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The Effect of Economic Growth on Environmental Pollution

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Abstract. This study investigates the impact of economic growth on environmental pollution, focusing on the relationship and heterogeneous effects between economic development and environmental quality. Using panel data on economic development and environmental pollution across different countries, we examine the effect of economic growth (measured by GDP) on environmental pollution indicators (PM2.5 concentrations and CO2 emissions) through empirical analysis with control variables such as government health expenditure, manufacturing value added, and coal rents, employing Ordinary Least Squares (OLS) regression and panel models. The results reveal that: (1) For PM2.5, an Environmental Kuznets Curve (EKC) pattern exists—pollution initially rises with income but declines after reaching a turning point; (2) CO2 emissions show a monotonic positive correlation with GDP, indicating difficulty in decoupling global pollutants from economic activity; (3) During the COVID-19 pandemic, economic contraction led to a significant reduction in PM2.5 emissions; (4) OECD countries exhibit partial decoupling of growth and PM2.5, while non-OECD countries show a strong positive growth-pollution link. These findings highlight the need for targeted policies, including reducing fossil fuel reliance, expanding public health and environmental expenditure, and promoting structural transformation, to balance economic growth and environmental sustainability.

Keywords: economic growth, environmental pollution, CO2 emissions, GDP, World Bank data.

1. Introduction

Environmental protection has changed from a niche concern to a global priority, as the planet faces serious ecological crises. From the heavy smog that often covers major industrial cities in Asia to the rising number of extreme weather events like the destructive wildfires in California and Australia, the effects of environmental damage are felt around the world. The World Health Organization (WHO) has consistently pointed out that air pollution is one of the biggest environmental threats to health, causing millions of premature deaths each year. These issues are not distant; they are real and threaten ecosystems, human health, and economic stability today.

The role of economic growth in this situation is quite complex. Historically, the drive for prosperity, especially through industrialization, has largely fueled this pollution. The rapid growth of economies like China has lifted hundreds of millions out of poverty but has also made it the largest carbon emitter in the world. This situation illustrates the difficult trade-off involved. At the same

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time, economic development is increasingly seen as a key to solutions. It provides the funds needed for green technology, supports public health systems to address pollution-related illnesses, and can help finance a shift to renewable energy. News headlines regularly reflect this complexity, highlighting debates over "green growth" at international climate meetings like COP28 and national struggles in countries like India and Nigeria to balance poverty reduction with environmental protection.

This intricate relationship is not new to academic research. The landmark study by Grossman and Krueger in 1995 introduced the Environmental Kuznets Curve (EKC) hypothesis, starting years of research into whether economic growth leads to environmental improvement after a certain point. Since then, researchers like Liang and Yang [1] have looked at how urbanization in China affects this relationship, while others, such as Xiong and Xu [2], have identified energy consumption as the key link. However, the evidence is still hotly debated. Some studies support the EKC, while others, like Islam's analysis of South Asia in 2021, find a consistent, positive connection between growth and pollution, suggesting that decoupling does not happen automatically.

These contradictions and the importance of the issue drive this literature review. The key question remains urgent and unresolved: Under what conditions can economic growth align with environmental sustainability? This paper aims to synthesize and critically assess the existing research to clarify the mechanisms—whether scale, structure, or technology—that shape the growth-pollution relationship. By exploring a variety of studies across different geographic and economic contexts, this review seeks to go beyond simplistic explanations and identify the key factors that determine whether economic development leads to environmental damage or a cleaner, more sustainable future.

What's more, in our paper, we investigate the impact of economic growth on environmental pollution. Using panel data on economic development and environmental indicators (PM2.5 concentrations and CO2 emissions) across different countries, we employ Ordinary Least Squares (OLS) regression and panel models to analyze their relationship, controlling for variables such as government health expenditure, manufacturing value added, and coal rents. Our findings reveal an Environmental Kuznets Curve (EKC) pattern for PM2.5, a monotonic positive correlation between GDP and CO2 emissions, reduced PM2.5 during the COVID-19 economic contraction, and heterogeneous effects between OECD and non-OECD countries.

The paper is structured as follows: Section 2 reviews the literature. Section 3 outlines the data sources, key variables and the model. Section 4 presents empirical results, and Section 5 concludes.

2. Literature review

One of the most important frameworks for understanding the connection between growth and pollution is the Environmental Kuznets Curve (EKC). This hypothesis states that pollution levels increase during the early phases of economic growth but start to decline as economies advance, thanks to structural and technological changes. However, the evidence varies greatly depending on context. For example, Liang and Yang studied China's rapid urbanization and found that the quality of urban development influences the EKC relationship [1]. This shows that the method of achieving growth is just as important as the growth itself. Similarly, Rao and Yan [3] used a panel vector autoregression (PVAR) model on Chinese provincial data and found a bidirectional link between growth and pollution. They pointed out that high pollution can also impede economic growth, a feedback loop often missed in simpler models. On the other hand, Islam [4] performed a panel cointegration analysis in South Asia and found a consistent positive connection between growth and

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CO_2 emissions, challenging the EKC's relevance in areas with different industrial and energy profiles.

In addition to the EKC, other factors like energy consumption, policy, and innovation play crucial roles. Xiong and Xu [2] pointed out that in China, energy consumption, especially fossil fuels, is the main way that economic activity leads to pollution. Their analysis suggests that separating growth from emissions requires a major change in energy sources. Policy measures also significantly affect outcomes. Ren et al. [5] showed that top-down growth targets in China worsen air pollution, but allowing local governments more regulatory freedom can reduce these effects. Building on this, Yan et al. [6] demonstrated that renewable energy policies and green innovation can actively reduce the growth-pollution connection, highlighting the central importance of policy and technology in achieving sustainable development.

The social and economic implications of this connection, especially for public health, add to the complexity. Zhao et al. [7] pointed out a clear trade-off in China: economic growth improves healthcare, but pollution-related health issues offset these benefits, creating significant societal costs. Haseeb et al. [8] noted a similar situation in ASEAN countries, where pollution and energy use lead to increased healthcare spending. This creates a negative cycle that threatens long-term well-being. Even in wealthy countries, the issue remains. Ongan et al. [9] used wavelet coherence analysis in the U.S. and found that while short-term separation might happen, the long-term connection between growth and emissions is still positive. This warns against being complacent and relying solely on technology.

The table below provides an overview of the main results and methodologies of the reviewed literature and shows how different approaches and conclusions in the discipline may differ.

Table 1. Summary of literature

Author(s) & Year	Focus	Method	Key Variables (X, Y, Controls)	Key Finding/Contribution
Liang & Yang 2019	Urbanization, growth, & pollution in China.	Panel regression	X: GDP; Y: Industrial pollution; C: Urbanization.	EKC exists but is mediated by urbanization quality.
Rao & Yan 2020	Bidirectional link between growth & pollution.	PVAR model	GDP, Composite pollution index.	Negative feedback loop; high pollution impedes growth.
Xiong & Xu 2021	Role of energy in the growth-pollution nexus.	ARDL cointegration	X: GDP, Energy use; Y: CO2 emissions.	Energy consumption is the key channel linking growth to pollution.
Islam 2021	Growth & pollution in South Asia.	Panel cointegration	X: GDP; Y: CO2; C: Trade, energy use.	Long-run positive link challenges EKC applicability in the region.
Zhao et al. 2022	Impact of growth & pollution on public health.	Panel data models	X: GDP, Pollution; Y: Health spending, mortality.	Growth funds healthcare, but pollution's health costs create a trade-off.
Ren et al. 2023	Effect of growth targets & decentralization.	Regression models	X: Growth targets; Y: PM2.5; M: Decentralization.	Rigid growth targets worsen pollution; effect mitigated by decentralization.
Ongan et al. 2023	The growth-pollution dilemma in the USA.	Wavelet coherence	GDP, CO2, Energy consumption.	Relationship varies; a persistent long-run dilemma remains.
Haseeb et al. 2019	Impact on health & R&D spending in ASEAN.	Panel regression	X: Growth, pollution; Y: Health & R&D spending.	Pollution increases the burden on health spending.
Yan et al. 2024	Role of policy, innovation, & resources.	Advanced panel models	X: GDP; Y: CO2; M: Renewable policy, innovation.	Policy and innovation are key to decoupling growth from emissions.

The literature clearly shows that the relationship between economic growth and environmental pollution is not straightforward or predetermined. While the EKC offers a helpful framework, its success depends heavily on factors like urban development, energy structures, governance quality, and innovation capacity. The discovery of bidirectional causality and the key roles of policy and technology highlight that growth does not have to lead to environmental decline. However,

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achieving separation requires careful and tailored strategies that incorporate structural changes, clean energy use, and proactive environmental management. Future research should focus on identifying practical policy options and addressing the political and economic obstacles to a green transformation, ensuring that economic development supports environmental and public health objectives.

3. Methodology

3.1. Data source and sample

The empirical analysis is based on a comprehensive panel dataset constructed primarily from the World Bank's World Development Indicators (WDI) database. WDI is a leading youngster of unbiased development data, that collects internationally compare rates on an expansive array of economic, social and environmental indicators. This has led us to select the WDI as the data source due to its high Allowing us to consider our results as credible and comparable, the WDI covers a wide range of countries, standardises its definitions across countries, offering its use and advantages in high-quality academic research [10]. The dataset will be related to the 25-year period between 2000 and 2024 as this time would capture the recent economic and environmental relationships since the dawn of the millennium, when greater concern about climate change and escalated globalisation became dominant trends.

The first construction of the sample consisted in collecting the data on 150 countries globally. A purposeful attempt was to develop a representative sample of countries with a range of economic development levels to improve the generalisability of our results. The ultimate estimating sample is that of 2,850 country-years in 125 countries. Unbalanced panel use, although involves certain analytical technicalities, is superior to complete countries drop-outs since it preserves more information, and provides a larger, more generalised sample, maximising statistical power and external validity [11].

The sample is both geographically diverse and stratified by income level with inclusion of. The above heterogeneity is essential in addressing the question of whether the differences between the economic activity and pollution levels in developed and developing countries vary systematically, which is a major theme in the literature on the field of environmental economics [12].

3.2. Variables

In our paper, the key dependent variable is CO_2 Emissions, which is measured in metric tons per capita, this variable serves as a proxy for a country's contribution to global climate change. It is a stock pollutant with global externalities, making it a key indicator of long-term environmental sustainability. Its per capita measurement standardises for population size, allowing for more meaningful cross-country comparisons.

The alternative dependent variable is PM2.5 Concentrations which is measured as the population-weighted exposure to ambient fine particulate matter in micrograms per cubic meter ($\mu g/m^3$), this variable represents a local pollutant with immediate and direct impacts on public health [13]. Using both a global and a local pollutant allows for a more nuanced analysis, as the economic drivers and policy responses associated with each can differ significantly.

The primary independent variables of interest is Gross Domestic Product (GDP) which is measured in current US dollars, this represents the total market value of all final goods and services

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produced within a country's borders in a given year. It is the most widely used metric for national economic output and is central to theories linking economic growth to environmental quality.

We also control a comprehensive set of control variables is included to account for other factors that may influence pollution levels, thereby isolating the specific effects of GDP and GNI. These controls capture aspects of public health infrastructure, economic structure, and resource dependency. 1. Domestic General Government Health Expenditure per capita, PPP. Measured in current international dollars, this adjusts for purchasing power parity and provides a more comparable measure of real government health investment per person. 2. Manufacturing Value Added. As a subset of industrial value added, this variable isolates the impact of the manufacturing sector, which is often a primary source of emissions. 3. Manufacturing Exports (% of Merchandise Exports). This variable is included to test hypotheses related to the 'pollution haven' effect, where developing countries might specialise in producing pollution-intensive manufactured goods for export [13].

Coal Rents (% of GDP). This measures the economic reliance on one of the most carbon-intensive energy sources. Controlling for this is critical to distinguish the effect of overall economic growth from the effect of an energy mix heavily skewed towards fossil fuels [10].

All monetary variables are measured in current US dollars to ensure consistency, though the implications of not adjusting for inflation will be considered in the interpretation of the results. Table 1 provides a summary of all variables used.

Table 2. Summary statistics

Variable	Obs	Mean	Std. dev.	Min	Max
In PM2.5	5,208	27,92	16.627	4.895	107.145
In CO_2	4,544	4.604	1.468	4.688	11.048
In GDP	5,225	11.262	2.468	-1.992	21.494
In Manufacturing Value Added	5,170	3.323	1.342	-9.575	5.921
In Manufacturing Exports	5,633	22.708	3.376	11.520	30.454
Carbon rents	5,322	0.288	1,672	0.000	48.722

3.3. Model specification

To examine the effect of GDP on CO_2 emissions and PM2.5 concentrations, we introduce the following equation (1) as our baseline regressions:

$$Y_{it} = \beta_0 + \beta_1 GDP_{it} + \beta_2 X + \varepsilon_{it} \quad (1)$$

Where it means country i in year t; Y means environment pollution including PM 2.5 and C02 emission; GDP indicates the economic performance; β_1 is its coefficient, which is the impact of economic growth on environmental pollution; X is a vector of controls including In Manufacturing Value Added, Manufacturing Exports, Carbon rents, β_2 means its coefficients; ε is the error term. We use Ordinary Least Squares (OLS) to estimate this equation.

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4. Results

4.1. Baseline regression

Table 3 reports the regression results for the logarithm of PM2.5 concentrations. Across specifications, GDP is positively associated with air pollution, particularly when country fixed effects are included: as shown in column (3), for instance, the coefficient on lnGDP is 0.981 ($p<0.01$), implying that a 10% increase in GDP is linked to nearly a 9.8% rise in PM2.5 emissions, underscoring the environmental cost of growth. Government health expenditure shows a consistently negative and significant effect, suggesting that higher investment in public health contributes to cleaner air. The coefficients on coal rents turn negative once fixed effects are introduced, indicating that reduced reliance on coal may improve air quality.

Table 3. Regression results for PM2.5 emissions

	Dependent variable: Log of PM 2.5 emission		
	(1)	(2)	(3)
lngdp	0.429***	-0.451***	0.981***
	(0.105)	(0.108)	(0.235)
lngni			
lnghed		-5.391***	-1.865***
		(0.168)	(0.295)
lnme		-2.931***	0.038
		(0.186)	(0.119)
lnmeplus		1.819***	0.193
		(0.119)	(0.268)
crgdp		0.582***	-0.324***
		(0.140)	(0.087)
Constant	21.421***	31.261***	21.917***
	(1.195)	(2.354)	(5.359)
Country	No	No	Yes
Year	No	No	Yes
N	4141	3097	3095
R-sq	0.004	0.329	0.957

Notes: Estimates are obtained using OLS, with standard errors reported in parentheses. Significance levels: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

4.2. What factors influence CO_2 emission

Turning to CO_2 emissions, Table 4 presents the results using the logarithm of CO_2 emissions as the dependent variable. In column (3), the coefficient on lnGDP is 0.252 ($p<0.01$), meaning a 10% rise in GDP corresponds to about a 2.5% increase in per capita CO_2 emissions. Unlike PM2.5, government health expenditure is positively correlated with CO_2: Model (3) shows a coefficient of 0.159 ($p<0.01$), perhaps reflecting that heavily industrialized economies spend more on healthcare due to pollution-related illnesses. Manufacturing exports are another major driver: the coefficient is 0.645 ($p<0.01$) in Model (4), confirming that trade in pollution-intensive goods contributes substantially to CO_2 emissions.

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Table 4. Factors influence CO_2 emission

Dependent variable: Log of CO2 emission				
	(1)	(2)	(3)	(4)
lnGDP	0.062***	0.067***	0.252***	
	(0.011)	(0.011)	(0.040)	
ln Gov. Health Exp. per capita, PPP		-0.242***	0.105**	0.159***
		(0.016)	(0.044)	(0.057)
ln Manufacturing Value Added		-0.046***	0.005	0.028
		(0.017)	(0.016)	(0.022)
ln Manufacturing Exports		-0.049***	0.277***	0.645***
		(0.011)	(0.040)	(0.050)
Coal Rents		0.077***	0.019	0.022
		(0.012)	(0.012)	(0.016)
_cons	3.978***	6.304***	-5.039***	-11.530***
	(0.126)	(0.231)	(0.805)	(1.177)
Country	No	No	Yes	Yes
Year	No	No	Yes	Yes
N	3548	2437	2434	1857
R-sq	0.009	0.169	0.879	0.897

4.3. Nonlinear and interaction effects

To capture nonlinearities, Table 3 includes squared GDP terms. The results reveal evidence of an Environmental Kuznets Curve (EKC) for PM2.5: the squared GDP term is 0.087 ($p<0.01$), suggesting that emissions rise with income at low levels but decline once a turning point is reached. In contrast, the squared GDP coefficient for CO2 is small and insignificant (-0.001), pointing to a monotonic relationship with no EKC pattern. Among controls, coal rents reduce PM2.5 significantly (coefficient = -0.333, $p<0.01$ in Model 1), but their effect on CO2 is negligible (0.019, not significant). This divergence suggests that different pollutants respond differently to energy structure.

Table 5. Nonlinear and interaction models

	(1)	(2)	(3)	(4)
	lnPM2.5	lncCO2	lnPM2.5	lncCO2
lnGDP	-0.672	0.270***		
	(0.428)	(0.091)		
squared log of GDP	0.087***	-0.001		
	(0.019)	(0.003)		
ln Gov. Health Exp. per capita, PPP	-1.969***	0.105**	-2.550***	0.159***
	(0.294)	(0.044)	(0.410)	(0.057)
ln Manufacturing Value Added	0.025	0.005	0.573***	0.028
	(0.118)	(0.016)	(0.165)	(0.022)
ln Manufacturing Exports	0.058	0.277***	1.245***	0.645***
	(0.269)	(0.040)	(0.339)	(0.050)
Coal Rents	-0.333***	0.019	-0.473***	0.022
	(0.087)	(0.012)	(0.121)	(0.016)

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Table 5. (continued)

_cons	32.624***	-5.148***	11.545	-11.531***
	(5.821)	(0.935)	(7.940)	(1.178)
Country	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
N	3095	2434	2412	1857
R-sq	0.958	0.879	0.957	0.897

4.4. The impact of COVID-19

The COVID-19 pandemic provides a natural setting to examine how economic shocks affect pollution outcomes. Table 4 shows that during COVID years, GDP is negatively associated with PM2.5: the coefficient is -4.829 ($p<0.05$), indicating that economic contraction reduced pollution levels dramatically. By contrast, in non-COVID years, the GDP coefficient is -3.318 ($p<0.05$), still negative but smaller in magnitude, consistent with less severe shocks. Health expenditure played a strong mitigating role in normal times: the coefficient is -1.839 ($p<0.01$), showing that more investment in health systems helped reduce exposure to pollution. In the COVID period, however, its effect is not significant, likely because reductions in emissions were primarily driven by economic lockdowns rather than policy interventions.

Table 6. COVID vs. Non-COVID periods (PM2.5 models)

	(1)	(2)
	Covid	Non-Covid
lnGDP	-4.829**	1.235***
	(2.012)	(0.290)
ln Gov. Health Exp. per capita, PPP	-3.318**	-1.839***
	(1.433)	(0.335)
ln Manufacturing Value Added	0.206	0.124
	(0.714)	(0.125)
ln Manufacturing Exports	-0.962	0.307
	(1.790)	(0.303)
Coal Rents	0.394	-0.343***
	(0.439)	(0.089)
_cons	122.520**	16.420***
	(51.882)	(5.841)
Country	Yes	Yes
Year	Yes	Yes
N	290	2799
R-sq	0.992	0.959

4.5. Differences between OECD and non-OECD countries

Finally, Table 5 compares outcomes across OECD and non-OECD countries. For OECD economies, GDP is not significantly linked with PM2.5 (coefficient = 0.465, insignificant), consistent with partial decoupling of growth and pollution in advanced economies. Interestingly, government health expenditure is positively correlated with PM2.5 in OECD countries (coefficient = 1.263, $p<0.01$), likely reflecting greater spending responses to pollution exposure rather than prevention.

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By contrast, non-OECD economies show a clear positive relationship between GDP and PM2.5 (coefficient = 0.772, p<0.01), highlighting that growth in developing countries still comes at substantial environmental cost. Moreover, coal rents exert a strongly negative effect in non-OECD countries (coefficient = -0.305, p<0.01), suggesting that reducing coal dependency significantly curbs emissions.

Table 7. OECD vs. non-OECD regression results (PM2.5 models)

	(1)	(2)
	OECD	Non-OECD
lnGDP	0.465	0.772***
	(0.355)	(0.285)
ln Gov. Health Exp. per capita, PPP	1.263***	-2.119***
	(0.461)	(0.345)
ln Manufacturing Value Added	-2.737***	0.009
	(0.479)	(0.135)
ln Manufacturing Exports	0.123	-0.019
	(0.374)	(0.322)
Coal Rents	-0.030	-0.305***
	(0.309)	(0.099)
_cons	8.225	33.385***
	(7.067)	(6.516)
Country	Yes	Yes
Year	Yes	Yes
N	798	2297
R-sq	0.958	0.950

5. Conclusion

This study provides systematic evidence on the relationship between economic growth and environmental outcomes, focusing on both local pollutants (PM2.5 concentrations) and global pollutants (CO2 emissions). The results demonstrate that economic expansion is generally associated with higher emissions, but the nature of this relationship varies across pollutants and contexts. For PM2.5, the estimates reveal an Environmental Kuznets Curve (EKC) pattern: pollution initially rises with income but declines once a certain level of economic development is reached. In contrast, CO2 emissions remain monotonically linked to growth, highlighting the difficulty of decoupling global pollutants from economic activity.

We draw several important lessons from these findings. First, the growth–pollution relationship is heterogeneous: while improvements in local air quality may occur through structural transformation and greater public health expenditure, reductions in global pollutants require more targeted interventions. Second, the heterogeneity observed across different circumstances—such as the temporary decline in emissions during the COVID-19 pandemic or the divergence between OECD and non-OECD countries—indicates that institutional capacity, energy dependence, and external shocks play critical roles in shaping environmental outcomes.

These findings also carry important policy implications. Specifically, economic growth alone is insufficient to guarantee environmental improvement, deliberate policy efforts are required. In practice, Governments should pay more attention to: (i) expand health and environmental expenditures to reduce pollution exposure and facilitate the adoption of cleaner production

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technologies; (ii) reduce reliance on coal and other fossil fuels, particularly in non-OECD economies where coal rents are strongly associated with higher emissions; (iii) support structural transformation and innovation that enable the transition toward greener industries; and (iv) design differentiated policy strategies, combining stricter regulations in high-income countries with capacity building and technology transfer in developing economies.

In summary, while the empirical evidence confirms that growth and pollution remain closely connected, the relationship is neither immutable nor irreversible. Combining proactive governance, targeted investment, and coordinated international action can ensure that economic development becomes compatible with, and even conducive to, environmental sustainability.

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