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Tax Policy on Air Pollution: New Evidence from an Impact Assessment

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Abstract:

Governments employ tax measures to improve environmental conditions and reduce atmospheric emissions. This paper aims to analyze the impact of specific types of environmental taxes on air pollutant emissions. The study utilizes OECD panel data on the volumes of four tax types and seven categories of pollutants from nine countries (Austria, Denmark, the Czech Republic, Poland, Hungary, Slovakia, Slovenia, Sweden, and Kazakhstan) from 2010 to 2022. The models, built using multiple linear regression, revealed a strong and statistically significant positive correlation between all types of pollutants, the volumes of resource taxes paid, and a negative correlation with transport and pollution taxes. The similarity of results across each model is explained by the high degree of correlation between the different types of pollutants. A potential factor of endogeneity in the models prevents a definitive conclusion about causality, but it contributes to econometric research in this area. A limitation of this study is the availability of data on the specific tax types and pollutant emissions. The research extends the ongoing discussion on the role of tax measures in reducing air pollution by providing new empirical evidence.

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1. Introduction

The world is facing various global challenges that threaten humanity's very existence. Governments must effectively utilize available tools to prevent or mitigate these threats (Breuer et al., 2021; Liu et al., 2019; Chen & Kan, 2008). One of the contemporary trends is urbanization, accompanied by economic development. However, uncontrolled urbanization leads to urban air pollution, posing a significant threat to human health and the environment in developed and developing countries. Air quality in urban areas is becoming an increasingly serious issue, especially as a growing proportion of the world's population resides in cities and demands a cleaner and more sustainable environment (Franchini & Mannucci, 2018; Hopke et al., 2011). According to the World Health Organization (WHO), 99% of the world's population breathes air with pollution levels exceeding the recommended limits (Aguilera et al., 2023). For example, in 2019, approximately 4.2 million people worldwide died prematurely due to outdoor air pollution (Maji et al., 2018; Shi et al., 2022; Malik et al., 2023).

Another equally serious consequence of global air pollution is global warming. Economic growth in developed countries has contributed to environmental degradation due to the expansion of the industrial sector and the overuse of natural resources. Scientists suggest addressing this issue, as industrial carbon emissions have significantly increased over the past three decades (Li et al., 2023). Sudden and sharp climate changes and the rapid rise in global temperatures serve as nature's warning to humanity. Greenhouse gases, including carbon dioxide, methane, and nitrous oxide, significantly impact global climate change, making it a critical worldwide concern (Babatunde et al., 2017). Among these gases, carbon dioxide is the most significant emission contributing to global climate change (Moiceanu & Dinca, 2021). Although China, the United States, and the 28 countries of the European Union account for more than 50% of global emissions (Ritchie et al., 2020), every member of the global community must take responsibility for the state of the atmosphere. Preserving a clean environment is one of the most important global challenges, requiring a governmental response (Hsu et al., 2021).

Governments implement interventions to address environmental issues in various ways. One such mechanism is tax regulation. Tax measures are widely considered the most equitable way to pay for environmental pollution management. These measures generate government revenue and provide incentives to reduce harmful emissions (Aghion et al., 2016; Hsu et al., 2021; Chien et al., 2021). However, the effectiveness of tax measures in addressing air pollution and environmental emissions remains a subject of ongoing academic debate. As Fremstad and Paul (2019) argue, carbon taxes can be regressive and contribute to rising inequality. Therefore, it is crucial to remain objective and avoid subjective judgments when discussing this issue (Hassan et al., 2022).

This article analyzes the impact of tax measures on air pollution. To achieve this, an econometric analysis of panel data from nine countries covering payments of various taxes that directly or indirectly affect air emissions, and the dynamics of specific pollutants was conducted for the period from 2010 to 2022.

This article significantly contributes to the existing scientific discourse by expanding the understanding of the effectiveness of tax measures in addressing air pollution. The work contributes to the ongoing discussion on improving environmental policy and enhancing environmental sustainability.

2. Theoretical framework

2.1. Environmental taxation: theoretical and practical background

The role of the public sector in managing air quality is predetermined by the fact that market regulation is insufficient to ensure it. Since property rights for environmental resources are nearly impossible to establish, this implies the inefficient use of the environment. In practice, governments face complex challenges in assessing the effectiveness of environmental protection measures. Equally challenging is determining the appropriate form of government intervention (Bovenberg & Goulder, 2002).

The primary theoretical foundation of this study is Pigouvian tax theory, proposed by Arthur Pigou in the 1920s. Pigouvian taxes are levied to account for the internal costs associated with negative externalities, such as environmental pollution. According to this theory, pollution taxes incentivize companies to reduce emissions and invest in cleaner technologies by incorporating environmental costs into their operating expenses. The goal of environmental taxes, in line with Pigou's theory, is not merely to generate government revenue but to induce behavioral shifts among companies toward adopting green technologies, thereby reducing environmental harm (Manta et al., 2023). However, the broader economic impact of environmental tax regulation remains unclear.

Another environmentalist theory shedding light on the economic consequences of environmental taxes is the Double Dividend Hypothesis. This theory posits that environmental taxes not only protect the environment but also enhance the economic efficiency of governments by reallocating additional revenue toward reducing other taxes (such as income tax). Fiscal policies geared toward environmental regulation can result in short-term employment growth (Carraro et al., 1996) and increased welfare for at least two generations (Chiroleu-Assouline & Fodha, 2006). However, as Bento and Jacobsen (2007) argue, environmental taxation must be part of an optimal tax system for such policies to be effective.

One of the foundations for implementing modern types of environmental taxation is the 'polluter pays' principle, proposed by the OECD in 1972 as a solution to

environmental problems. Environmental taxes are designed to influence consumer behavior while simultaneously increasing government revenues. Since then, numerous taxes aimed at sustainable development have been introduced over the decades (Tan et al., 2022). Countries actively employ various methods of Environmental Tax Regulation to improve air quality and reduce emissions. It is important to note that tax measures to reduce emissions prevail in most countries. These measures can be divided into fiscal and incentive-based categories, with many taxes serving fiscal and incentive functions. Among fiscal measures, emissions taxes (based on emission ingredients), emissions trading, transport taxes, fuel taxes, vehicle import taxes, and waste disposal fees are widely used. Taxes on transport, resources, and energy contribute to reducing emissions and improving air quality by encouraging clean technologies and decreasing the consumption of polluting resources (Faure & Weishaar, 2012; Saad, 2017; Alshawi & Hashim, 2024). When systematizing the central environmental taxes used globally, most are directly or indirectly aimed at regulating air emissions (Table 1).

Table 1:
Environmental taxes overview

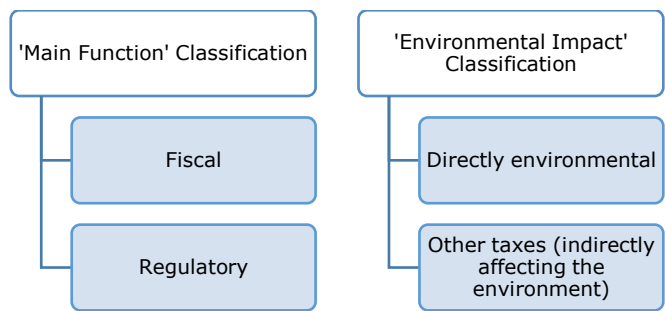
Tax Category	Types of Taxes	General Characteristics
Air Emission Taxes	Carbon tax Pollution tax SOx/NOx taxes	Taxes aimed at reducing harmful emissions into the atmosphere, often targeting industries or companies that emit greenhouse gases (GHG) and other pollutants (e.g., sulfur oxides, and nitrogen oxides).
Energy and Resource Taxes	Energy tax Resource extraction tax Water use tax Natural gas tax	Taxes designed to limit resource consumption and promote energy efficiency by taxing fossil fuels, energy production, or resource extraction.
Transport-Related Taxes	Vehicle registration tax Road use tax Fuel excise tax Tax on new cars (based on emissions)	Taxes related to transportation that either target emissions directly or incentivize the use of cleaner vehicles through fuel or emissions-based taxation.
Waste and Disposal Taxes	Waste disposal tax Landfill tax Packaging tax	Taxes imposed on waste generation and disposal, aimed at reducing waste and promoting recycling and sustainable disposal methods.
Eco-Incentive Taxes	Tax benefits for electric vehicles Green technology tax rebates Renewable energy tax credits	Fiscal incentives that encourage the adoption of environmentally friendly technologies, including tax benefits or subsidies for electric vehicles and renewable energy.
Water and Air Protection Taxes	Water pollution tax Air quality improvement tax Water use fees	Taxes specifically designed to reduce pollution and encourage the sustainable use of air and water resources.
Carbon Pricing Systems	Carbon cap-and-trade Emissions Trading System (ETS)	Market-based approaches where companies buy and sell emission allowances to reduce overall carbon footprints, incentivizing lower emissions through trade.

Sources: World Bank (2022), Tax Foundation Europe (2023), Eurostat (2023), OECD Stat., Eurostat Statistics Explained (2024), Statutory Taxation Administration of the Republic of China (2020), and the like.

Environmental taxation can be systematically classified based on specific criteria, such as fiscal and regulatory functions, as illustrated in Figure 1.

Figure 1:

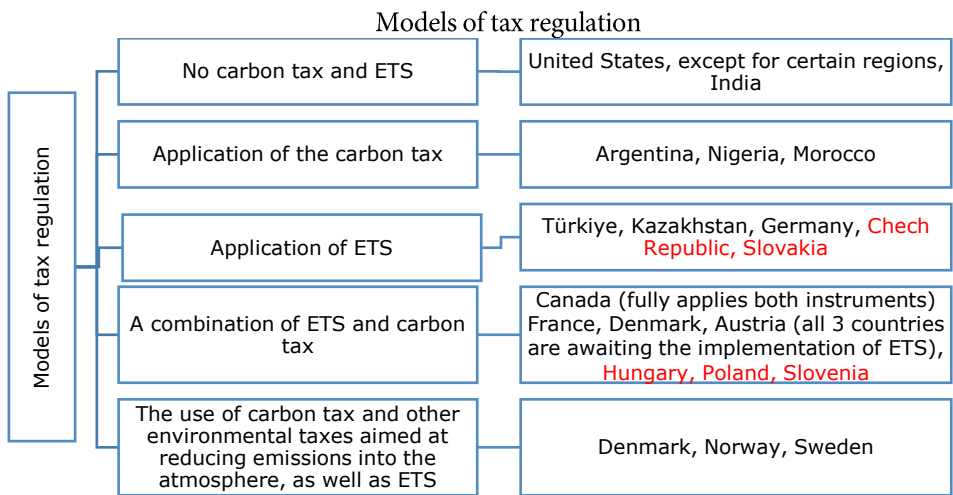
The environmental tax is classified based on two functions: fiscal and regulatory



Source: Authors’ own, 2024

Fiscal environmental taxes are used to replenish the budget and finance projects to improve the environment, such as air pollution control. Regulatory taxes, also known as behavioral taxes, are designed to encourage society to adopt behaviors that reduce air pollution, such as purchasing cleaner vehicles or using air filters. Special-purpose taxation and direct environmental taxes aim to reduce greenhouse gas emissions and influence pollution levels. Other taxes, such as transport and property taxes, may indirectly affect air pollution. By studying tax administration models in different countries, potential strategies for protecting the atmosphere from pollution can be identified (Figure 2).

Figure 2:



Source: Compiled by the authors based on data from the Carbon Pricing Dashboard of the

World Bank, 2024 (The World Bank, 2024)

Thus, environmental taxation is based on theories such as Pigouvian tax and the double dividend hypothesis, which justify the necessity of taxes to reduce negative externalities and improve economic efficiency. Introducing taxes on emissions, energy, and resources allows for pollution control and encourages the use of 'green' technologies. Despite broad support for environmental taxes, their effectiveness and economic impact remain subjects of debate, which will be discussed below. The importance of a systematic approach to classifying taxes by their fiscal and regulatory functions highlights the need for further research to develop effective measures to reduce emissions and improve the environment.

2.2. Empirical and theoretical Study

A significant debate among researchers continues regarding the impact of tax measures on air pollutant emissions. The issue of regulating taxes to protect the atmosphere from pollution is widely studied globally due to the importance of environmental issues that threaten society.

One research direction shows the positive effect of tax regulation on emission volumes. This impact has been studied by evaluating tax measures on various emissions and pollutants. Morley (2012), using panel regression estimates for EU countries, found that carbon emission taxes reduce greenhouse gas emissions. The empirical work by Martini (2009) demonstrated the environmental effectiveness of introducing a carbon emissions tax in Italy. According to Hieu (2022), environmental taxes and 'green investments' negatively correlate with carbon dioxide emissions. Moreover, Goers and Schneider (2019), in their study on Austria, highlighted that environmental tax reform not only led to a significant reduction in CO₂ emissions but also positively impacted employment and GDP. A study by Rybak et al. (2022), which explored the relationship between environmental taxes and emissions of two types of greenhouse gases (CO₂ and methane) in Poland and Sweden, confirmed the stimulating role of taxation in categories such as transport, resources, and pollution. Through an optimized economic model, Mardones and Cabello (2019) measured the reduction of CO₂, SO₂, NO_x, and PM emissions in industrial and thermoelectric facilities under various tax scenarios, noting a compounding effect when all pollutant tax rates were simultaneously impacted. While studying the relationship between environmental taxes and environmental degradation, Rafique et al. (2022) and Bozatli and Akca (2023) use the broader concept of ecological footprint, a comprehensive measure of human resource consumption and waste production.

Another research focus is examining the positive link between environmental taxes and environmental conditions and exploring different types of payments. Introducing stricter environmental taxes (compared to pollution fees) could significantly encourage the adoption of 'green' innovations in heavily polluting industries (Huang et al., 2022). Guo et al. (2022), based on data from 289 cities in China

from 2010 to 2019 in a quasi-natural experiment, confirmed the effectiveness of environmental tax reforms, which significantly reduced urban air pollution. According to Peng et al. (2022), environmental taxes increase 'green' energy consumption by encouraging individuals and businesses to adopt energy-efficient technologies and innovations. These conclusions align with earlier findings by Acemoglu et al. (2016), which suggest that carbon emission taxes are sufficient to promote clean innovations and transition to clean technologies. Additionally, Runst and Höhle (2022) found that introducing a fossil fuel tax reduced carbon dioxide emissions in Germany and motivated German car manufacturers to improve engine technology.

The automotive sector is traditionally one of the leading air polluters. In this regard, adding a tax to the price of gasoline, or any other direct or indirect tax regulation, can incentivize car manufacturers and citizens to use more environmentally friendly transportation. Aghion et al. (2016), conducting an econometric analysis of firm-level panel data from 80 countries, confirmed a theoretical model of the positive correlation between firms' inclination to adopt "clean" innovations (e.g., alternative fuel engines) and tax-inclusive fuel prices in the automotive industry. Additionally, several studies suggest that higher fuel prices encourage the adoption of less harmful technologies (Giménez-Nadal & Molina, 2019; Aklilu, 2020), indirectly supporting the positive impact on environmental emissions. Peng et al. (2021) experimentally modeled the impact of environmental tax rates on reducing emissions from ships in port cities. The authors found that optimal tax solutions can reduce emissions of sulfur oxides, nitrogen oxides, carbon dioxide, and particulate matter while simultaneously reducing costs. A country-specific focus is seen in studies by Javed et al. (2023), Ullah et al. (2023), and others, which provide evidence of environmental improvements influenced by environmental taxes.

Thus, studies show that environmental taxes and tax measures positively impact emissions reduction and stimulate the adoption of environmentally friendly innovations, as evidenced by examples from various countries and industries. At the same time, as noted by Esen et al. (2021), a well-designed system of environmental tax regulation has high potential for solving environmental problems if such policies are not coupled with exemptions or reimbursements, which limit their effectiveness.

In contrast, when measuring the relationship between environmental tax regulation and pollution, other researchers find no significant correlation or arrive at conflicting results. For instance, introducing air pollution charges in the Czech Republic showed low economic efficiency and weak influence on companies' behavior regarding emissions reduction (Pavel et al., 2008). Godawska and WYROBEK (2021), exploring the influence of environmental policy stringency on renewable energy production in Hungary, the Czech Republic, Slovakia, and Poland, did not find a significant correlation between environmental taxes and renewable energy production. Telatar and Birinci (2022) examined the influence of environmental taxes (ETs) on Turkey's environmental footprint and CO₂ emissions. The authors used nonlinear models that included types of ETs such as the environmental cleaning tax (ECT), the special

consumption tax (SCT), and the motor vehicle tax (MVT), concluding that these taxes have no long-term effect on the dependent environmental variables.

Koziuk et al. (2020) cross-correlation analysis of European Union countries' data showed diametrically opposed relationships between environmental payments and environmental conditions for different groups of countries. These results may be linked to the possibility of post-facto tightening of environmental regulation in response to increased pollution and nonlinear dependencies that require alternative analysis methods. When examining the carbon tax, several studies debate its environmental performance compared to alternative regulatory tools. For instance, Hu et al. (2020) found that the carbon tax is less beneficial than cap-and-trade for developing sectors.

The discussion about the impact of tax measures on air pollutant emissions continues among researchers. Some studies confirm the positive impact of environmental taxes on emissions reduction and the promotion of clean innovation. Examples from various countries show that taxes such as carbon and resource taxes help reduce CO₂ and other pollutants while fostering the growth of 'green' energy use. However, other studies question the effectiveness of tax regulation, pointing to weak or conflicting relationships between taxes and environmental outcomes. The above reflects the complexity and ambiguity of the impact of tax measures, which depends on many factors, including national policies, economic structure, and regulatory technology.

Our study focuses on examining the relationship between taxes such as energy taxes, resource taxation, transport taxes, and environmental pollution taxes with atmospheric pollutant emissions, including sulfur oxides, nitrogen oxides, particulate matter (PM₁₀ and PM_{2.5}), carbon monoxide, non-methane volatile organic compounds, and ammonia. Despite the considerable attention given in the literature review to the role of environmental measures in fostering innovations for reduced pollutant production, our study does not directly explore this aspect. Instead, we concentrate on analyzing the effect of specific tax measures on pollutant emissions. The analysis is based on data from nine countries from 2010 to 2022. Thus, our research will continue the ongoing discussion on the role of tax measures in reducing air pollution, providing additional empirical data for developing effective environmental tax policies.

3. Methodology

Data from nine countries from 2010 to 2022 were used to analyze the impact of tax measures on air pollutant emissions. The selected countries for the analysis included Austria, Denmark, the Czech Republic, Poland, Hungary, Slovakia, Slovenia, Sweden, and Kazakhstan. The key criteria for selecting these countries were their geographic, economic, and environmental diversity, which allowed the study to cover different regions, such as Central and Eastern Europe, countries with high environmental performance indices, and Kazakhstan, representing the unique Central Asian context.

An important limitation in selecting the countries was data availability. To ensure the accuracy and comparability of the results, the decision was made to use data from the Organisation for Economic Co-operation and Development (OECD, n.d.). This source provides complete and standardized data on various environmental indicators and tax measures, which helps reduce the risk of systematic errors in the estimates. Using data from other sources could have resulted in incorrect comparisons due to differences in data collection and processing methodologies. Therefore, countries with the most comprehensive data for the selected period were included in the sample to ensure the validity of the results.

As for the tax measures (independent variables), four types of taxes were analyzed: 'energy taxes,' 'transport taxes,' 'environmental pollution taxes,' and 'resource taxation,' measured in monetary terms (USD). The dependent variables included seven types of pollutants (annual emission volumes, in thousand tons): 'Sulfur Oxides (SOx),' 'Nitrogen Oxides (NOx),' 'Particulate Matter (PM10),' 'Particulate Matter (PM2.5),' 'Carbon Monoxide (CO),' 'Volatile Organic Compounds (VOC),' and 'Ammonia (NH3).' It should be noted that the analysis was based on 117 observations, which is sufficient to obtain statistically significant results (Schmidt, 1971), considering the number of independent variables.

This study does not account for a time lag in the analysis, as it assumes that environmental taxes immediately impact taxpayer behavior. As a regulatory tool, environmental taxes are expected to prompt a rapid response from industrial enterprises, encouraging them to reduce emissions promptly in reaction to the increased tax burden.

Multiple Linear Regression Equation

The multiple linear regression model is represented by Equation (1):

$$Y_i = b_0 + b_1 \text{Energy tax} + b_2 \text{Transport tax} + b_3 \text{Pollution tax} + b_4 \text{Resource tax} + \epsilon \quad (1)$$

Where:

Y is the dependent variable

b_0 – is the intercept term

b_1, b_2, b_3, b_4 are the regression coefficients for each independent variable

ϵ is the error term

All calculations were performed using Jamovi and Microsoft Office Excel Software.

Based on this, we hypothesize that an increase in taxes leads to a reduction in pollutant emissions.

4. Findings

4.1. Empirical results

The Shapiro-Wilk test indicated that the data do not follow a normal distribution; therefore, Spearman's correlation was calculated (Table 2).

Table 2:
Spearman Correlation Matrix of Emissions and Taxes

	Energy tax	Transport tax	Pollution tax	Resource tax	SOx	NOx	PM10	PM2.5	CO	VOC
Transport tax	0.824***									
Pollution tax	0.015	0.101								
Resource tax	-0.064	-0.041	0.596***							
SOx	-0.046	-0.278**	0.002	0.424***						
NOx	0.339***	0.185*	0.102	0.543***	0.786***					
PM10	0.196*	-0.050	0.184*	0.540***	0.904***	0.906***				
PM2.5	0.118	-0.170	0.113	0.515***	0.942***	0.830***	0.960***			
CO	0.112	-0.048	-0.113	0.442***	0.880***	0.910***	0.902***	0.883***		
VOC	0.313***	0.083	0.263**	0.594***	0.845***	0.927***	0.964***	0.908***	0.843***	
NH3	0.159	0.114	0.439***	0.785***	0.666***	0.789***	0.801***	0.771***	0.735***	0.811***

Note. * $p < .05$, ** $p < .01$, *** $p < .001$

Source: Authors' own calculations, 2025

According to the correlation results, resource taxes demonstrate the broadest impact on multiple pollutants, ranging from high positive to moderate correlations, as noted by Hinkle et al. (2003). The above suggests that regulating resource extraction could yield significant environmental benefits. In contrast, transport taxes appear to have a more targeted effect, primarily reducing sulfur oxides (SOx), while their influence on other pollutants is limited or insignificant. Furthermore, energy taxes strongly correlate with nitrogen oxides (NOx) and volatile organic compounds (VOC) emissions.

Notably, the transport tax strongly correlates with the energy tax (0.824), indicating that these taxes may be applied in conjunction. Additionally, the pollution tax has a significant positive interconnection with the resource tax (0.596).

The Spearman correlation matrix also reveals high degrees of multicollinearity among the pollutants, suggesting that many strongly correlate. This correlation is often attributable to shared sources, such as industrial activity, transportation, and energy production.

Given the severe multicollinearity present in the data, the authors conducted separate regression models for each pollutant. This approach facilitates an independent

analysis of the effects of tax measures on each pollutant.

Table 3:
Regression Model 1 (SOx)

Variable	Coefficient	SE	t	p
Intercept	111.590	54.88339	2.033	0.044
Energy tax	-0.006	0.00757	-0.761	0.448
Transport tax	-0.067	0.01832	-3.660	<.001
Pollution tax	-0.030	0.21527	-0.138	0.890
Resource tax	1.527	0.101	15.137	<.001

R2 = 0.765
Adj. R-squared = 0.757

Source: Authors’ own, 2025

The regression analysis for SOx emissions reveals a mixed relationship between taxes and sulfur oxide levels (Table 3). Transport taxes have a statistically significant negative impact, reducing SOx emissions, suggesting that policies targeting transportation can play a role in mitigating sulfur-related air pollution. The above indicates that for every unit increase in the transport tax, SOx emissions decrease by 6.7%.

On the other hand, resource taxes positively affect SOx emissions, indicating that industries reliant on natural resources may contribute to sulfur pollution regardless of the tax rate. Additionally, there may be an endogeneity issue in constructing this model, where the causal relationship runs from the dependent variable to the independent variable. An increase in resource taxes is often associated with a rise in the extraction of natural resources, such as coal, oil, or gas, which, in turn, can lead to increased industrial activity and, consequently, higher emissions of sulfur oxides (SOx) or other pollutants.

Energy and pollution taxes show no significant effect, suggesting that their influence on SOx emissions may be limited or indirect. The model explains 76.5% of the variance in SOx emissions.

Table 4:

Regression Model 2 (NOx)

Variable	Coefficient	SE	t	p
Intercept	43.613	21.584	2.02	0.046
Energy tax	0.035	0.00300	11.62	<.001
Transport tax	-0.049	0.007	-6.74	<.001
Pollution tax	-0.153	0.085	-1.80	0.074
Resource tax	0.594	0.040	14.97	<.001

R² = 0.779

Adj. R-squared = 0.771

Source: Authors' own, 2025

In the case of NOx emissions (Table 4), there is a moderately strong positive correlation between resource taxation and nitrogen oxide emissions, indicating that as resource taxes increase, NOx emissions also tend to rise. Energy taxes show a significant positive correlation with NOx emissions, suggesting that raising energy taxes may inadvertently lead to higher NOx emissions, possibly due to shifts in energy production methods. While pollution taxes have a moderate effect in reducing NOx emissions, this effect is not statistically significant, indicating their impact may be weaker than transport taxes. The model explains 77.9% of the variation in NOx emissions.

Table 5:

Regression Model 3 (PM10)

Variable	Coefficient	SE	t	p
Intercept	13.279	13.880	0.957	0.341
Energy tax	0.023	0.002	12.126	<.001
Transport tax	-0.042	0.005	-8.995	<.001
Pollution tax	-0.134	0.054	-2.463	0.015
Resource tax	0.408	0.026	15.990	<.001

R² = 0.807

Adj. R-squared = 0.801

Source: Authors' own, 2025

For PM10 emissions (Table 5), among the taxes demonstrating statistically significant coefficients, resource taxes have the most significant impact, with an increase of one unit leading to a rise of 0.408 units in PM10 emissions. Similar to SOx emissions, the issue of endogeneity in the model cannot be ruled out. The model's high R² value (80.7%) indicates that these taxes can significantly influence PM10 levels. However, the

positive effects of energy and resource taxes suggest a need for more targeted environmental policies in these areas.

Table 6:

Regression Model 4 (PM2.5)				
Variable	Coefficient	SE	t	p
Intercept	3.676	10.613	0.340	0.735
Energy tax	0.019	0.001	13.190	<.001
Transport tax	-0.032	0.004	-9.099	<.001
Pollution tax	-0.090	0.042	-2.149	0.034
Resource tax	0.220	0.012	11.282	<.001
R2 = 0.749				
Adj. R-squared = 0.741				

Source: Authors' own, 2025

Like PM10, the regression model for PM2.5 emissions shows a reduction linked to transport and pollution taxes (Table 6). The smaller particulate size makes PM2.5 a more dangerous pollutant, and the effectiveness of transport taxes in reducing these emissions highlights their critical role in public health policies. However, the positive impact of energy and resource taxes on PM2.5 indicates that industries reliant on energy and natural resources may contribute to increased fine particulate emissions. This positive correlation calls for re-evaluating energy and resource taxation strategies to minimize negative environmental impacts. The model explains 74.9% of the variation in PM2.5 emissions, showing the relevance of tax policy, but it also reveals unintended consequences associated with specific tax measures.

Table 7:

Regression Model 5 (CO)				
Variable	Coefficient	SE	t	p
Intercept	531.405	157.923	3.36	0.001
Energy tax	0.119	0.022	5.48	<.001
Transport tax	-0.225	0.0527	-4.27	<.001
Pollution tax	-2.001	0.619	-3.23	0.002
Resource tax	2.928	0.290	10.08	<.001
R2 = 0.576				
Adj. R-squared = 0.561				

Source: Authors' own, 2025

Various tax policies notably influence carbon monoxide emissions (Table 7).

Transport taxes significantly reduce CO emissions, aligning with the findings for other pollutants, and supporting the view that transport-based taxes are effective in reducing vehicular emissions. However, both energy and resource taxes show a positive relationship with CO emissions, suggesting that these taxes could lead to more carbon monoxide output, potentially due to shifts in industrial production or energy use. Pollution taxes are the most effective in reducing CO emissions, indicating their importance in managing industrial emissions related explicitly to carbon monoxide. With 57.6% of the variation explained by the model, the results suggest that while taxation can reduce CO levels, energy and resource taxes may need careful reconsideration.

Table 8:

Regression Model 6 (VOC)

Variable	Coefficient	SE	t	p
Intercept	86.407	22.076	3.91	<.001
Energy tax	0.036	0.003	11.86	<.001
Transport tax	-0.058	0.007	-7.90	<.001
Pollution tax	-0.262	0.087	-3.03	0.003
Resource tax	0.621	0.041	15.30	<.001

R² = 0.789

Adj. R-squared = 0.781

Source: Authors' own, 2025

Like other pollutants, both transport and pollution taxes reduce volatile organic compounds (VOCs) (Table 8). However, energy taxes again show a positive relationship with increased VOC emissions, highlighting a pattern of counterproductive effects across several pollution categories. The model explains 78.9% of the variation in VOC emissions.

Table 9:Regression Model 7 (NH₃)

Variable	Coefficient	SE	t	p
Intercept	28.816	10.597	2.72	0.008
Energy tax	0.012	0.001	8.31	<.001
Transport tax	-0.019	0.004	-5.33	<.001
Pollution tax	-0.054	0.042	-1.31	0.194
Resource tax	0.340	0.019	17.47	<.001

R² = 0.800

Adj. R-squared = 0.793

Source: Authors' own, 2025

The model for ammonia emissions also follows a familiar pattern: transport taxes

effectively reduce emissions, while energy and resource taxes lead to significant increases in NH₃ levels (Table 9). The absence of a significant effect from pollution taxes is unique to this pollutant and may suggest that ammonia emissions are less influenced by general industrial regulation. The positive relationship between resource taxes and ammonia emissions indicates that industries dependent on natural resources are major contributors to ammonia pollution, and higher taxes may not provide the desired deterrence. The model explains 80% of the variation in ammonia emissions, underscoring the need for targeted interventions in resource-based sectors to reduce ammonia levels.

4.2. Discussion and policy lesson

Correlation analysis reveals significant multicollinearity between pollutants, indicating that many pollutants share common sources. For conventional pollutants like sulfur dioxide (SO₂), nitrogen oxides (NO_x), carbon monoxide (CO), volatile organic compounds (VOCs), and particulate matter (PM), fossil fuel combustion is typically the primary anthropogenic source (Holman, 1999). Vehicles emit many pollutants in urban settings (Baldauf et al., 2009). Therefore, the strong correlation between emissions of different pollutants may be attributed to many originating from shared sources, such as industrial production, energy, transportation, and extractive industries. High correlation among pollutants presents challenges in statistical analysis when working with multicomponent mixtures and multiple exposures (Zhu et al., 2024). However, this study aims to investigate the impact of environmental tax regulation on individual air pollutants, so this issue did not limit the research. Although most researchers have used similar environmental tax datasets, no studies have been conducted using the specific pollutants examined in this article. Other studies exploring the relationship between environmental tax changes and emissions volumes have primarily focused on CO₂ emissions models (Silajdzic & Mehic, 2018; Savranlar et al., 2024; Li & Masui, 2019).

All estimated models (Tables 3-9) show a substantial positive impact of resource taxes on emissions of the seven types of air pollutants. Alola and Nwulu (2022) arrived at similar conclusions regarding greenhouse gas emissions in North American countries. Conversely, Roy and Dastidar (2021), examining UK data from 1997 to 2017, found no significant impact of resource taxes on air quality. Resource taxes are often linked to the extraction volume of natural resources, such as oil, coal, gas, or minerals. The higher the extraction, the higher the tax revenue and emissions, as extractive industries typically have high levels of environmental pollution. In countries with substantial extractive sectors, these emissions can be tied to intensive economic activity, increasing emissions of all types of pollutants (CO₂, NO_x, SO_x, PM, etc.). Resource taxes may encourage more intensive natural resource usage, especially if extractive companies can pass the tax burden onto end consumers. As Hui et al. (2022) note, resource-dependent cities suffer from a vicious cycle in which fiscal pressure exacerbates air pollution emissions. Implementing robust production capacity is a more effective approach to mitigating environmental degradation, implying investment in education,

innovation, digital technologies, and sustainable business practices (Youssef et al., 2023).

Another finding was a statistically significant reduction in all types of pollutants as the amount of transport taxes paid increased. The most substantial individual effect of the independent variable was observed for CO emissions. This negative coefficient indicates that, holding all other factors constant, an increase in transport tax is associated with decreased carbon monoxide (CO) emissions. Previous studies on the impact of transport taxes on air pollution have not reached a consensus regarding this effect. For instance, Aydin and Bozatli (2022), analyzing data from ten countries with the highest transport tax revenues, observed an increase in air pollution with rising transport taxes in Brazil and emphasized the need for restructuring transport taxes to enhance their environmental effectiveness. The results from Aydin and Esen (2018) in a nonlinear regression model linking transport taxes and CO₂ emissions demonstrated a minimum threshold for the fiscal instrument beyond which the relationship loses statistical significance, suggesting that transport taxes may be ineffective in improving environmental outcomes. Although our study reaches somewhat different conclusions, it is important to note the following. Emissions are measured in absolute values for the reporting years and do not reflect changes over time. This approach was also applied to the amounts of taxes paid. Analyzing time series data from a sufficient number of countries over a specific period could yield more valid results; however, the absence of such data posed a limitation for this study.

4.3. Policy implications to improve Environmental taxation on air pollution:

- (i) Multicollinearity among different air pollutants suggests that regulatory efforts targeting specific pollutants could have broader effects, potentially reducing emissions of other correlated pollutants. Previously, Dong et al. (2019) identified a synergistic effect, concluding that efforts to reduce CO₂ emissions contribute significantly to reductions in PM_{2.5}. For example, controlling sulfur dioxide (SO₂) emissions from power plants by enforcing stricter limits on coal combustion may also reduce emissions of particulate matter (PM) and nitrogen oxides (NO_x), as they are by-products of the same combustion process. The practical policy applicability of these findings is that evaluating the distributive effect of local air pollutant taxes is essential.
- (ii) Relying solely on resource taxes to curb air pollution could be strategically misguided in economies with significant extractive industries. To mitigate the environmental impact of resource extraction, governments should consider supplementary policies, such as investing in cleaner technologies, providing incentives for sustainable practices, and imposing stricter industrial emissions regulations. Furthermore, taxes should be designed to avoid incentivizing increased resource extraction, perhaps by combining them with limits on extraction volumes or stricter emissions monitoring.

- (iii) The impact of transport taxes can be leveraged to regulate air pollution; however, this effect may not be sufficient to drive substantial improvements.
- (iv) While environmental taxes remain a crucial tool for combating pollution, their design and implementation must be closely aligned with specific economic and industrial contexts to avoid unintended consequences and maximize their positive impact on environmental quality.

5. Conclusion

This article analyzed the impact of tax measures on air pollution. Panel data from nine countries regarding the payment of specific types of taxes and the dynamics of emissions of individual pollutants from 2010 to 2022 revealed the following results.

A strong positive correlation was found among all types of pollutants. Similar economic activities, such as transportation, industry, and energy generation, produce many pollutants. For instance, transportation emissions produce carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons, and particulate matter. The same applies to coal-fired power plants, which simultaneously emit multiple types of pollutants.

A common trend observed in the constructed models relating the volumes of individual emissions to the four types of environmental taxes was an increase in emissions with rising payments of resource taxes. In contrast, transport and energy taxes demonstrated a statistically significant negative correlation with emissions.

Further research is needed to determine the causes of the positive correlation between tax measures and emissions. Additional factors influencing air quality, such as technological innovations, economic growth, and industrial structure, should be considered. It is important to analyze the effectiveness of various tax measures and develop more efficient tools to encourage reductions in air pollution. Overall, the study confirms the importance of tax policy in managing environmental quality. However, a comprehensive approach considering various economic and social factors is necessary to achieve the desired outcomes.

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