAR) model to measure the spillover effects of energy taxation on energy consumption across EU member states. The SAR model used in this study is specified as follows:

$$lnEC_{it} = a_i + \rho \sum_{j=1}^{N} w_{ij} lnEC_{jt} + \beta_1 ETAX_{it} + \beta_2 lnGDPpc_{it} + \beta_3 TOP_{it} + \beta_4 lnUR_{it} + \beta_5 FD_{it} + \varepsilon_{it} \quad (2)$$

where ρ is the spatial autoregressive coefficient measuring the strength of spatial dependence. w_{ij} is the (i, j)th element of the N × N spatial weight matrix W (Elhorst, 2014). The spatial weight matrix W, is constructed based on the Euclidean distance between country centroids. The elements of W are defined as $w_{ij} = 1/d_{ij}$ for $i \neq j$ and $w_{ii} = 0$. Here, d_{ij} represents the geographic distance between countries i and j. The matrix is row-standardised to ensure that each row sums to unity. This specification assumes that spatial interdependencies decline with geographic distance, consistent with patterns of energy trade and infrastructure linkages across the EU. Geographic distance is used to construct the spatial weight matrix because it is exogenous, unlike measures such as trade flows or energy-network connections, which may introduce endogeneity and bias the results. We do not use a contiguity matrix because it fails to account for spatial relationships beyond shared land borders. Country-level longitude and latitude data used to construct the weight matrix were obtained from the CEPII database (Mayer & Zignago, 2011). As an alternative specification, the spatial error model (SEM) accounts for spatial dependence by incorporating spatial correlation into the error term.

III. Results

In this study, we first test for the presence of spatial dependence by applying LM tests to the residuals of the estimated fixed-effects model. The estimation results are reported in Table 2. The LM tests indicate the presence of both spatial lag and spatial error dependence. When both LM tests are significant, their robust versions guide model choice; here, the insignificant robust LM error test supports the SAR model over the SEM. A more generalised specification, the Spatial Durbin model, was not used as it suffered from overparameterisation, resulting in statistically insignificant results for several critical variables. After the appropriate spatial model determination, the SAR model is estimated using maximum likelihood. In addition, the LR statistic (1802.368) is significant, confirming that a fixed effects structure is preferred over the pooled alternative.

The results of the SAR model indicate strong spatial dependence in EU energy consumption. The spatial autoregressive coefficient of 0.66 is notably high and significant, indicating a more pronounced degree of spatial dependence than previously documented in the literature (Flores-Chamba et al., 2019; Shahnazi & Dehghan Shabani, 2020). This high value suggests strong regional clustering and policy synchronisation in energy consumption across EU member states, consistent with the economic integration of EU energy markets.

According to the estimation results, all explanatory variables in both the fixed effects and SAR (1) models are statistically significant. The sign of the coefficients is also consistent with our expectations. However, since the SAR model was identified as the more appropriate specification, the coefficients from the standard fixed-effects model may be biased. The coefficients in the SAR (1) model cannot be interpreted as marginal effects (LeSage & Pace, 2009). When energy consumption changes in one country, it affects neighbouring countries through the spatial lag. These changes then feed back to the origin country (Elhorst, 2014). Therefore, the marginal impacts are decomposed into direct and indirect effects using the partial-derivatives approach of LeSage & Pace (2009), based on the matrix $(I - \rho W)^{-1}$. In this framework, direct effects capture domestic impacts, including feedback effects; indirect effects capture spillovers transmitted through the spatial network; and total effects represent the overall equilibrium impact across the system.

All direct and indirect effects are found to be statistically significant and consistent with our expectations. The direct effects confirm that domestic energy consumption is significantly influenced by internal policy and economic factors. On the other hand, the significant indirect effects imply the

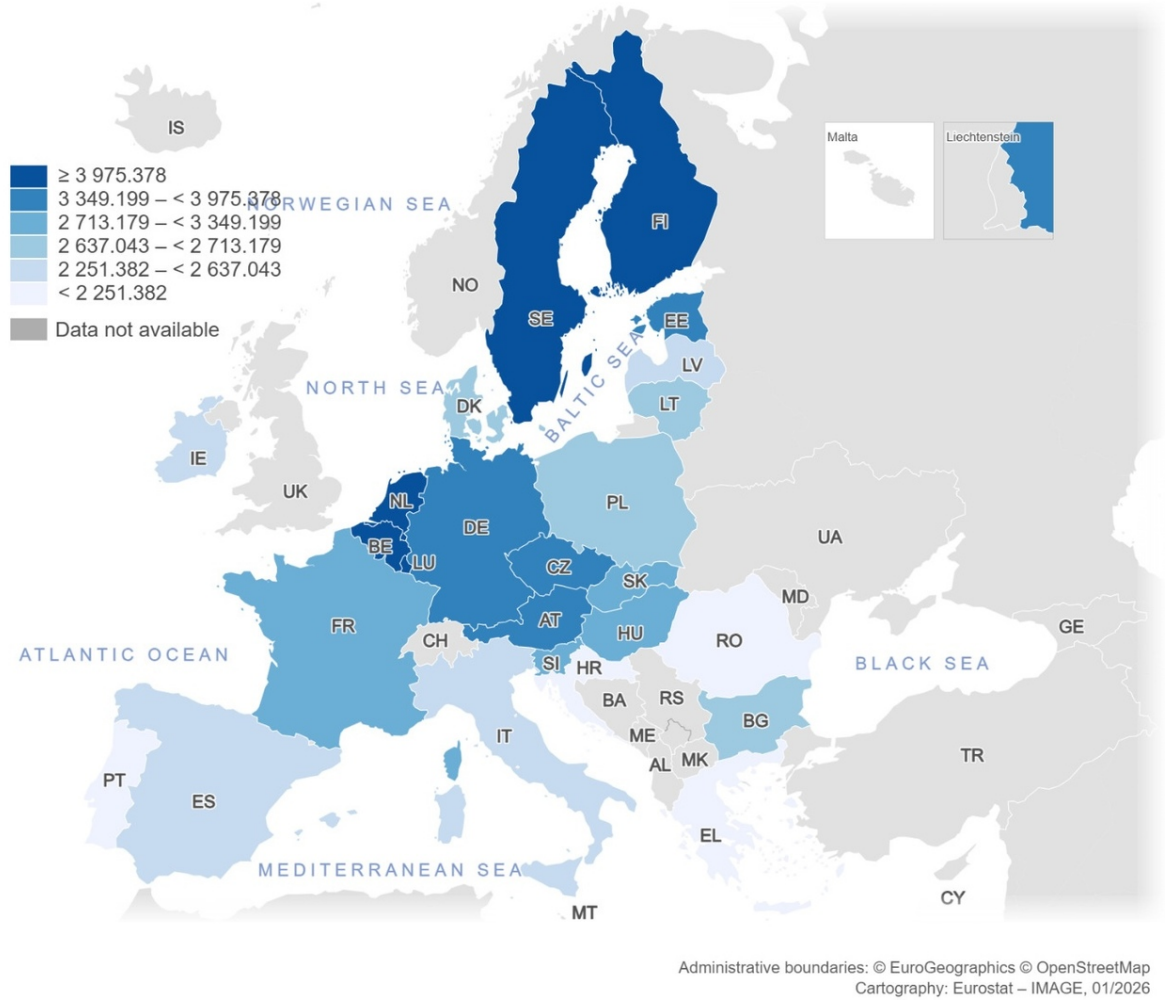

Figure 1. Energy consumption in 2020

Note: This figure maps energy consumption across EU countries in 2020 using the IMAGE Interactive Map Generator.

Table 1. Descriptive statistics

Variable	$lnEC_{it}$	$ETAX_{it}$	$lnGDP_{PCit}$	TOP_{it}	$lnUR_{it}$	FD_{it}
Mean	8.102	2.036	9.985	107.197	15.626	0.529
Median	8.088	1.980	9.960	91.754	15.645	0.546
Maximum	9.152	3.830	11.630	382.661	17.981	0.902
Minimum	7.365	0.540	8.171	36.126	12.733	0.092
Std. Dev.	0.372	0.519	0.755	54.943	1.248	0.208
Skewness	0.379	0.630	-0.167	1.923	0.002	-0.244
Kurtosis	2.654	3.693	2.326	8.248	2.540	1.812
Observations	650	650	650	650	650	650

Note: This table reports descriptive statistics of the variables used in the analysis.

presence of spatial spillovers across EU countries. Specifically, energy taxation has a negative and statistically significant effect on energy consumption in the SAR model. The direct effect of *ETAX* is -0.024, suggesting that higher energy taxes reduce domestic energy consumption. The indirect effect is -0.045, which is also negative and significant. This shows that higher energy taxes in neighbouring countries lower a country's energy consumption as well. The spillover is found to be larger than the direct impact. The implied total effect is -0.070. This effect can be explained by rising energy costs constraining consumption, encouraging firms to adopt more efficient production techniques and motivating households to practice energy conservation. The magnitude of the coefficient demonstrates a substantial economic effect.

Table 2. Estimation results

Dep. Var: $lnEC_{it}$		Fixed Effects	SAR (1)	Direct effect	Indirect effect	Total effect
$ETAX_{it}$		-0.035***	-0.022***	-0.024***	-0.045***	-0.070***
$lnGDP_{PCit}$		0.066***	0.077***	0.083***	0.154***	0.237***
TOP_{it}		-0.000***	-0.0004**	-0.0004*	-0.0007*	-0.001*
$lnUR_{it}$		-0.567***	-0.421***	-0.448***	-0.833***	-1.281***
FD_{it}		0.220***	0.089**	0.092**	0.169*	0.261*
ρ			0.666***			
LR (Pooled/Fixed Effects)			1802.368***			
R^2 (Within)		0.309	0.392			
Log likelihood			912.397			
SAR	LM_ρ (Fixed/SAR)	370.155***				
	RobustLM_ρ (Fixed/SAR)	96.847***				
SEM	LM_λ (Fixed/SEM)	273.687***				
	Robust-LM_λ (Fixed/SEM)	0.378				

Note: This table reports the estimation results. $lnEC_{it}$ denotes energy consumption per capita; $ETAX_{it}$ denotes energy tax revenue (% of GDP); $lnGDP_{PCit}$ denotes GDP per capita; TOP_{it} denotes trade openness; $lnUR_{it}$ denotes the urban population; and FD_{it} denotes the financial development index. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

The control variables, *lnGDPpc and FD, have* positive and significant direct and spillover effects. This suggests that higher income and greater financial development are associated with higher energy consumption both domestically and through regional linkages. Trade openness has a small but negative effect. *lnUR* shows a strong negative association, with sizeable direct and indirect effects, implying that greater urbanisation is linked to lower energy consumption and that this relationship also transmits across borders. The negative coefficients for trade openness and urbanisation point to efficiency gains within the EU, acting both directly and indirectly. In this respect, trade openness may facilitate the adoption of cleaner technologies, while urbanisation may support more efficient infrastructure and public transport networks. Both factors may thereby reduce overall energy consumption.

To check the robustness of the estimated coefficients, the models were re-estimated using alternative weight matrices based on five nearest neighbours (k5) and ten nearest neighbours (k10) (Bucak et al., 2024). The weights are defined as the inverse of the distance between neighbouring countries and are set to zero for all other country pairs. As shown in Table 3, the coefficients, including the spatial autoregressive term, obtained from SAR (2) and SAR (3) are consistent with those from SAR (1), while the direct and indirect effects of *ETAX* are negative and significant under both specifications, indicating that the main findings are robust to the choice of weight matrix. Because SAR (1) yields the highest log-likelihood value and thus a better fit than SAR (2) and SAR (3), it is retained as the primary specification for the main analysis.

To extend the analysis to 2023, the model is re-estimated without the FD variable. As shown in Table 3, the results remain consistent with the benchmark estimates, indicating that the estimated impact of energy taxation is not sensitive to the time frame or the omission of the financial development variable.

IV. Conclusion

This study examines the spatial impacts of energy taxation on energy consumption across 25 EU countries. We use a novel empirical framework to analyse cross-border spatial spillovers, demonstrating how the EU's high level of economic integration amplifies the impact of national energy taxation on regional energy consumption. We demonstrate that energy taxation effectively reduces energy consumption through both direct and indirect channels. The results emphasise the importance of energy taxation as a policy instrument with substantial cross-border effects within the EU, suggesting that national policies alone may be insufficient to achieve long-term sustainability goals. These findings highlight the need for policy coordination at the EU level, including harmonised energy tax rates, joint renewable energy infrastructure frameworks, and synchronised incentive mechanisms.

This study is subject to limitations arising from potential endogeneity between energy consumption and the explanatory variables, as well as from the omission of relevant factors because of data limitations. Future research should consider applying advanced spatial instrumental-variable methods and incorporating a broader set of control variables.

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Table 3. Estimation results using alternative models

	Model with Different Spatial Weight Matrices (1995-2020)						Model without FD variable (1995–2023)		
Dep.Var.: $lnEC_{it}$	SAR (2)	Direct (k5)	Indirect (k5)	SAR (3)	Direct (k10)	Indirect (k10)	SAR (4)	Direct	Indirect
$ETAX_{it}$	-0.026***	-0.027***	-0.021***	-0.024***	-0.026***	-0.031***	-0.016***	-0.017**	-0.037**
$lnGDP_{PCit}$	0.067***	0.071***	0.056***	0.069***	0.074***	0.090***	0.104***	0.115***	0.241***
TOP_{it}	-0.0005**	-0.0005**	-0.0004**	-0.0004**	-0.0005**	-0.0006**	-0.0006***	-0.0007***	-0.001***
$lnUR_{it}$	-0.380***	-0.404***	-0.318***	-0.375***	-0.403***	-0.490***	-0.470***	-0.516***	-1.084***
FD_{it}	0.092**	0.099**	0.077*	0.084**	0.090**	0.110*			
ρ	0.473***			0.576***			0.702***		
R^2 (Within)	0.328			0.345			0.450		
Log likelihood	889.083			901.538			979.463		

Note: This table presents the robustness-analysis estimates. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.
The SAR (4) specification is based on a Euclidean-distance matrix.

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