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SPATIAL CORRELATION BETWEEN CLIMATE CHANGE AND ECONOMIC GROWTH IN EU

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Abstract. Over the past decade, Europe has faced significant challenges due to the increase in net greenhouse gas emissions and the resulting economic losses associated with climate change. This article focuses on a detailed analysis of the trends in such emissions, the economic losses incurred, and the impact of adopted environmental taxation policies. Utilizing data from Eurostat spanning from 2013 to 2021, our study aims to explore the interconnections among these factors, evaluate the effectiveness of implemented fiscal policies in mitigating these impacts, and examine their spatial distribution. Through the application of the Moran's Index, we examined the presence of spatial autocorrelation in the data to identify any significant geographic patterns. Results reveal that there has been a slight decrease in net greenhouse gas emissions across Europe from 2013 to 2021, thanks the efforts to curb them also through environmental taxation policies. The analysis indicates that while environmental taxation policies have been implemented, their effectiveness in reducing emissions and mitigating economic losses varies across regions. Some areas have seen more success in curbing emissions and minimizing economic impacts compared to others.

1. Introduction

The industrial revolution at the beginning of the 20th century led to an increase in global average temperature (Leggett, 2007). Today, rapid climate change is an urgent concern (Tashilova *et al*., 2019). Over the past 200 years, human activities have played a critical role in global warming through the greenhouse effect (Alirezaei *et al*., 2017), with emissions of gases such as carbon dioxide, methane and nitrous oxide resulting from high levels of industrial and economic production (Albergel *et al*., 2010), population growth, deforestation, globalisation, economic expansion and consumption of manufactured goods (Chen *et al*., 2015; Cloy *et al*., 2017). Extreme weather events such as hurricanes, floods, droughts and heatwaves are becoming more frequent and intense (Stott, 2016). The economic impacts of climate change are significant, with predominantly negative effects (Tol, 2009). Extreme events such as hurricanes and droughts damage infrastructure, agriculture, and buildings, resulting in substantial economic losses for governments, businesses, and individuals. In agriculture, reduced productivity decreases food availability, driving up prices and causing economic and social instability (Su and Wen, 2023).

The analysis of per capita income and temperature suggests that climate can contribute to poverty (Masters and McMillan, 2001; Van Kooten, 2004). Low-income countries, already vulnerable, could suffer greater economic damage due to rising temperatures (Dell *et al*., 2008). Reducing greenhouse gas emissions is crucial to mitigating these impacts (Zheng *et al*., 2019), becoming a priority on every country's political agenda. To this end, governments are adopting strategic and concerted policies aimed at environmental sustainability and climate resilience. The OECD recommends the use of fiscal mechanisms to protect the environment, which may include the introduction of new taxes, the restructuring of existing taxes or the reform of legislation to remove subsidies for environmentally harmful activities (Barde, 1999). In this context, environmental taxes play a fundamental role in implementing the concept of sustainable development (Wang *et al*., 2022).

This analysis aims to extend academic literature by exploring the links between increases in net greenhouse gas emissions, economic losses due to climate change and the effectiveness of fiscal policies. Specifically, it investigates spatial autocorrelation in the data and evaluates environmental fiscal policies in mitigating economic impacts in Europe. The document includes the sections: "Data," "Methodology," "Results," and, the final section, "Discussion and Conclusions" provides an in-depth analysis of the results and the conclusions drawn from the study.

2. Data

The study uses the Eurostat time series from 2013 to 2021 to analyse greenhouse gases, energy taxes and climate-related economic losses. This dataset contains a total of 262 observations, including data on emissions of a range of greenhouse gases, measured in CO2 equivalents to allow a standardised comparison of their impact on global warming. In addition to emissions data, the study also examines energy taxes, which are key fiscal instruments used by governments to incentivise reductions in fossil fuel use and promote cleaner energy alternatives (Qadir *et al*., 2021). By analysing energy tax data, the study aims to understand how these fiscal mechanisms have been applied in different countries and to assess their effectiveness in reducing greenhouse gas emissions. The study focuses on 29 European countries (Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland), which provides a robust context to explore the linkages between these factors, to assess the effectiveness of the fiscal policies implemented in mitigating these impacts, and to understand the broader economic implications of climate change (Adger *et al*., 2011; Klein *et al*., 2005). This geographical scope includes countries with varying levels of industrialization, energy use, and climate policies, providing a comprehensive view of European climate policies. The study also examines climate-related economic losses, including costs from extreme events and long-term changes. By correlating these losses with emissions and energy tax policies, the analysis aims to understand how current policies are mitigating the economic damages of climate change.

3. Methodology

Once having selected the indicators of Greenhouse gases (GHG), Energy taxes, and Climate related economic losses, we analyse whether these indicators exhibit spatial correlation. This involves determining if two or more geographic units (countries) are spatially correlated. In line with the study's aim, we subsequently examine the spatial influence of Energy taxes and Climate related economic losses on climate-related economic losses by establishing a Spatial Autoregressive Regression Model.

The theory of spatial correlation has evolved from the necessity to compare geographical units and maps, along with the understanding that georeferenced observations tend not to be independent of each other (Griffith, 2021). Unlike unidirectional temporal correlation, spatial autocorrelation requires identifying correlations in all geographical directions, making the study of this phenomenon particularly complex (Wagner and Fortin, 2005). Nonetheless, the procedures for studying spatial autocorrelation share many similarities with those used for temporal autocorrelation, such as identifying outliers, trends (temporal/spatial) (Fallah Ghalhari and Dadashi Roudbari, 2018), degrees of association, statistical significance, and relevant models.

A fundamental contribution by statistician Moran (1948) was to delineate the mathematical characteristics of spatial autocorrelation, initially referred to as the "contiguity ratio." Moran developed join count statistics based on the probability that neighbouring spatial units were of the same type more often than expected by chance. The Moran’s Index, which measures spatial autocorrelation, can be formalized as follows:

$$\mathrm{I} = \frac{\mathrm{n}}{\sum_{\mathrm{i}=1}^{\mathrm{n}} \sum_{\mathrm{j}=1}^{\mathrm{n}} \mathrm{w}_{\mathrm{ij}} (\mathrm{x}_{\mathrm{i}} - \tilde{\mathrm{x}}) (\mathrm{x}_{\mathrm{j}} - \tilde{\mathrm{x}})}$$

where n is the number of spatial units, x_{i} and x_{j} are values of the variable being analyzed for spatial units i and j, respectively, $\tilde{\mathrm{x}}$ is the mean of the variable, and w_{ij} is the spatial weight between spatial units i and j. The p-value indicates the significance of Moran's I statistic.

Spatial Autoregressive (SAR) models are commonly employed in various fields such as geography (Dong and Harris, 2015) or economics (Bekti *et al*., 2014) to analyse spatial relationships and make predictions based on spatially correlated data. SAR models aim to estimate spatial regression coefficients and generate values at spatial sites. By leveraging information from neighbouring locations, SAR models enhance the accuracy of estimations by smoothing observed data (Thorson, 2019).

Let Y be the dependent variable used to model observations. The spatial regression framework can be expressed as:

$$Y = \rho WLY + X\beta + \varepsilon$$

or adopting the notation of the variables used in this study:

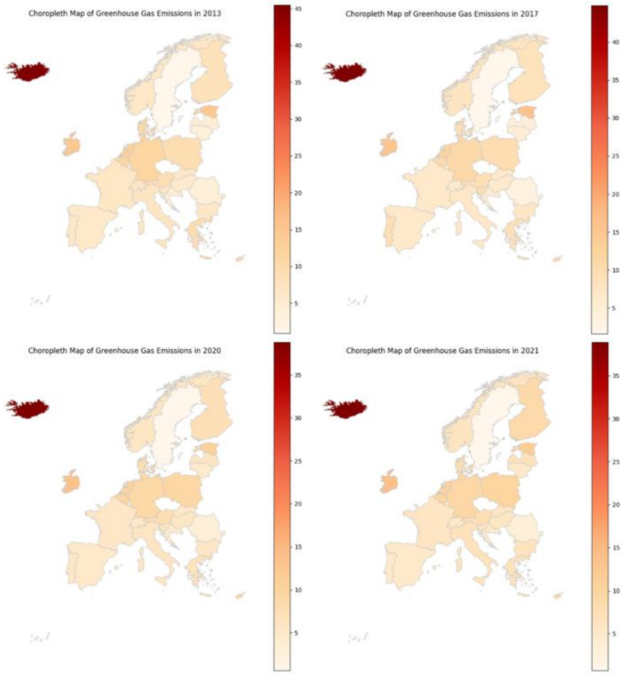
$$C - rel_i = \rho WLC - rel + \mathrm{GHG}\beta_1 + Energy\ taxes\beta_2 + \varepsilon$$

where ρ is the spatial autoregressive parameter, W represents the matrix of weights, $C - rel$ identifies the climate-related economic losses of neighboring areas, and GHG and Energy taxes are the climate change indicators (independent variables). β_1 and β_2 are the coefficients, and ε is the error term.

4. Results

In this section, thematic choropleth maps (Figure 1, 2, and 3) are presented, using a colour scale to represent the variation of our three variables of interest between 2013 and 2021 across European countries. This visualization technique is employed to display quantitative data and their spatial distribution, aiding in understanding the geographical and temporal differences among the various states. Figure 1 illustrates the variation and spatial distribution of net greenhouse gas emissions. Between 2013 and 2017, there was a modest decrease in net greenhouse gas emissions in some countries such as Germany, Belgium, and the Netherlands, while Portugal saw a slight increase. Emissions remained virtually unchanged between 2020 and 2021.

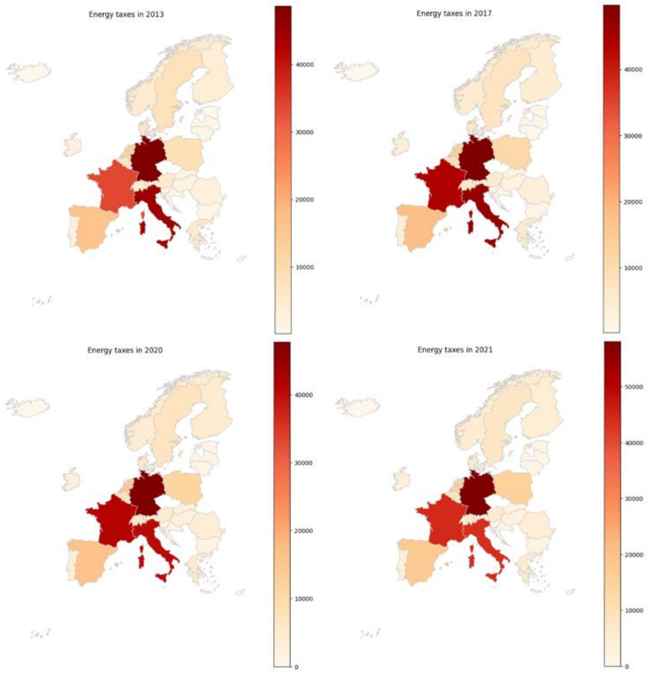
Figure 1 - *Net greenhouse gas emissions between 2013 and 2021.*



Source: own elaboration.

Figure 2, on the other hand, highlights the changes and geographic distribution of energy taxes, noting that starting from 2013, there was a significant increase in environmental taxation policies in France, while these policies were already widespread in Italy, Germany, and Spain. From 2020 onwards, there has been a slight decrease in these policies in Italy and France, whereas they have remained unchanged in Germany, Spain, Poland, and the Netherlands.

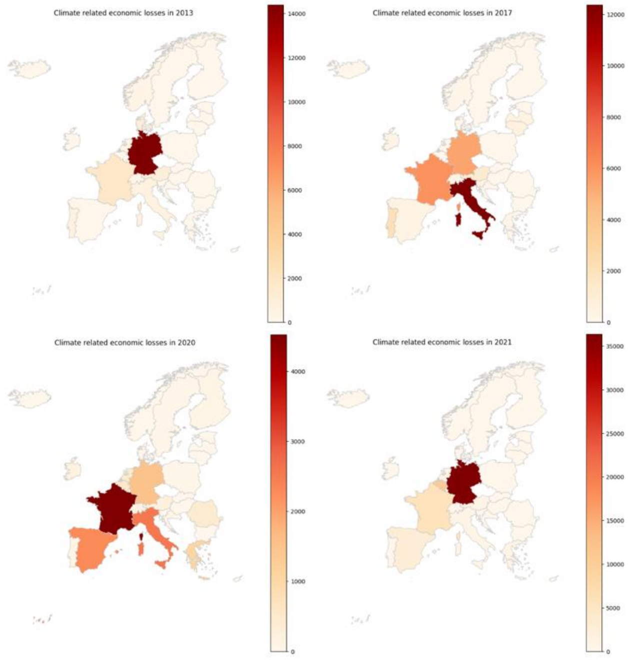
Figure 2 - *Energy taxes between 2013 and 2021.*



Source: own elaboration.

Figure 3 highlights the economic losses caused by climate change. Between 2013 and 2017, these losses increased in France, Portugal, and especially in Italy, but decreased in Germany. In 2020, losses increased in Spain, France, and Greece, while decreasing in Germany and Italy. However, in 2021, there was a reversal of this trend in Germany, followed by Belgium, while most European countries experienced an overall decrease in total losses.

Figure 3 - *Climate related economic losses between 2013 and 2021.*



Source: Own elaboration.

Additionally, the study reports the p-value associated with the Moran's Index, which measures the statistical significance of calculated spatial autocorrelation (Table 1). In the first row of each variable, the p-value indicates the correlation with neighbors, while the second row shows the corresponding p-value. A p-value less than 0.1 suggests significant spatial autocorrelation, as seen for environmental taxes and economic losses related to climate change, indicating a non-random spatial pattern. On the other hand, a p-value greater than 0.1, as observed for net greenhouse gas emissions, suggests that the variations do not exhibit any particular spatial autocorrelation.

Table 1 - *Moran Index.*

Variable/Year		2013	2014	2015	2016	2017	2018	2019	2020	2021
Greenhouse gases	coef.	0.07	0.07	0.06	0.05	0.04	0.04	0.06	0.07	0.06
	pvalue	0.10	0.12	0.12	0.17	0.21	0.21	0.16	0.12	0.16
Energy taxes	coef.	0.22	0.22	0.25	0.26	0.28	0.29	0.28	0.29	0.26
	pvalue	0.08	0.08	0.05	0.04	0.05	0.05	0.05	0.05	0.05
Climate related economic losses	coef.	0.22	0.22	0.25	0.26	0.28	0.29	0.28	0.29	0.26
	pvalue	0.08	0.08	0.06	0.06	0.05	0.04	0.04	0.05	0.05

Source: own elaboration.

Finally, Table 2 presents the SAR model, an econometric model used to analyse spatial data (Pineda-Ríos *et al.*, 2019) and based on the idea that observations in a given area depend on the characteristics of neighboring areas. The model highlights a significant relationship between the economic losses related to climate change in one country and those observed in neighboring countries, as well as between environmental fiscal policies, as shown by statistically significant coefficients with p-values below 0.1. These results suggest that the policies adopted by one country also influence neighboring countries, particularly in the context of climate change.

Table 2 - *SAR Model.*

Variable	Coeff.	p-value
WLClimate related economic losses	-0.202	0.084
CONSTANT	-301.479	0.266
GHG	13.060	0.540
Energy taxes	0.1410	0.000

Source: own elaboration.

The model has an adjusted R-squared of 0.371, indicating that 37.1% of the variability in the data is explained by the model's variables. Although this value is not particularly high, the model effectively captures the relationships between the variables. The Akaike Information Criterion (AIC) is 4780, suggesting a good fit of the model to the data. A lower AIC, when comparing models, would indicate greater effectiveness of the SAR model in representing the data.

5. Discussion and Conclusions

This study highlights significant differences in the geographical distribution of net greenhouse gas emissions, energy taxes and economic losses associated with climate change across European countries. These differences can be understood by analysing the underlying factors that influence the three variables studied. Between 2013 and 2017, Germany, Belgium and the Netherlands experienced a modest reduction in net greenhouse gas emissions, suggesting the effectiveness of the environmental policies implemented or the adoption of cleaner technologies. Previous studies (Clinch *et al.*, 2006; Do Valle *et al.*, 2012) argue that environmental taxes can generate significant environmental benefits. Albrecht (2002) examined the case of Belgium and showed that environmental subsidies in the transport sector contributed to reduced energy consumption and CO2 emissions. In Germany, GHG emission reductions have been supported by industrial change and a partial shift to cleaner energy sources (Pauliuk and Heeren, 2021). The Federal Climate Change Act sets binding annual emission targets for each sector. However, COVID-19 influenced the results, in some cases helping to meet the targets (Shammugam *et al*., 2022). Overall, net GHG emissions in Europe remained stable between 2020 and 2021, largely due to the economic slowdown caused by the pandemic (Kumar *et al*., 2022).

As highlighted in Figure 2, between 2013 and 2017, France strengthened its environmental tax policy and implemented various fiscal measures aimed at reducing carbon emissions, which proved to be particularly effective (Fiedler and Rihs, 2020). However, the Yellow Vest protests that began in November 2018 against the planned doubling of the carbon tax prompted the government to halt the trajectory of tax increases that had begun in 2014 (Douenne and Fabre, 2020). Figure 3 highlights the increasing economic losses caused by climate change, mainly due to the increasing frequency and intensity of extreme events such as heat waves, floods and storms, which directly affect national economies (Diab *et al*., 2022). In particular, Italy has suffered significant economic damage in critical sectors such as agriculture, with significant production losses, and tourism, due to reduced demand (Galeotti and Roson, 2011). Furthermore, the analysis reveals a pronounced spatial pattern in the relationship between environmental fiscal policies and economic losses related to climate change. This pattern, which is observed in many European countries, is not random. In particular, among the Member States of the European Union (EU), the importance of common environmental policies emerges as essential to address global environmental challenges. Such policies, aimed at promoting sustainable development and enhancing economic competitiveness, play a crucial role in coordinating national responses to environmental issues (Stojanović and Radukić, 2006).

This study analyzed emissions, energy taxation policies, and economic losses related to climate change, assessing the effectiveness of current policies in mitigating these damages. The results highlight the need for coordinated environmental policies at the European level and common strategies, given the geographical interdependence of emissions and measures implemented. However, the limited number of observations in this analysis is a limitation as it may reduce the ability of the model to capture more complex spatial relationships. Future research should extend the analysis to other European countries in order to increase the robustness of the results. In addition, an important area for future research could focus on updating the data to assess the implementation of the European Green Deal and whether this environmental policy plan is effectively contributing to the goal of reducing greenhouse gas emissions by 55% to achieve climate neutrality.

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