Justyna GODAWSKA

THE IMPACT OF ENVIRONMENTAL TAXES ON THE LEVEL OF NOx AND SOx EMISSIONS

Justyna **Godawska** (ORCID: 0000-0002-7470-7696) – *AGH University*

Correspondence address:
Gramatyka Street 10, 30-067 Cracow, Poland
e-mail: godawska@agh.edu.pl

ABSTRACT: The purpose of the article is to examine whether environmental taxes affect the level of nitrogen oxides (NOx) and sulfur oxides (SOx) emissions based on the data for 33 countries in the years 1996-2021. The research method used is the analysis of panel regression with fixed effects. For both pollutants, a model without lags and models with one-year and two-year lags were estimated. The results show that environmental tax revenues have a negative and statistically significant but rather symbolic impact on SOx emissions, while these revenues do not affect NOx emissions. In addition, the gross domestic product (GDP) per capita and the share of the urban population in the total population are found to be significant determinants of NOx emissions. The higher the GDP per capita and the share of the urban population, the lower the NOx emissions per capita. The results can be useful for policymakers in assessing the effectiveness of environmental taxes.

KEYWORDS: air pollution, environmental taxes, environmental policy effectiveness

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Introduction

Environmental taxes, next to emission standards and subsidies, are one of the basic instruments of environmental policy in many countries around the world. Acccording to the OECD database (OECD, 2023) environmental taxes have been introduced in over 100 countries, both developed and developing. They are aimed among others at reducing air pollution such as carbon dioxide, sulphur oxides and nitrogen oxides.

Taxes as economic instruments of environmental policy influence the behaviour and preferences of producers and consumers. Their flexibility enables businesses and households to adapt to specific realities and individual adjustments of consumption and/or production (Małolepszy, 2022). According to the Pigou tax concept, an environmental tax causes the internalisation of external costs, leading to the attribution of environmental costs to the polluter, and setting the tax rate at an appropriate level guarantees the maximisation of social welfare. In theory, this appropriate tax rate should be determined individually for each polluter, but in practice, due to the difficulties in estimating the external costs of individual polluters, a uniform rate is set for all polluters.

According to Eurostat classification (Eurostat, 2013), environmental taxes are divided into four main categories analogous to the four categories of tax bases. These are energy taxes (including fuel for transport), transport taxes (excluding fuel for transport), pollution taxes, and resource taxes.

Energy taxes include taxes on energy production and on energy products used for both transport and stationary purposes (e.g. taxes on diesel). Transport taxes mainly comprise taxes related to the ownership and use of motor vehicles. The category of pollution taxes encompasses taxes on measured or estimated emissions to air and water, management of solid waste and noise (with the exception of CO_2 taxes, which are classified as energy taxes). Resource taxes include taxes linked to the extraction or the use of natural resources, such as water, forests, wild flora and fauna, etc.

The cost-effectiveness of environmental taxes is higher than that of emission standards and similar to the cost-effectiveness of tradeable emission allowances. In terms of environmental efficiency, environmental taxes are worse in comparison to theses two alternative instruments (allowances and standards).

The use of environmental taxes may bring the so-called ‘double dividend’, which means that taxes, on the one hand, contribute to abating emissions by internalising external costs, and, on the other hand, the revenues generated by them may allow for the concurrent reduction of other taxes such as income tax or corporation tax (Pearce, 1991). Increasing the importance of environmental taxes in a country’s tax system at the expense of other (labour, capital, or consumption) taxes, which is called environmental tax reform, was implemented among others by Denmark, Greece and Estonia. Tax revenues can be used not only to reduce the tax burdens from other sources (thus ensuring fiscal neutrality) but also to finance additionally predetermined tasks, including those of an ecological nature. It is so-called earmarking, i.e. the process of pre-assigning revenue to particular agencies or allocating it to meet certain expenditure needs (Patterson III, 2000). The extent to which revenues from environmental taxes are earmarked for financing environmental protection depends on the country. According to the research results by Dyduch and Stabryła-Chudzio (2017), in the years 2006-2015, the average ratio of environmental protection expenditures to environmental tax revenues in the particular EU countries varied from 10.1% to 55.4% and in most EU countries less than a half of environmental tax revenues was spent on environmental protection.

The impact of taxes on improving environmental quality is therefore twofold and results from their stimulus function (motivating polluters to reduce their emissions), as well as from their fiscal function, thanks to allocating (part of) the tax revenues to finance environmental protection activities.

The purpose of the article is to examine whether environmental taxes affect the level of nitrogen oxides (NOx) and sulfur oxides (SOx) emissions based on data from 33 countries in the years 1996-2021. The emissions of these pollutants have significant negative consequences for human health and the economy. They have a harmful effect on the human respiratory system and impair respiratory functions. SOx emissions additionally cause acidification of soil and water and destroy sensitive forest ecosystems and buildings. NOx emissions contribute to the eutrophication of water reservoirs. In order to investigate the relationship between environmental taxes and NOx and SOx emissions, an analysis of panel regression with fixed effects was used based on the character of the empirical data.

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The rest of the paper is structured as follows. Firstly, the relevant literature on the the impact of environmental taxes on reducing pollutant emissions is discussed. Next, the variables, data, and methodology are presented. The following section provides the results of the regression analysis and discusses them. Finally, conclusions, recommendations for policymakers, research limitations and suggestions for further research are presented.

An overview of the literature

The issue of the impact of environmental taxes on reducing pollutant emissions or, more generally, improving environmental quality is the subject of many studies. Research devoted to the role of environmental taxes in mitigating greenhouse gas (GHG) emissions clearly dominates.

Dogan et al. (2022) found that environmental taxes, along with renewable energy and energy efficiency, are key factors in reducing carbon dioxide (CO_2) emissions. Their research covered the years 1994-2018 and focused on the 25 most environmentally friendly countries, selected based on the Environmental Performance Index, which takes into account climate change performance, environmental health and ecosystem vitality.

Yilanci and Pata (2022) analysed a long time series of data (1875-2016) in order to examine the role of fiscal policy and economic growth in CO_2 emissions in G7 countries. They found that fiscal policy, as an important determinant of environmental policy, combined with increased government spending, can help lower CO_2 emissions in four of the seven countries. Moreover, their research results indicate that the causal relations between economic growth and CO_2 emissions follow a stable path and contradict the environmental Kuznets curve hypothesis.

Khan and Idrees (2023) examined the determinants of greenhouse gas emissions per capita in the European Union countries in 2012-2019, considering, among others, environmental taxes. According to their study, environmental taxes may contribute to lowering these emissions. Specifically, a 1% increase in environmental taxes (measured as the percentage of these taxes in total taxes) is going to reduce GHG emissions by 0.461 tonnes. For comparison, greenhouse gas emissions in the European Union (EU-27) in these years were in the range of 7.48-8.28 t CO_2 eq per capita (European Environment Agency, 2024).

The impact of environmental taxes and green investments on CO_2 emissions in ASEAN (Association of Southeast Asian Nations) countries was studied by Hieu (2022). The sample covered Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Vietnam and the period 1981-2020. Hieu showed that environmental taxes and green investments help reduce CO_2 emissions in ASEAN countries.

Radulescu et al. (2017) tested the double dividend hypothesis of the environmental taxation in Romania and the EU in 1996-2015. They considered environmental taxes as a share of gross domestic product. The research results showed that in Romania the environmental taxes lower greenhouse gas emissions but they do not have bring economic benefits and in the EU these taxes contribute to both the reduction of GHG emissions and economic growth.

Wolde-Rufael and Mulat-Weldemeskel (2022b) investigated the effect of environmental taxes (measured per capita, as a share of gross domestic product and a share of total taxes) on CO_2 emissions per capita in 18 Latin America and Caribbean countries in 1994-2018. Their results revealed that the impact of environmental taxes depends on the level of emissions. In countries with higher emissions, taxes help reduce CO_2 emissions, while in countries with lower emissions, the impact of taxes is insignificant. Moreover, environmental taxes contribute to the development of renewable energy.

Roy and Dastidar (2021) studied the empirical relationship between different types of environmental taxes and GHG emissions in the UK in the years 1997-2017. They suggest that only energy taxes have effectively reduced GHG emissions, while other environmental taxes such as transport, pollution and resources taxes have had no significant impact on air quality. Similar conclusions regarding the role of energy taxes in reducing GHG emissions were reached by Alola and Nwulu (2022), who studied the impact of environmental taxes on reducing these emissions in Denmark, Finland, Norway and Sweden over the period 1995–2020. Their results revealed that only energy taxes significantly reduce GHG emissions and energy intensity, while pollution and resource taxes

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increase them. However, the research by Križanič et al. (2019) shows that transport taxes are more effective than energy taxes in reducing CO_2 emissions in European Union member states.

Ptak (2016) analysed the literature and reports containing the results of research on the effectiveness of environmental taxes in decreasing CO_2 emissions. This effectiveness depends on various elements of the tax design (such as tax rates, tax base, tax exemptions), demand for price elasticity of taxable goods and the availability of more environmentally friendly substitutes.

Hassan et al. (2022) explored the impact of energy taxes on carbon dioxide emissions from fossil fuel combustion and cement production based on a sample of 31 OECD countries over the period 1994-2013. Their research revealed that energy taxes have negatively influenced CO_2 emissions in both the short and long term.

An environmental tax on a specific pollutant may also reduce emissions of other pollutants. An example is the carbon tax, the use of which in environmental policy brings benefits in the form of reducing emissions not only of CO_2, but also of other air pollutants such as particulate matters (PM), sulfur oxides and nitrogen oxides. Li et al. (2018), using China as an example and a modelling approach to quantify air quality co-benefits of carbon tax show that this tax set at USD 72 per tonne of CO_2 can contribute by 2030 to a 24% reduction in CO_2 emissions by 2030, as well as to reduce SO_2, NOx and PM2.5 by 25%, 19% and 12% respectively. Huang et al. (2023), based on scenario analysis, suggest that a carbon tax could reduce PM2.5 emissions and associated mortality risks in the most polluted countries. However, in less polluted economies, carbon taxation may be counterproductive in some scenarios due to increases in emissions from bioenergy and land use changes (mainly deforestation). Also, Parry et al. (2015) confirm the positive impact of a carbon tax on decreasing local air pollution in the 20 largest emitting countries. They point out that these additional benefits from a carbon tax depend on the country (in particular on the size of the population exposed to air pollution). They indicate Saudi Arabia, Iran, Russia, China and Poland as the economies that stand to gain the most from taxing carbon emissions in the context of abating emissions of other air pollutants.

The effectiveness of environmental taxes in mitigating GHG emissions is also demonstrated in the studies by Mardones and Baeza (2018), Hashmi and Alam (2019), and Wolde-Rufael and Mulat-Weldemeskel (2022a).

There are also studies that do not confirm the positive impact of the carbon tax (or generally environmental taxes) on abating CO_2 emissions. Loganathan et al. (2014) claim that the influence of carbon tax on CO_2 emissions in Malaysia is statistically insignificant. They suggest that the reason for this is, among others, the fact that the tax applies to companies engaged in the oil business, with the main producers of CO_2 being manufacturing companies.

Nerudova and Solilova (2016) investigated the impact of environmental taxes, government spending on environmental protection, and the price of greenhouse gas emission allowances traded in the EU ETS ('carbon price') on CO_2 emissions in the Czech Republic over the period 1996-2012. They found that government environmental spending and a carbon price have a greater influence on CO_2 emissions than environmental taxes. They concluded that environmental taxes serve mainly as a source of increasing budget revenues without in any way affecting the level of consumption of goods generating CO_2 emissions and a carbon price.

Dehdar et al. (2022) studied the effect of environmental taxes on CO_2 emissions as a share of gross domestic product (GDP) and as a share of total taxation based on 36 OECD countries in the years 1994-2015. The results of their research are ambiguous because the environmental tax revenues as a share of gross domestic product have a positive impact on CO_2 emissions, whereas the environmental tax revenues as a share of the total tax revenues curb these emissions.

Zaghdoudi and Maktouf (2017) examined the effect of environmental taxes on CO_2 emissions, considering the non-linear relationship between them. Their research concerned 26 OECD countries in the years 1994-2014. According to their results, below a certain threshold level of environmental taxes (i.e. in the case of a low environmental tax policy), the impact of taxes on CO_2 emissions is statistically significant and negative. Specifically, a 15% increase in environmental tax revenues contributes to reducing CO_2 emissions by 10%. However, above the estimated threshold level for the environmental taxes (i.e. in the case of a high environmental tax policy), the taxes have a positive impact on CO_2 emissions. A 1% increase in environmental tax revenues results in an 8% increase in CO_2 emissions. Zaghdoudi and Maktouf concluded that effectively reducing CO_2 emissions requires properly implemented environmental taxes.

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Al Shammre et al. (2023) reached the opposite conclusion of Zaghdoudi and Maktouf (2017). They analysed the impact of different types of environmental taxes (total, energy, transport, pollution and resource) on CO_2 emissions in 34 OECD countries over the period 1995 – 2019. Their results show that total environmental taxes and taxes on energy, transport and pollution effectively reduce emissions only after exceeding a certain threshold (i.e. 3.002% of GDP for environmental taxes, 1.991% for energy taxes and 0.377% for pollution taxes). Resource taxes are the only environmental taxes that significantly help abate CO_2 emissions both below and above a given threshold level (0.170% of GDP).

Liobikienė et al. (2019) analysed the impact of energy taxes on GHG emissions in EU countries, taking into account the direct and indirect (due to the decline in fossil energy consumption and energy intensity, as well as the increase in renewable energy consumption) impact of energy taxes. Their results show that energy taxes were ineffective and did not contribute (both directly and indirectly) to changing the level of GHG emissions. In general, the reasons why taxes are ineffective in curbing pollution may be poor tax structure, incorrect tax exemptions and inadequately planned refund systems (Roy & Dastidar, 2021).

Much less research examines the impact of environmental taxes on non-greenhouse gas emissions (e.g. SOx, NOx, PM) or on other environmental issues (such as waste, water management, and energy consumption).

Erbertseder et al. (2023) investigated the impact of a local NOx tax on NOx emissions using data for the Spanish Valencian Community. They showed that the impact of the NOx tax is rather small (NOx emissions in 2013-2016 decreased by 1.2%). Moreover, they found that NOx emission reductions are greater in areas with higher business density and in areas where innovative and large companies operate.

Sackitey (2023) analysed the impact of environmental taxes on energy consumption and energy intensity using data from 35 OECD countries over the period 1995-2014. He stated that in the long run, environmental taxes contribute to reducing energy consumption and energy intensity. However, the role of individual taxes varies, i.e. energy taxes exert a greater impact on energy consumption and energy intensity than pollution and transport taxes.

Misztal (2020) showed, based on the data for Polish transport companies in 2009-2018, that the increase in environmental taxes has a statistically significant, negative and rather small effect on the self-established environmental indicator. This indicator takes into account, in addition to greenhouse gas emissions (carbon dioxide, nitrous oxide, and hydrofluorocarbons), as well as emissions of nitrogen oxide, sulfur dioxide, ammonia, and dust.

Tang et al. (2017) simulated the impact of China's carbon resource tax reform on CO_2, NOx and SO_X emissions. They found that emissions of these pollutants would be significantly reduced thanks to the reform introduced in 2014.

Križanič et al. (2019) examined the effect of environmental taxes on collected waste in the EU countries in 2004-2012 and found the negative linkage between these variables. In particular, a 1% increase in environmental taxes contributes after one year to reduction in the amount of waste collected by 0.13% per inhabitant.

He et al. (2019) explored the relationship between environmental taxes and emissions of various pollutants (CO_2, GHG, NOx and SOx) in 35 OECD countries in 1994-2016 and the relationship between a quasi-environmental tax and emissions of SO_X and ammonia nitrogen, industrial solid waste production, and chemical oxygen demand from wastewater of 31 Chinese inland provinces in 2004–2016. Their results confirmed the effectiveness of environmental taxes in improving environmental quality in both OECD countries and China.

Freire-González and Ho (2018) simulated the economic and environmental effects of an environmental fiscal reform examining 101 industries and commodities in Spain and 31 different local and global pollutants and the total use of coal, oil and gas. Environmental fiscal reform, compared to environmental tax reform, additionally includes a liquidation of subsidies that are not conducive to environmental policy. The simulation results showed that three to four years after the implementation of environmental fiscal reform, all emissions of the analysed pollutants were reduced.

To sum up, although most studies confirm the effectiveness of environmental taxes in reducing pollutant emissions and improving environmental quality there is a research gap concerning the

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impact of these taxes on NOx and SOx emissions taking into account especially the newer data and countries not only from the OECD.

Research methods

This study examines the relationship between environmental taxes and the emissions level of two air pollutants (NOx and SOx) using panel regression analysis. Two basic regression models used for the study are as follows:

$$NOX\_PC_{i,t} = ET\_PC_{i,t}\beta_1 + GDP\_PC_{i,t}\beta_2 + URB_{i,t}\beta_3 + v_{i,t}, \quad (1)$$

$$SOX\_PC_{i,t} = ET\_PC_{i,t}\beta_1 + GDP\_PC_{i,t}\beta_2 + URB_{i,t}\beta_3 + v_{i,t}, \quad (2)$$

where:
$NOX\_PC_{i,t}$ – nitrogen oxides emissions per capita,
$SOX\_PC_{i,t}$ – sulfur oxides emissions per capita,
$ET\_PC_{i,t}$ – environmental taxes per capita,
$GDP\_PC_{i,t}$ – gross domestic product per capita,
$URB_{i,t}$ – urban population,
β_1, β_2, β_3 – parameters,
$v_{i,t}$ – a total random error consisting of a purely random part $\varepsilon_{i,t}$ and an individual effect u_i referring to the specific unit i of the panel ($v_{i,t} = \varepsilon_{i,t}+u_i$),
i – the index i=1,2, ...,N denoting objects (countries),
t – the index t =1,2, ...,T denoting time units.

Additionally, in order to check the robustness of the results, four models with lagged variables for environmental taxes per capita ($ET\_PC_{i,t-1}$; $ET\_PC_{i,t-2}$) were used:

$$NOX\_PC_{i,t} = ET\_PC_{i,t-1}\beta_1 + GDP\_PC_{i,t}\beta_2 + URB_{i,t}\beta_3 + v_{i,t}, \quad (3)$$

$$SOX\_PC_{i,t} = ET\_PC_{i,t-1}\beta_1 + GDP\_PC_{i,t}\beta_2 + URB_{i,t}\beta_3 + v_{i,t}, \quad (4)$$

$$NOX\_PC_{i,t} = ET\_PC_{i,t-2}\beta_1 + GDP\_PC_{i,t}\beta_2 + URB_{i,t}\beta_3 + v_{i,t}, \quad (5)$$

$$SOX\_PC_{i,t} = ET\_PC_{i,t-2}\beta_1 + GDP\_PC_{i,t}\beta_2 + URB_{i,t}\beta_3 + v_{i,t}. \quad (6)$$

In research on the relationship between environmental taxes and pollutant emissions, both unlagged variables (e.g. Wolde-Rufael & Mulat-Weldemeskel, 2022b; Al Shammre et al., 2023) and lagged variables (e.g. Liobikienė et al., 2019; Roy & Dastidar, 2021) are used for taxes. Both approaches are justified because, on the one hand, reducing emissions by polluters may take time, and on the other hand, the tax rates applicable in a given country are usually known sometime in advance.

There are different methods in the empirical studies in terms of environmental taxes measurement. Environmental taxes can be considered as a percentage of gross domestic product (Dehdar et al., 2022), a percentage of total tax revenues (Wolde-Rufael & Mulat-Weldemeskel, 2022b; Khan & Idrees, 2023), a total value of revenues (Nerudova & Solilova, 2016; Rybak et al., 2022) and a value of revenues per capita (He et al., 2019). This study adopts the latter approach.

Two control variables are used in the regression models: gross domestic product (following Loganathan et al., 2014; Wolde-Rufael & Mulat-Weldemeskel, 2022b) and urban population (following Dehdar et al., 2022; Al Shammre et al., 2023). All variables (dependent and independent) are defined in Table 1.

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Table 1. Variables used in the regression models

Variables	Definitions	Source of data
NOX_PC	Total nitrogen oxides emissions in kilograms per capita	OECD
SOX_PC	Total sulfur oxides emissions in kilograms per capita	OECD
ET_PC	Environmental tax revenues per capita (2015 USD PPP)	OECD
GDP_PC	Gross domestic product per capita (constant 2015 USD)	World Bank
URB	Urban population as a percentage of the total population	World Bank

Source: author's work based on OECD [11-10-2023] and World Bank [12-10-2023].

The research sample covers 33 countries, including:

- OECD members (Australia, Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Lithuania, Luxembourg, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Türkiye, United Kingdom, United States), and
- non-OECD economies (Bulgaria, Cyprus, Malta, Romania).

The period of 1996-2021 was taken into account in the analysis. The selection of countries and the study period resulted from the availability of data. There were 858 observations in total (in basic regression models with unlagged environmental taxes variables).

In order to investigate the relationship between environmental taxes and NOx and SOx emissions analysis of panel regression was used. Panel regression analysis is a method used for analysing relationships between phenomena for data combining temporal and cross-sectional dimensions. Panel data make it possible to simultaneously take into account the diversity of the studied objects and their evolution over time. The panel regression analysis method was used, among others, by Tantau et al. (2018) and Liobikienė et al. (2019).

Three methods of estimation were considered: ordinary least squares (OLS) panel regression, fixed effects panel regression and random effects panel regression. The selection of the most appropriate estimator was made on the basis of the Breusch-Pagan test, and then, if necessary, on the basis of the Hausman test. The assumed significance level was 0.05. The Gretl software was used for calculations.

Results of the research and discussion

Table 2 presents descriptive statistics of dependent and independent variables. SOx emissions (per capita) show very strong variability (156% measured by the coefficient of variation). NOx emissions, GDP and environmental tax revenues (all variables per capita) have strong variability and urban population low variability (76%, 65%, 52% and 16%, respectively, measured by the coefficient of variation).

Table 2. Descriptive statistics of variables

Variable	Mean	Standard deviation	Minimum	Maximum
NOX_PC	29.65	22.41	7.853	121.2
SOX_PC	24.01	37.39	0.396	264.8
ET_PC	926.7	480.0	90.03	3077
GDP_PC	32,660	21,078	3,540	112,418
URB	74.80	12.28	50.65	98.12

The countries with the highest NOx emissions per capita are Australia, Iceland and Luxembourg, and the countries with the smallest emissions are Japan, Romania and Türkiye. The largest emitters of SOx per capita are Iceland, Australia and Bulgaria, and the smallest are Austria, the Netherlands

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and Sweden. The most revenues from environmental taxes per capita were collected in the Netherlands, Norway and Ireland and the least in Romania, Bulgaria and the United States.

Figures 1 and 2 show the average per capita levels of NOx and SOx emissions, while Figure 3 shows the average per capita levels of environmental tax revenues in the sample. NOx emissions in 1996-2021 decreased by 53%. In 1996, NOx emissions averaged 39.6 kg per capita, and in 2021, they amounted to only 18.6 kg per capita. SOx emissions have also been reduced (by 71%) from 41.5 kg per capita in 1996 to 11.9 kg per capita in 2021. The average value of revenues from environmental taxes in the analysed period fluctuated and ranged from USD 761.1 in 1996 to USD 1000.8 in 2018.

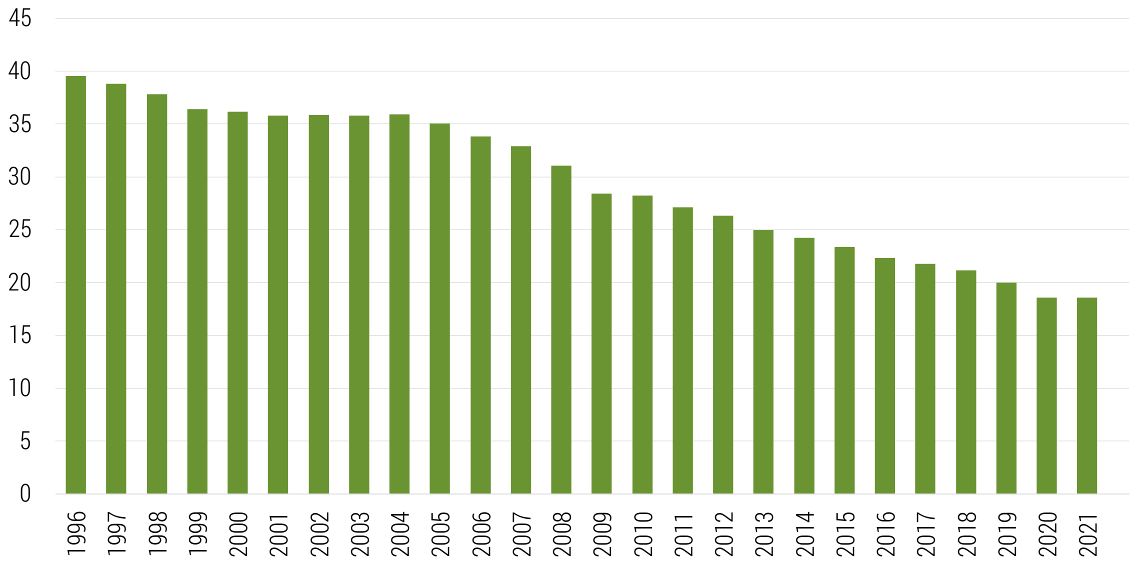

Figure 1. The average value of NOx emissions in analysed countries [in kilograms per capita]
Source: author's work based on OECD [11-10-2023].

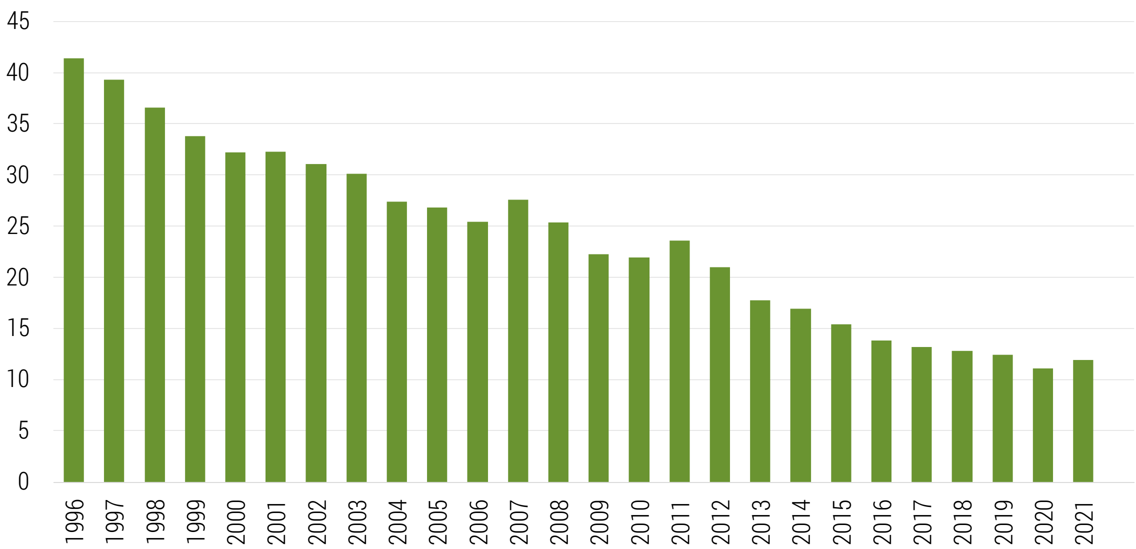

Figure 2. The average value of SOx emissions in analysed countries [in kilograms per capita]
Source: author's work based on OECD [11-10-2023].

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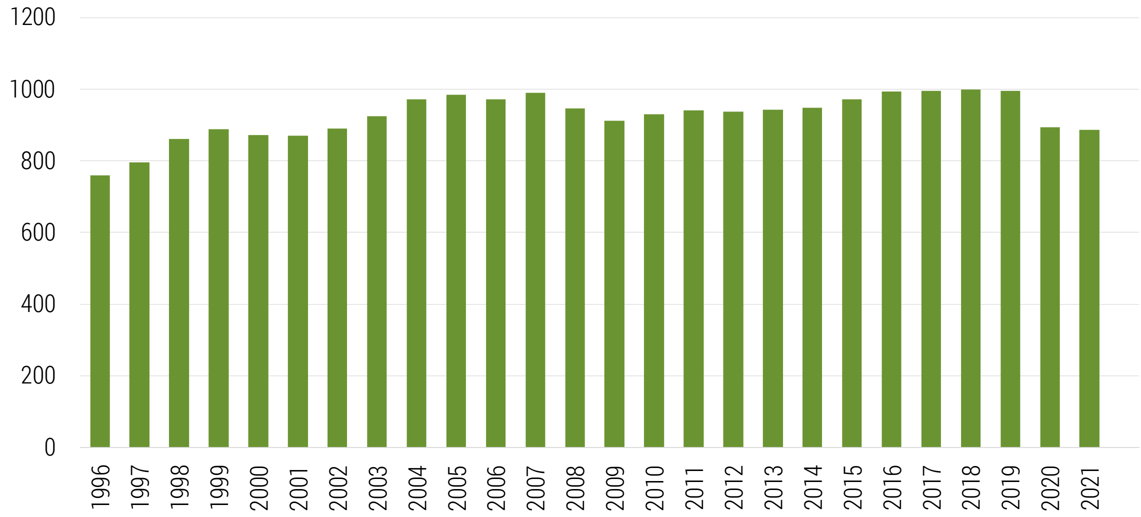

Figure 3. The average value of environmental tax revenues per capita in analysed countries [in 2015 USD PPP]
Source: author's work based on OECD [11-10-2023].

The values of variance inflation factors (i.e. lower than 10) indicate that the problem of multicollinearity does not occur in any of the six models used (cf. Table 3).

Table 3. Variance inflation factors for the regression models

Variables	Models (1) and (2)	Models (3) and (4)	Models (5) and (6)
$ET\_PC_{i,t}$	2.157	-	-
$ET\_PC_{i,t-1}$	-	2.248	-
$ET\_PC_{i,t-2}$	-	-	2.334
$GDP\_PC_{i,t}$	2.715	2.808	2.897
$URB_{i,t}$	1.409	1.407	1.406

Table 4. The choice of appropriate estimation method for the regression models

Models	Results of Breusch-Pagan test	Results of Hausman test	Appropriate method for estimating regression
Model (1)	LM = 4437.72 p = 0.000	H = 166.294 p = 8.03082e-036	Panel regression with fixed effects
Model (2)	LM = 6007.33 p = 0.000	H = 40.1232 p = 1.00333e-008	Panel regression with fixed effects
Model (3)	LM = 4187.18 p = 0.000	H = 176.895 p = 4.13058e-038	Panel regression with fixed effects
Model (4)	LM = 5838.37 p = 0.000	H = 37.2649 p = 4.04433e-008	Panel regression with fixed effects
Model (5)	LM = 3950.73 p = 0.000	H = 187.11 p = 2.56944e-040	Panel regression with fixed effects
Model (6)	LM = 5668.99 p = 0.000	H = 34.513 p = 1.54382e-007	Panel regression with fixed effects

The selection of appropriate models was made based on the results of the Breusch-Pagan and Hausman test (cf. Table 4). For all models, the results of the Breusch-Pagan test indicate the rejection of hypothesis H0 that ordinary least squares panel regression is correct, given hypothesis H1 that

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random effects panel regression is more appropriate. The Hausman test allows one to choose between panel regression with random effects and fixed effects. The results of this test allow us to reject the null hypothesis that the random effects estimator is more effective than the fixed effects estimator. Therefore, all models were estimated using panel regression with fixed effects.

Table 5 shows the estimation results of panel regression for model 1 (relationship between environmental tax revenues per capita and NOx emissions per capita). The model has a good fit (the coefficient of determination LSDV R-squared=0.904). Environmental taxes do not have a significant impact on the level of NOx emissions (at the adopted significance level of 5%, p-value equals 0.0883). Meanwhile, a share of the urban population in total population and gross domestic product per capita significantly and negatively affect NOx emissions. The greater the share of urban population and GDP per capita, the lower the NOx emissions per capita.

The analysis of the relationship between environmental tax revenues per capita and NOx emissions per capita with one-year and two-year lags (models 3 and 5, respectively) does not change the significance of the independent variables in explaining NOx emissions. The share of urban population and GDP have a negative and statistically significant impact on emissions, while the effect of environmental taxes is insignificant (cf. Tables 6 and 7). Models 3 and 5 show an adequate explanation of NOx emission according to LSDV R-squared (0.904 for model 3 and 0.903 for model 5).

Tables 8-10 present the panel regression estimation results for models 2, 4, and 6 explaining the relationship between per capita environmental tax revenues and per capita SOx emissions without lags, with one-year and two-year lags, respectively. For all three models, the coefficient of determination is sufficient to explain SOx emissions (LSDV R-squared equals 0.814, 0.826, and 0.843 respectively).

The results of model 2 (without lags) and models 4 and 6 (with lags) show similar significance of the independent variables. Environmental tax revenues have a negative and statistically significant but rather very small impact on SOx emissions. Control variables (share of urban population in total population and GDP per capita) do not have a significant impact on SOx emissions.

Table 5. Results of fixed effects panel regression analysis with robust standard errors for model (1) (858 observations)

Variable	Coefficient	Standard deviation	t-statistics	p-value	Significance
Constant	136.033	22.5546	6.031	<0.0001	***
URB	−1.18558	0.368521	−3.217	0.0030	***
GDP_PC	−0.00103358	0.000321451	−3.215	0.0030	***
ET_PC	0.0173133	0.00984641	1.758	0.0883	*
Arithmetic mean of the dependent variable		29.64545	Standard deviation of the dependent variable		22.41390
Sum of squared residuals		41304.24	Standard error of residuals		7.088616
LSDV R-squared		0.904065	Within R-squared		0.465605
Log-likelihood		−2879.445	Akaike information criterion		5830.890
Schwarz Bayesian criterion		6002.056	Hannan-Quinn criterion		5896.427
Autocorrelation of residuals		0.917990	Durbin-Watson statistics		0.138415

*** significance level at 1%, * significance level at 10%.

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Table 6. Results of fixed effects panel regression analysis with robust standard errors for model (3) (825 observations)

Variable	Coefficient	Standard deviation	t-statistics	p-value	Significance
Constant	145.968	24.3722	5.989	<0.0001	***
URB	−1.30182	0.406456	−3.203	0.0031	***
GDP_PC	−0.00106130	0.000353148	−3.005	0.0051	***
ET_PC	0.0169616	0.0105337	1.610	0.1172	
Arithmetic mean of the dependent variable		29.24783	Standard deviation of the dependent variable		22.25962
Sum of squared residuals		38993.73	Standard error of residuals		7.030058
LSDV R-squared		0.904494	Within R-squared		0.450167
Log-likelihood		−2761.131	Akaike information criterion		5594.261
Schwarz Bayesian criterion		5764.015	Hannan-Quinn criterion		5659.378
Autocorrelation of residuals		0.906461	Durbin-Watson statistics		0.170241

*** significance level at 1%.

Table 7. Results of fixed effects panel regression analysis with robust standard errors for model (5) (792 observations)

Variable	Coefficient	Standard deviation	t-statistics	p-value	Significance
Constant	157.038	27.5820	5.693	<0.0001	***
URB	−1.42680	0.453248	−3.148	0.0035	***
GDP_PC	−0.00107633	0.000387527	−2.777	0.0091	***
ET_PC	0.0156696	0.0109417	1.432	0.1618	
Arithmetic mean of the dependent variable		28.84766	Standard deviation of the dependent variable		22.10953
Sum of squared residuals		37353.01	Standard error of residuals		7.029135
LSDV R-squared		0.903397	Within R-squared		0.426845
Log-likelihood		−2649.828	Akaike information criterion		5371.656
Schwarz Bayesian criterion		5539.940	Hannan-Quinn criterion		5436.334
Autocorrelation of residuals		0.917213	Durbin-Watson statistics		0.174774

*** significance level at 1%.

Table 8. Results of fixed effects panel regression analysis with robust standard errors for model (2) (858 observations)

Variable	Coefficient	Standard deviation	t-statistics	p-value	Significance
Constant	199.064	92.5702	2.150	0.0392	**
URB	−1.67075	1.21992	−1.370	0.1804	
GDP_PC	−0.000620298	0.000422387	−1.469	0.1517	
ET_PC	−0.0321937	0.0141883	−2.269	0.0301	**
Arithmetic mean of the dependent variable		24.00601	Standard deviation of the dependent variable		37.39217

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Variable	Coefficient	Standard deviation	t-statistics	p-value	Significance
Sum of squared residuals		222387.4	Standard error of residuals		16.44823
LSDV R-squared		0.814404	Within R-squared		0.195624
Log-likelihood		-3601.648	Akaike information criterion		7275.295
Schwarz Bayesian criterion		7446.461	Hannan-Quinn criterion		7340.831
Autocorrelation of residuals		0.868678	Durbin-Watson statistics		0.172930

** significance level at 5%.

Table 9. Results of fixed effects panel regression analysis with robust standard errors for model (4) (825 observations)

Variable	Coefficient	Standard deviation	t-statistics	p-value	Significance
Constant	190.001	89.0273	2.134	0.0406	**
URB	-1.59547	1.17331	-1.360	0.1834	
GDP_PC	-0.000609868	0.000405327	-1.505	0.1422	
ET_PC	-0.0292105	0.0131768	-2.217	0.0339	**
Arithmetic mean of the dependent variable		23.30822	Standard deviation of the dependent variable		37.21553
Sum of squared residuals		196646.3	Standard error of residuals		15.78718
LSDV R-squared		0.827690	Within R-squared		0.182917
Log-likelihood		-3428.558	Akaike information criterion		6929.116
Schwarz Bayesian criterion		7098.870	Hannan-Quinn criterion		6994.233
Autocorrelation of residuals		0.853757	Durbin-Watson statistics		0.188884

** significance level at 5%.

Table 10. Results of fixed effects panel regression analysis with robust standard errors for model (6) (792 observations)

Variable	Coefficient	Standard deviation	t-statistics	p-value	Significance
Constant	179.663	85.0721	2.112	0.0426	**
URB	-1.50148	1.12422	-1.336	0.1911	
GDP_PC	-0.000623147	0.000378302	-1.647	0.1093	
ET_PC	-0.0255281	0.0123483	-2.067	0.0469	**
Arithmetic mean of the dependent variable		22.63874	Standard deviation of the dependent variable		37.06234
Sum of squared residuals		171124.9	Standard error of residuals		15.04512
LSDV R-squared		0.842503	Within R-squared		0.170247
Log-likelihood		-3252.532	Akaike information criterion		6577.064
Schwarz Bayesian criterion		6745.348	Hannan-Quinn criterion		6641.742
Autocorrelation of residuals		0.842161	Durbin-Watson statistics		0.206644

** significance level at 5%.

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The results of this study regarding the negative impact of environmental taxes on SO_x emissions are consistent with the results of research by Freire-González and Ho (2018), He et al. (2019), Misztal (2020), and Tang et al. (2017). However, this study shows that the effect of environmental taxes is rather symbolic. In particular, a 10% increase in per capita environmental tax revenues contributes immediately to the reduction in per capita SO_x emissions by only 0.32%. Twice the per capita tax revenues would reduce per capita emissions by just 3.2%. A 10% increase in environmental tax revenues after one year reduces SO_x emissions by only 0.13 % and after two years by only 0.12%.

Regarding the effectiveness of environmental taxes in lowering NO_x emissions, the results of this study are not in line with the results of research by Erbertseder et al. (2023), Freire-González and Ho (2018), He et al. (2019), Misztal (2020), and Tang et al. (2017), who found the negative and significant relationship between these variables. According to the results of this study, per capita environmental tax revenues are statistically insignificant in terms of abating per capita NO_x emissions.

The fact that the greater the share of the urban population, the lower NO_x emissions can be explained by the fact that transport is an important source of NO_X emissions, and the more people live outside urban areas, the greater the need to use cars due to the long distances. Moreover, according to Al Shammre et al. (2023), urbanisation can result in more efficient transportation and energy consumption. A positive phenomenon is the negative impact of GDP per capita on the reduction of NO_x emissions, which means that a higher level of GDP can be achieved without causing deterioration of the quality of the natural environment.

Conclusions

The effectiveness of environmental taxes consists of reducing emissions of pollutants, sewage, waste and energy consumption. Although the assessment of this effectiveness is the subject of interest to many researchers, no consensus has been reached on this matter so far, although most studies indicate the significant role of environmental taxes in improving the quality of the environment. This study examines whether environmental taxes affect the level of NO_x and SO_x emissions based on data from 33 countries (mostly European) in the years 1996-2021. The research results do not confirm the (high) effectiveness of environmental taxes. Their impact on NO_x emissions turned out to be statistically insignificant, and on SO_x emissions, it was negative, statistically significant, but symbolic. In addition, the gross domestic product per capita and the share of the urban population in the total population are found to be significant determinants of NO_x emissions.

These results may be useful for policymakers in assessing the effectiveness of environmental taxes as one of many environmental policy instruments. Policymakers should bear in mind that the use of environmental taxes does not 'automatically' mean a reduction in pollutant emissions and that when imposing new taxes or revising the assumptions of existing ones, it is worth paying particular attention to their effectiveness in reducing emissions in the context of tax rates and/or the allocation of tax revenues. In addition, increasing GDP per capita and developing urbanisation may contribute to reducing NO_x emissions.

A limitation of the study is the lack of consideration of various types of environmental taxes in the analysis (e.g. energy, transport, pollution and resource taxes). Future research could consider different types of environmental taxes and, in addition, focus on finding the reasons for the low effectiveness of environmental taxes.

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Justyna GODAWSKA

WPŁYW PODATKÓW ŚRODOWISKOWYCH NA POZIOM EMISJI NOx I SOx

STRESZCZENIE: Celem artykułu jest zbadanie, czy podatki środowiskowe wpływają na poziom emisji tlenków azotu (NOx) i tlenków siarki (SOx) na podstawie danych dla 33 krajów w latach 1996-2021. Zastosowaną metodą badawczą jest analiza regresji panelowej z efektami stałymi. Dla obu zanieczyszczeń oszacowano model bez opóźnień oraz modele z opóźnieniami rocznymi i dwuletnimi. Wyniki pokazują, że dochody z podatków środowiskowych mają negatywny i istotny statystycznie, ale raczej symboliczny wpływ na emisje SOx, natomiast dochody te nie wpływają na emisje NOx. Ponadto stwierdzono, że produkt krajowy brutto (PKB) per capita i udział ludności miejskiej w całkowitej liczbie ludności są istotnymi determinantami emisji NOx. Im wyższy PKB na mieszkańca i udział ludności miejskiej, tym niższa emisja NOx na mieszkańca. Wyniki mogą być przydatne dla decydentów przy ocenie skuteczności podatków środowiskowych.

SŁOWA KLUCZOWE: zanieczyszczenie powietrza, podatki środowiskowe, efektywność polityki środowiskowej

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