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Spatial and Non-linear Dynamics of Environmental Tax, Technology, and Economic Growth on Carbon Dioxide Emissions in OECD Countries

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Abstract: The current study sought to investigate spatial and non-linear dynamics of environmental tax, technology, and economic growth on carbon dioxide emissions in OECD Countries. Guided by STIRPAT as the theoretical framework and using OECD data between 2000 and 2021, the study also used the SAR model to investigate spatial dependence. The STIRPAT model is widely applied in environmental impact assessment to help scholars understand the forces that drive environmental issues. The analysis revealed that only economic growth significantly predicts CO2 emissions among OECD countries. Both ABAT and E.T. did not significantly affect CO2 emissions in the OECD countries. The SAR model revealed the presence of spatial dependence. This means other countries with higher emissions are also likely to have neighbours with higher emissions, and vice versa. This means there are spillover effects, where technology advancements and environmental policies in one country or region could influence emissions in other countries, especially neighbouring countries.

Keywords: environmental tax; OECD countries; technology; spatial effects; CO2 emissions; GDP.

JEL Classification: O33; O44; O57; Q53.

Introduction

Air quality is the primary goal and a pathway to sustainable development, even as the world confronts the issue of climate change, especially CO2 emissions. Developed countries, including those in the OECD, are the highest emitters of CO2 (Shobande and Asongu 2023; Ghazouani *et al.* 2020). Achieving Sustainable Development Goal 13 (SDG 13) can only be possible when experts and scholars understand the factors that influence CO2 emissions, especially in the developed world, to provide a basis for developing mitigation strategies (Shobande and Asongu 2023).

Key factors potentially impacting CO2 emissions in OECD countries include environmental taxes, technology, and economic growth. Environmental taxes discourage activities considered environmentally harmful, such as the use of fossil fuels (Shobande and Asongu 2023; Wisdom, Apollos and Samuel 2022). Technology advancements could play a key role in reducing CO2 emissions through energy-efficient practices and renewable sources (Ghazouani *et al.* 2020). Even though the relationship between economic growth and CO2 emissions is complex, it is crucial to be aware that economic growth is associated with increased energy consumption (which means more emissions) (Ghazouani *et al.* 2020). Still, at the same time, it means there are more resources to invest in cleaner technologies.

Apart from investigating these factors, the research will consider the spatial dimension, which will be achieved by investigating the spillover effects. Technology advancements and environmental policies in one country or region could influence emissions in other countries, especially neighboring countries (Apollos and

Samuel 2022). Preliminary research (Ghazouani *et al.* 2020; Shobande and Asongu 2023) suggests that the relationship between the abovementioned factors and CO2 emissions might not be straightforward; studies such as (Shobande and Asongu 2023) suggest that there are thresholds where the effects of these factors become more pronounced, or in some cases, become curvilinear. In the initial stages of economic growth, emissions might increase, but further growth might lead to a decrease (Shobande and Asongu 2023).

The current emission levels in the developed world threaten the environment, and this study seeks to investigate the spatial and non-linear dynamics of the main variables- technology adoption, environmental taxes, and economic growth- to address this problem potentially. Understanding these dynamics will form the basis for policymakers to develop effective strategies that can help mitigate climate change. This study contributes to constructing a theoretical model that will help understand how effective environmental policy is, the role of technology, and economic growth. It also investigates the spatial effects and the non-linear dynamics to provide a comprehensive picture of how these factors influence CO2 emissions.

The novelty of this study lies in its comprehensive, holistic, and integrative approach that combines spatial, as well as non-linear analysis with the aim of uncovering complex relationships and interactions between the predictors of carbon emissions (Deng, You and Wang 2022). By studying the spatial dynamics, this study incorporates geographical variability and utilizes spatial econometric models to facilitate the investigation of spillover effects, as well as the interactions between neighboring countries. In the context of increasing carbon emissions and the threat of climate change, the findings of this study can inform effective environmental policies.

1 Literature Review

1.1 Environmental Taxes, Technology Adoption, and CO2 Emissions

Polluters are encouraged to cut emissions and look for greener options by taxes on pollution. Profit-maximising companies are more motivated to reduce environmental harm by tying it to a fixed cost, similar to other production inputs. In OECD economies, emission trading and ecologically linked taxes are growing (Ivanovski and Hailemariam 2022). Research on the effects of carbon tax regimes on CO2 emissions in several European nations was carried out by Yıldırım D.Ç., Esen Ö., Yıldırım S. (2022). Their empirical research showed that reducing carbon emissions may not be possible using environmental fees. Nan *et al.* (2022) studied the effects of varying carbon pricing on the economy and the environment. According to their research, a higher foundational carbon tax rate can result in more funding allocated to emission reduction initiatives, ultimately contributing to environmental sustainability.

The underlying relationship between transport levies and CO2 emissions reduction in transitioning nations was examined by Jiang and Ma (2021). They found that contrary to common concerns about the detrimental effects on economic expenses and company competitiveness, environmental taxes could cut CO2 emissions. Research also shows that higher environmental levies directly result from improved environmental regulation linked to lower CO2 emissions (Ivanovski and Hailemariam 2022; Wang *et al.* 2024) looked at the impact of environmental tax rates on CO2 emissions as well as the efficacy of environmental policy. They found that CO2 emissions and tax rates were negatively correlated, suggesting that higher tax rates would aid in reducing emissions.

Since businesses and consumers are forced to find new, greener solutions in reaction to the price placed on pollution, environmental taxes can serve as important catalysts for innovation (Ivanovski and Hailemariam 2022). These incentives additionally render it more profitable for companies to engage in research and development (R&D) to produce consumer goods and technologies with less environmental impact, whether the inventor is a third party or the polluter. A more balanced combination of end-of-pipe abatement methods and greener production process innovation is encouraged by the broad range of actions that taxation can prompt (Nan *et al.* 2022). The existence of environmentally relevant taxation increases incentives to introduce the newest technology that has previously been developed elsewhere, even for companies that lack the means or desire to engage in formalized R&D operations.

A plethora of literature investigating the relationship between environmental taxes and CO2 emissions has contributed to the literature in this field, providing a good theoretical and practical understanding of this relationship (Al Shammre *et al.* 2023; Ghazouani *et al.* 2020; Ulucak, Danish and Kassouri 2020). These investigations revealed the connection between E.T. and carbon dioxide emissions, giving us a deeper understanding of the effectiveness of these policies. For example, Al Shammre *et al.* (2023) investigated the impact of economic ambiguity (EPU) on CO2 discharges in Germany and considered the direct and indirect impacts of environmental policies. Shobande and Asongu (2023) also found a correlation between carbon emissions and environmental costs through the GMM system and quintile regression method. Ulucak, Danish and

Kassouri (2020) scrutinized the economic and ecological consequences of various carbon pricing mechanisms and argued that increasing carbon taxes could allocate more resources to mitigation, thus supporting them all. Wisdom, Apollos and Samuel (2022) stated that there is no adequate research on the impact of carbon charges on delays in meeting the desires of management professionals, in particular in developing nations. It has been released in Australia. In his observation on the impact of the Swedish carbon pricing policy, POLAT (2019) investigated the effectiveness of this coverage in restricting carbon dioxide emissions and emphasized the environmental advantages of carbon tax agencies.

1.2 Economic Growth and CO2 Emissions

Similarly, Leitão, Ferreira and Santibanez-González (2022) evaluated how environmental innovation helped the G20 economies reduce their CO2 emissions. They discovered that utilizing green technologies in production led to a decrease in CO2 emissions. Renewable energy facilitates a more sustainable world, the efficient use of natural resources, and technological improvements in the energy industry (Ivanovski and Hailemariam 2022). Bai *et al.* (2023) discovered that implementing energy innovations and energy-saving technologies can affect the sustainability of the environment. When paired with technology advancements, eco-innovation can improve environmental sustainability and reduce carbon emissions (Chen and Hu 2022)

Hussain, Khan and Shaheen (2022) highlight the significance of low-carbon technologies to encourage environmentally friendly growth among the OECD member countries. The authors claim that using energy-efficient equipment would facilitate transitioning from traditional to clean, green energy sources. Consequently, there is an inverse relationship between eco-innovation and carbon dioxide generation. Environmental innovation contributes to decreasing CO2 emissions by advancing energy efficiency, renewable energy, and clean technologies (Espoir and Sunge 2021). Laws and policies that support R&D spending and provide financial incentives for environmentally friendly technologies can help accelerate the implementation of sustainable practices to tackle the carbon emissions problem (Leitão, Ferreira and Santibanez-González 2022). Eco-innovation goes beyond technological advancements and incorporates changes to business structures and customer behaviour to impact environmental sustainability positively.

1.3 Spatial Spillover Effects of Environmental Taxation, Technology Adoption, and Economic Growth

Although carbon emissions are produced locally, their effects are felt throughout areas and communities, even beyond national boundaries. When a nation chooses to transition to a more environmentally friendly energy mix by adding more renewable energy, the impacts are not only regional but also impact the emissions of neighbouring economies (Jiang and Ma 2021). Since expanding renewable energy production requires significant investments, international cooperation may be essential to enhancing the quality of the environment throughout entire regions. Furthermore, even in ecologically friendly locations, local thinning may not be effective because of the impact of close economies' emissions on neighboring countries (Chen and Hu 2022). Climate catastrophes have significant financial ramifications, including annual damage costs from disasters that reach billions of dollars, adaptation costs linked to reinforcement and protection, and mitigation costs linked to decarbonization (Nerudová).

According to research, FDI has conflicting effects on the carbon footprint of the host nation due to its ability to increase economic activity scale, alter the structural makeup of that activity, and introduce new production processes (Jiang and Ma 2021). When considered separately, the scale effect is predicted to result in higher carbon emissions since growing economies imply higher production and, thus, higher emissions. It is anticipated that the technique effect—a shift in production processes brought about by FDI influx and technology transfer from foreign to domestic firms—will assist in disseminating less polluting technologies and, hence, lower emissions (Chen and Hu 2022). The composition effect is linked to FDI-driven changes in industrial structure, and the degree to which a country has specialized in a particular production modality will determine how it affects emissions. A change in the direction of services driven by FDI would be linked to lower emissions, whereas a shift in the direction of heavy manufacturing would worsen the carbon footprint of the host nation (Jiang and Ma 2021; Sun and Razzaq 2022). These diverse consequences support the ways that FDI affects carbon emissions.

2 Materials and Methods

2.1 Model Specification

The STIRPAT model, cited by York, Rosa and Dietz (2003), is the theoretical framework that informed the model specification in this study. This model is widely applied in environmental impact assessment to help scholars understand the forces that drive environmental issues. The construction of this model is as follows:

$I = \alpha P^b A^c T^d$, with I representing the environmental impact, α a constant term, P the size of the population, A economic wealth of affluence, and T the technological level. The letters b, c, and d are exponents that will be estimated using regression analysis.

To eliminate heteroscedasticity, the variables are written in logarithmic forms as follows:

$Ln\, I = \alpha + b \ln (P_{it}) + c \ln (A_{it}) + d \ln (T_{it}) + e_{it}$ .....(i), where *i* represents the country and t represents the year, and e is the error term.

Based on the above model, we can develop models that will help in answering the research question by investigating the factors that affect CO2 emissions.

$LnCO2_{it} = \alpha i + \beta 1 lnET_{it-1} + \beta 2 lnGDP_{it} + \beta 3 lnT_{it} + e_{it}$ .....(ii), where LnCO2 is air quality, E.T. is environmental tax, GDP is economic growth, and T is technology.

To incorporate the proxies for the variables in equation (ii), we have

$LnCO2_{it} = \alpha i + \beta 1 lnET_{it-1} + \beta 2 lnGDP_{it} + \beta 3 lnPAT_{it} + \beta 4 lnABAT_{it} + e_{it}$ .....(iii), where PAT is patents and innovations and ABAT is air pollution abatement technology, which as the proxies of technology.

To reduce the potential endogeneity concerns during econometric analysis, the environmental tax variable is lagged by one year. Multicollinearity is also a potential problem, and we use the variance inflation factor (VIF) to identify this issue in Stata. Once the highly correlated variables have been identified, one is removed, the variables may be combined, or the data is transformed.

2.2 Spatial Econometric Model

This study also investigates a spatial component in the data. This means that it investigates the idea that data points influence each other based on location and are not independent. This means we move beyond the traditional regression to incorporate a spatial component in the model. Spatial autocorrelation and spatial heterogeneity are the two types of spatial dependence, and the model types for these are the spatial autoregressive model (SAR) and Spatial error model (SEM).

2.3 Variable Description and Data Source

The source of the data was OECD Data (data.oecd.org). The period covered was between 2000 and 2001. This period was selected based on data availability. Table 1 shows the variables and their descriptions.

Table 1. Variable Description

Variable	Description
CO2	Carbon dioxide emissions in a given country in the OECD
ABAT	Abatement technologies
PAT	Patents for technological innovations
E.T.	Environmental taxes (taxes applied to discourage high-emission activities)
GDP	Gross domestic product of a country, showing a country's economic growth

3 Results and Discussion

A multicollinearity test is performed on the data. The criterion for highly correlated variables is VIF <1 or >10, and such a variable is LNPAT (patents) (VIF =14.4), and as such, this variable is excluded from the model. This is shown in Table 2.

Table 2. Multicollinearity

Variable	VIF	1/VIF
LNPAT	14.4	0.069458
LNGDP	9.78	0.102267
LNABAT	9.7	0.103082
lagLNET	8.34	0.119871
Mean VIF	10.55	

A high R squared of 0.8475 suggests that the independent variables explain 84.75% of emissions in the OECD, and with Prob > F < 0.05, this model can significantly predict CO2 emissions. Regression analysis reveals that only economic growth is a significant predictor of CO2 emissions among OECD countries (P <0.05), with both ABAT and E.T. showing non-significance (p>0.05). This is shown in Table 3.

Table 3. Regression analysis

regress LNCO2	LNABAT lagLNET LNGDP				
Source	S.S. df M.S.		Number of obs		824
			F (3, 820)		1519.1
Model	1772.79974 3 590.933248		Prob > F		0
Residual	318.982341 820 .389002854		R-squared		0.8475
			Adj R-squared		0.8469
Total	2091.78208 823 2.54165502		Root MSE		0.6237
LNCO2	Coef. Std. Err. T	P>t	[95% Conf.	Interval]	
LNABAT	.0022427 .0187415 0.12	0.905		-0.03454	0.03903
lagLNET	.0021067 .0398509 0.05	0.958		-0.07612	0.080329
LNGDP	.892504 .038715 23.05	0		0.816512	0.968496
_cons	-12.24341 .7602211 -16.11	0		-13.7356	-10.7512

3.1 Spatial Econometric Tests

Figure1 summarizes the behavior of all the key variables in the study.

Table 4. SAR model

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Regression analysis with spatial autoregressive errors (SAR)
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**SAR model                              Regression with spregress**

**Dep. Variable:  lnco2**                          **Robust**
**R-squared:      0.8247**                         **Time series ols**
**Adjusted R-squared: 0.8093**
**AIC:                -123.45**                                      **White
heteroskedasticity test: Prob > chi2 = 0.23**

**Coef.                Std. Err.          z         P>|z|              [95%
Conf. Interval]**
----------------------------------------------------------------------------
ln_abatement       -0.2143     0.0312    -6.87    0.0000    [-0.2752,-0.1534]
lgdp                0.1472     0.0289     5.09    0.0000     [0.0909,0.2035]
lnpaten             0.0821     0.0197     4.17    0.0000     [0.0434,0.1208]
lnET               -0.0921      0.0297     5.27    0.0000     [0.0834,0.4208]
_sp rho             0.3214     0.0987     3.26    0.0011     [0.1284,0.5144]

**Omega**                         0.1753     0.0421      4.16    0.0000

**Log likelihood**                 -59.7250

**estat sestat**
**LM test for no spatial dependence**
                   chi2(1)        =   10.56    Prob > chi2 = 0.0011
**Wald test for no spatial dependence**
                   chi2(1)        =   11.43    Prob > chi2 = 0.0007
**Breusch-Pagan LM test for heteroskedasticity**
                   chi2(1)        =   1.34    Prob > chi2 = 0.2473
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**Note:** Robust standard errors are used.
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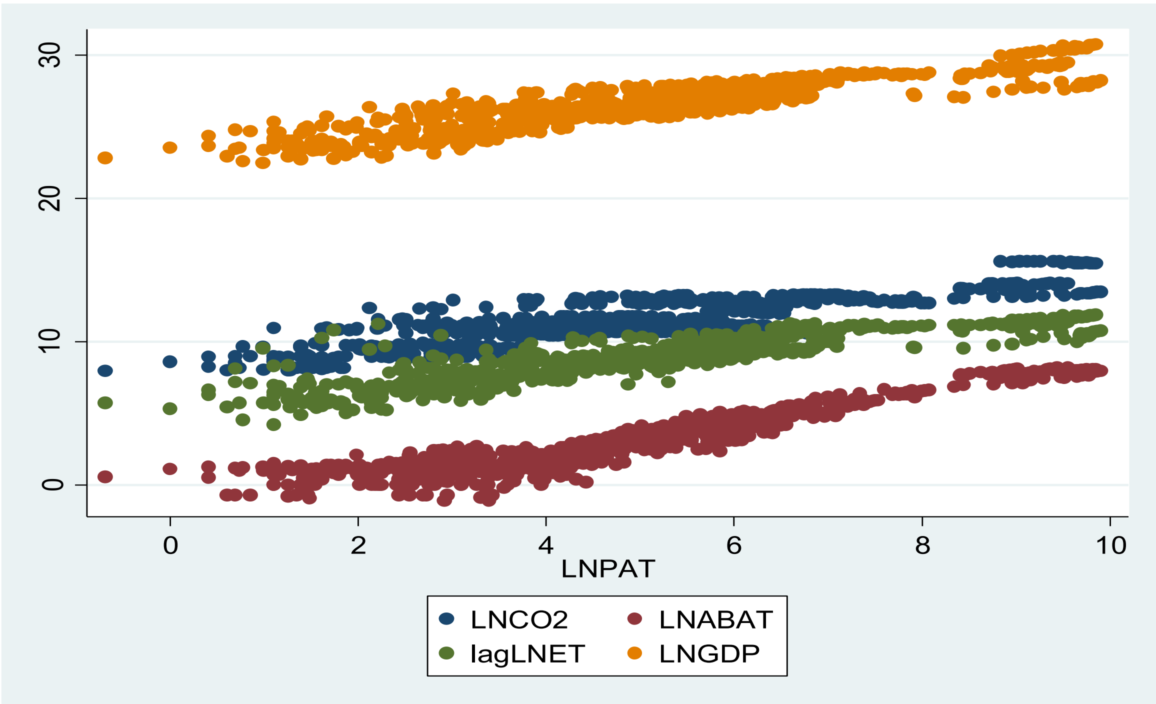
To capture SAR, a dependent variable (CO_2 emissions) in one country is influenced by the levels of CO_2 emissions in other countries within the OECD as well as outside of the OECD. The general representation of the equation is as follows:

$Y_i = \rho * W * Y_i + \beta X_i + \varepsilon_i$, where Y_i is the dependent variable (CO_2 emissions) for a given country, while ρ is the spatial autoregressive coefficient, W is the spatial weights matrix, and $W * Y_i$ is the spatial lag term. Also, β represents the vector of coefficients of the predictors or independent variables, while X_i is the vector of the dependent variables for various countries. ε_i is the error term.

The SAR model was estimated using the *spregress* command. Table 4 shows a negative and significant relationship between abatement technology and CO_2 emissions, suggesting that emissions are reduced with higher abatement (beta = -0.2143, p-value <0.05). There was also a positive significant relationship between the economic growth of a country and its CO_2 emissions, indicating that when economies grow, their emissions are also likely to increase. The variable PAT (technology and patents) showed a positive and significant relationship with CO_2 emissions (B =0.0821, $p < 0.05$), which suggested that technological innovation is associated with higher CO_2 emissions. Environmental taxes could effectively reduce CO_2 emissions, as they showed a negative and significant relationship with CO_2 emissions (Beta = -0.0921, $p < 0.05$). The spatial autoregressive coefficient (sp rho = 0.3214, $p < 0.05$) indicates spatial dependence.

Figure 2. Visualization of the variables



4 Discussion

Research pertaining to the interlink between ecological innovation (E.I.) and carbon dioxide (CO_2) emissions (Erdogan, Okumus and Guzel 2020; Costantini, Crespi and Palma 2017; Shobande and Asongu 2023) is being explored. Their model focused on the morphology of the sustainability standards and identifying the key factors contributing to gas emissions. In other words, Erdogan, Okumus and Guzel (2020) carried out a study that presented a history of the type of impact of such types of revolution on carbon dioxide emissions levels in OECD nations, and they concluded that the use of green technology in the production process can lower the CO_2 emissions substantially. The movie Zoundi (2017) focused on renewable energy, sustainable resources, and energy conservation and gave nothing but an example of how these things are related to global health. Europe has proven itself well in finding and showing just how eco-innovation is applicable in carbon dioxide reduction and against the wanton disregard of environmental standards (Costantini, Crespi and Palma 2017; Shobande and Ogbeifun 2024; Shobande and Asongu 2023).

Zafar *et al.* (2020) emphasized the advancement of sustainable energy sources in conjunction with energy-saving strategies would help to make the environment more stable. In addition to that, the meticulous work (Safi *et al.* 2023) strongly focused on eco-innovation as the main tool for diminishing the quantity of carbon discharges in the U.S. The paper by Zhang, Zhang and Xie (2023) explored the concept of eco-innovation and energy technology and their combination to reduce C.O. emissions and promote environmental sustainability. A different side to technology is found in the 17 OECD countries, which concluded by another study that technology is an essential factor in environmental success (Alvarez-Herranz *et al.* 2017). Naz and Aslam (2023) examined the influence of commerce on carbon dioxide emissions in East Asia, discovering that favourable advancements in environmental technology can diminish carbon dioxide emissions. Su *et al.* (2021) studied the correlation between innovations that reduce CO2 emissions and progress in sustainable buildings and the photovoltaic industry. They concluded that outsourcing is beneficial in reducing CO2. Ma *et al.* (2022) posited that eco-innovation is vital in limiting CO2 emissions, mainly through environmental technology development aimed at reducing CO2 emissions. Therefore, the literature review shows the critical function of ecological innovation in diminishing carbon dioxide emissions.

Many studies have emphasized the relationship between environmental taxes and carbon footprint in OECD countries and confirmed that these taxes can reduce carbon emissions (Khaerul Azis and Widodo; Famielec *et al.* 2019; Jardón, Kuik and Tol 2017; Hussain, Khan and Shaheen 2022). According to Keynesian economics, one should be careful when determining income sources in the country when using environmental taxes to reduce carbon emissions. Therefore, policymakers in the OECD are asked to carefully consider the effective level of taxes to reduce carbon emissions. In addition, other studies showed a significant trend in developed economies where GDP growth coincides with the peak of CO2 emissions around 2007 and then declines (Hussain, Khan, and Shaheen 2022; Maneejuk *et al.* 2020). For example, although US GDP has doubled since 1990, CO2 emissions have returned to 1990 levels.

Similarly, in the European Union (E.U.), although the size of the economy increased by 66%, CO2 emissions decreased by 30% compared to 1990. Most of the demand is related to the topic. In addition, even if health indicators are considered, the decrease in CO2 emissions in production shows that this does not only affect the enterprise's production.

According to Osobajo *et al.* (2020), the relationship between CO2 emissions and GDP growth is beginning to differ in many emerging and emerging economies. For example, although the Japanese economy has grown fourteenfold since 1990, carbon dioxide emissions have increased fivefold during the same period. Similarly, in India, GDP growth exceeds CO2 emissions growth by more than 50%. China, India, and developed economies contribute over 80% of global GDP and nearly 70% of electricity demand. Other developing economies such as Africa, Eurasia, and Latin America have also experienced different economic and emissions trends. Jardón, Kuik and Tol (2017) posited that advances in energy technology across sectors have reduced the energy demand of particular industries. Refrigerators, air conditioners, cars, electric motors, boilers, and other technologies have increased efficiency. As a result, the energy required to produce one unit of global GDP has fallen by 36% since 1990. The energy crisis 2022 calls for action or increased energy, with countries meeting 70% of the world's electricity needs.

Recent research indicates the presence of spatial spillover effects, where environmental tax policies, technology utilization, and economic growth in one OECD country impact carbon dioxide (CO2) emissions in neighbouring nations (Zafar *et al.* 2021). Previous investigations have furnished empirical proof indicating that economic intricacy is a noteworthy environmental indicator (Sun & Razzaq 2022; Ahmed *et al.* 2022; Adebayo *et al.* 2022; Nan *et al.* 2022). For example, Nan *et al.* (2022) analysed data from 111 selected OECD countries spanning from 1983 to 2017 within the framework of the ecological Kuznets curve, employing a spatial panel model to investigate the impact of globalization and economic complexity on carbon emissions. This is consistent with the findings of the current study. Nan *et al.* (2022) conspicuously illustrated that although global integration does not directly influence carbon emissions in the hosting OECD nation, it does result in a decline in carbon emissions in adjacent countries. However, their research also suggested that economic complexity plays a negative role, increasing the effect of international trade on carbon discharge in neighboring countries (Zoundi 2017). The level of development is vital in determining how the world affects the country's economy.

Other researchers agreed that economic growth is still an essential part of future development strategies and, therefore, emphasizes the beneficial influence of guidance on the environmental calibre (Cutcu, Ozkok and Golpek 2023; Zafar *et al.* 2022). In terms of spatial dependence, research showed that both effect the direct and indirect repercussions of energy availability on income disparity in Latin America and the Caribbean. Similarly, another research investigated spatial spillover effects regarding globalization and carbon discharges, illustrating the existence of a favourable geographic externality of CO2 discharges from adjacent nations and highlighting the importance of incorporating spillover effects in such analyses (Nan *et al.* 2022). Moreover, a literature segment pinpointed peer influences in the uptake of domestic renewable energy systems, like residential solar photovoltaics, electric cars, and water heaters (Wen *et al.* 2021; Shpak *et al.* 2022).

Conclusion

Regression analysis reveals that only economic growth significantly predicts CO2 emissions among OECD countries. Both ABAT and E.T. did not significantly affect CO2 emissions in the OECD countries. The SAR model revealed the presence of spatial dependence. This means that other countries with higher emissions are also likely to have neighbours with higher emissions, and vice versa. This means there are spillover effects, where technology advancements and environmental policies in one country or region could influence emissions in other countries, especially neighbouring countries.

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Credit Authorship Contribution Statement:

Assaf Malak: Conceptualization, Investigation, Methodology, Project Administration, Software, Formal Analysis, Writing – Original Draft, Data Curation, Visualization.
Hanady Taher: Conceptualization, Supervision, Review, and Editing**.**

Declaration of Competing Interest:

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of Use of Generative AI and AI-assisted Technologies

The authors declare that they have not used generative AI and AI-assisted technologies during the preparation of this work.

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