




Article

A Dynamic Analysis of Air Pollution: Implications of Economic Growth and Renewable Energy Consumption

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Abstract: This paper examines how economic growth and renewable energy consumption are associated with air pollution using a dynamic panel approach. Focusing on several major air pollutants, namely, particulate matter, sulfur dioxide, nitrogen oxide, and carbon monoxide, this paper tests the environmental Kuznets hypothesis and determines whether the use of renewable energy sources contributes to a reduction in air pollution. Data from a balanced panel of 145 countries for the period between 2000 and 2014 was used for the estimation of the dynamic panel model. The results of the dynamic panel model showed inverted U-shaped curves for the relationship between economic development and particulate matter and sulfur dioxide emissions. The results also revealed that increasing renewable energy consumption contributes to an improvement in air quality. Moreover, it was found that urbanization tends to decrease sulfur dioxide and nitrogen oxide emissions, while trade openness reduces particulate matter and carbon monoxide emissions but increases sulfur dioxide emissions.



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Keywords: particulate matter; sulfur dioxide; nitrogen oxide; carbon monoxide; air quality; environmental Kuznets curve; renewable energy; dynamic panel

1. Introduction

Air pollution is a global issue because it not only causes global warming but also affects human health. Human activities have exacerbated global warming through the production of excessive greenhouse gases, which induce harmful effects on human health. According to the World Bank and the Institute for Health Metrics and Evaluation [1], about 92% of people worldwide do not breathe clean air due to air pollution, and the resultant costs of air pollution stand at USD 5 trillion every year. Short-term exposure to air pollutants causes dizziness, nausea, asthma, pneumonia, and heart problems [2]. Specifically, exposure to air pollutants affects human skin, causing symptoms such as skin aging, eczema, acne, and urticaria, and affects the eyes, causing irritation or dry eye syndrome [3,4]. Long-term exposure can even induce cancer or death [5]. Particulate matter, benzene, ozone, and dust cause serious damage to the human respiratory system, and some of these substances can even accumulate in cells and blood, having been ingested through the airways [6,7]. Studies have shown that air pollution could be the main cause of cardiovascular disease and affect the immune system extensively [8,9].

As air pollution is known to vary with the rate of industrialization or structural change in economy, and many previous studies have explored how air pollution is related to the stages of economic growth. Grossman and Krueger [10] first found a nonlinear inverted U-shaped curve between per capita income and air pollution, showing that air quality tends to get worse as economies grew until the gross domestic product (GDP) per capita reaches a certain level, after which it gradually improves. They found a tendency for early economic development to neglect ecological protection, and for industrialization

processes to cause serious environmental pollution. Many subsequent studies confirmed the inverted U-shaped curve [11–16], and subsequently the literature was extended to find an N-shaped curve representing the relationship between economic growth and air pollution [17–22]. Most past studies emphasized that sufficient economic growth is required before air pollution problems are addressed.

Moreover, energy consumption has been considered a key factor of driving air pollution. Past studies have focused on the effects of using fossil fuels on air pollution, but the use of renewable energy sources recently became of interest for policy makers because these are environmentally friendly energy sources with potential for sustainable development. Due to the interest in renewable energy, consumption increased dramatically from 520,370.4 ktoe (approximately 7.4% of total energy consumption) in 2000 to 902,546.4 ktoe (approximately 9.7% of total energy consumption) in 2014, according to the International Energy Agency (IEA). In addition, the 2015 Paris Agreement on climate change motivated many countries to develop renewable energy policies. Renewable energy consumption is beneficial for environment: many studies have confirmed that increasing renewable energy intensity improves environmental quality and leads to a decline in carbon dioxide emissions [23–29]. However, with regard to air pollution, only a few studies in the literature have found evidence that the use of renewable energy sources can ease air pollution problems [23,24,28,30].

Due to the importance of economic growth and renewable energy consumption in addressing the problem of air pollution, this paper pursues a deeper understanding of the nexus between air quality, economic growth, and renewable energy consumption. Since the literature has paid little attention to the dynamics of air pollution at a global level, this paper contributes to understanding how air pollution varies dynamically with both economic growth and renewable energy consumption. The specific objective of this paper is as follows. First, it evaluates the dynamic adjustment of air pollution, which shows how fast air pollution changes over time. Second, it examines how economic growth is associated with air pollution. With regard to major air pollutants such as particulate matter, sulfur dioxide, nitrogen oxide, and carbon monoxide, this paper tests the environmental Kuznets hypothesis that economic growth initially increases the levels of these pollutants and then reduces them. Third, this study examines the effects of renewable energy consumption on air pollution. Since the existing literature focuses mainly on analyzing the relationship between carbon dioxide emissions and renewable energy consumption at the single-country or regional levels, this paper contributes to determining whether the use of renewable energy sources can contribute to reducing air pollution at a global level. Fourth, it examines how air pollution is associated with urbanization and trade openness. Since the literature points out that urbanization and trade openness occur in economic development stages, this paper contributes to understanding how they affect air pollution levels.

2. Literature Review

An extensive literature review was conducted, and the results are presented in Appendix A. Grossman and Krueger [10] first investigated the impact of the North American Free Trade Agreement (NAFTA) on pollutant emissions. They found that sulfur dioxide and smoke increased with per capita GDP at low national income levels but decreased with economic growth at high national income levels. Later, Panayotou [31], focusing on deforestation, sulfur dioxide, nitrogenous oxides and solid particulate matter as pollution indicators, confirmed the inverted U-shaped curve. Scholars who agreed with the environmental Kuznets curve (EKC) hypothesis believed that in the early stage of economic growth, energy consumption increased due to the scale effect, which led to increased emissions of pollutants. When the economy grew to a certain stage, energy consumption reduced due to the technology effect, resulting in a reduction in the emission of pollutants. At this stage, the use of renewable energy and increasing in consumer demand for clean products can also lead to a reduction in emissions.

The existing literature on air pollution focuses mainly on specific regions and countries. In recent studies, To et al. [32] employed the panel cointegration model to examine emerging markets in Asian regions over the 1980–2016 period, and found that the EKC was generally valid across the regions. As for country-specific studies, Fang et al. [33] investigated the EKC in cubic settings for the linkage between carbon dioxide emissions and economic growth across three regions in China. Tutulmaz [34] investigated linear, quadratic and cubic relationships between carbon dioxide emissions and per capita GDP in Turkey over a period of 40 years, showing that environmental pressure and economic development displayed an inverted U-shaped curve relationship. While many empirical studies found inverted U-shaped curves [14,16,35–43], linear and cubic relationships between income and pollution were also supported by a number of studies [14,18,32–34,44–49].

Regarding energy sources, past studies have focused mainly on fossil fuel consumption, but interest has recently shifted to renewable energy sources, which are seeing increasing use [50]. Many studies have confirmed that increasing renewable energy intensity decreases carbon dioxide emissions [23–29,51,52]. However, only a few have tested whether the use of renewable energy sources can ease air pollution. For instance, Boudri et al. [24] examined how the use of renewable energy sources would be effective in air pollution abatement in China and India for the period of 1990–2020, and they confirmed that using renewable energy could cut the costs of reducing sulfur dioxide emissions. Zhu et al. [30] tested the effectiveness of renewable energy in improving air quality using a panel dataset covering China's 31 provinces from 2011 to 2017. Their results indicated that technological innovations in renewable energy would be beneficial for alleviating nitrogen oxide emissions and respirable suspended particle concentrations, but were not significantly associated with a reduction in sulfur dioxide emissions.

Other variables are also considered driving factors of air pollution. The literature mainly outlines the environmental effects of urbanization and trade openness [16,29,35,42,53–62]. Urbanization refers to the transformation of a country from a rural–agricultural base to an urban–industrial base, which is a key stage in its economic development. [55]. The process of urbanization is typically accompanied by a high degree of resource consumption and serious discharge of pollutants [53]. In addition, urbanization promotes the development of large-scale infrastructure construction and transportation, and in turn, encourages the rapid development of energy-intensive industries [61]. Xie et al. [42] clarified that there is a clear inverted U-shaped relationship between economic growth and fine particulate matter concentrations, and found that population density, industrialization, urbanization and the development of transportation contributed to an increase in fine particulate matter emissions.

Regarding trade openness, the literature indicates that the effects of trade openness on pollution can be divided into three aspects: the scale effect (size of the economy), the composition effect (specialization), and the technology effect (production methods) [35,54]. The scale effect means that an increase in trade volume affects output and energy consumption, and thus carbon dioxide emissions. The composition effect is related to the redistribution of a country's trade commodity basket, so energy use and environmental quality may increase or decrease depending on whether the country's specialized industries require more or less energy. The technology effect implies that trade liberalization leads to an improvement in the environment as better technology is applied to produce goods and use energy more efficiently. Cole and Elliott [35] and Antweiler et al. [54] found trade openness is beneficial for environment, and Kacar and Kayalica [16] found that trade openness could reduce sulfur emissions. Salim et al. [29] also found that renewable energy, urbanization, and trade liberalization could reduce pollutant emissions.

In relation to the literature, as detailed in Appendix A, this study differs in three aspects from the previous studies. First, it covers major air pollutants with an extensive panel dataset. The panel dataset reflects the countries that have different air quality at varying economic growth stages. Second, it evaluates the dynamic adjustment of air pollution using the dynamic panel model. Estimating the adjustment speed of air pollution

helps us to understand how fast air pollution changes with economic growth, renewable energy consumption, urbanization, and trade openness. Third, this paper focuses the effects of economic growth and renewable energy consumption on air pollution. Since there are few studies that focus on the relationships of air pollution with both economic growth and renewable energy consumption, this study contributes to policies focused on the energy transition from fossil fuels to renewable energy sources at varying economic growth stages.

3. Methodology

3.1. Dynamic Panel Model

To test our research hypotheses, we first constructed a panel model for air pollution, which included the following explanatory variables: gross domestic product (GDP) per capita, the ratio of renewable energy consumption to total energy consumption (REC), urbanization (URB) and trade openness (TRA). We also added the squared term of the GDP variable to determine whether there is an inverted U-shaped curve. The conventional fixed-effect panel model is specified as follows.

$$y_{it} = \beta x'_{it} + v_t + u_i + \varepsilon_{it}, \quad (1)$$

where subscript i denotes country and t denotes year. The dependent variables include particulate matter 2.5 average exposure (PMA), sulfur dioxide (SO₂), nitrogen oxide (NO_x) and carbon monoxide (CO) emissions. In Equation (1), u_i represents the individual fixed-effect term, v_t indicates the time fixed-effect term, and ε_{it} denotes the idiosyncratic error term. As the air pollution indicators, GDP and its squared terms are expressed in natural logarithmic form, their estimated coefficients can be interpreted as elasticities.

While we estimated the two-way fixed effect model as a baseline, we also employed the dynamic panel model, which introduces the lagged variable to the original static panel model as follows:

$$y_{it} = \delta y_{i,t-1} + \beta x'_{it} + \mu_{it} \quad (2)$$

where δ is the autoregressive parameter to be estimated. In Equation (2), μ_{it} is the composite error term, $\mu_{it} = u_i + \varepsilon_{it}$ where u_i is the unobservable individual effect and ε_{it} is the random disturbance.

Since traditional regression techniques produce biased and unreliable estimates when the interference term is correlated with endogenous variables, Anderson and Hsiao [63] introduced the first differencing of the model to Equation (2). The differential dynamic panel model is constructed as follows:

$$\Delta y_{it} = \delta \Delta y_{i,t-1} + \beta \Delta x'_{it} + \Delta \varepsilon_{it} \quad (3)$$

where $\Delta y_{i,t-2}$ is used as an instrument for $\Delta y_{i,t-1}$. As instrumental variable estimation leads to consistent but not necessarily efficient estimates [64], the generalized method of moments (GMM) developed by Arellano and Bond [65] is employed to include additional instruments and all the available moment conditions. The GMM performs a first-order difference to remove the influence of the fixed effects, and then uses a set of lagged explanatory variables as instrumental variables for the corresponding variables in the difference equation.

3.2. Data Description

A panel dataset covering 145 countries over the period from 2000 to 2014 was used for our empirical analyses. Air pollution was represented by particulate matter 2.5 average exposure (PMA), sulfur dioxide (SO₂), nitrogen oxide (NO_x) and carbon monoxide (CO) emissions. The yearly data for PMA were obtained from the Environmental Performance Index (EPI) compiled by Yale University (2016), and those for SO₂, NO_x, and CO were

obtained from the Community Emissions Data System (CEDS). PMA emissions were measured in $\mu\text{g}/\text{m}^3$, whereas the emissions of SO_2 , NO_x , and CO were measured in t/km^2 .

The explanatory variables were renewable energy consumption (REC), gross domestic product (GDP) per capita, urbanization (URB), and trade openness (TRA). The yearly data for renewable energy consumption rate (the ratio of renewable energy consumption to total final energy consumption), GDP per capita (constant 2010 USD), urbanization rate (the ratio of urban population to total population), and trade openness (the ratio of total trade to GDP) were obtained from the World Development Indicator of the World Bank. Detailed descriptions of the variables are listed in Table 1.

Table 1. Descriptive Statistics of Variables.

Variable	Mean	Std. Dev.	Min.	Max.
PMA ($\mu\text{g}/\text{m}^3$)	8.78	6.31	0.10	50.30
SO_2 (t/km^2)	11.59	129.72	0.00	2069.88
NO_x (t/km^2)	1.89	3.35	0.01	27.13
CO (t/km^2)	9.07	14.87	0.12	129.33
GDP (\$)	11,649.26	17,304.65	221.10	111,968.30
REC (ratio)	0.34	0.30	0.00	0.97
URB (ratio)	0.55	0.22	0.08	0.97
TRA (ratio)	0.82	0.42	0.00	3.93

Note: PMA is particulate matter 2.5 average exposure; SO_2 is sulfur dioxide; NO_x is nitrogen oxide; CO is carbon monoxide; GDP is per-capita gross domestic product; REC is renewable energy consumption; URB is urbanization; TRA is trade openness. Sources: Environmental Performance Index (EPI); Community Emissions Data System (CEDS); and World Bank.

4. Results

The estimation results for the major air pollutants are shown in Tables 2–5. While the results of the fixed-effect model are reported for the static results, our interpretations are based on the results of the dynamic panel model. Overall, the estimates of the lagged variables of the air pollutants represent the dynamics of air pollution. The estimates for PMA, SO_2 , NO_x , and CO were 0.43, 0.88, 0.93, and 0.83, respectively, implying that the adjustment of most air pollutants is sluggish; the speed of change for PMA is faster than in the other air pollutants.

Table 2. Estimation Results for Particulate Matter 2.5 Average Exposure (PMA).

	Fixed Effect Model	Dynamic Panel Model
$\ln PMA_{t-1}$	-	0.433 *** (0.007)
$\ln GDP$	1.546 *** (0.345)	0.813 *** (0.109)
$(\ln GDP)^2$	-0.086 *** (0.021)	-0.043 *** (0.006)
REC	-0.151 ** (0.193)	-0.036 (0.033)
URB	0.811 *** (0.540)	0.190 (0.125)
TRA	-0.034 (0.049)	-0.027 *** (0.007)
Constant	-5.196 *** (1.431)	-

Notes: *** and ** denote the level of significance at 1%, 5% and 10% respectively; numbers in parentheses are robust standard errors.

Table 3. Estimation Results for Sulfur Dioxide Emissions (SO₂).

	Fixed Effect Model	Dynamic Panel Model
$\ln SO_2_{t-1}$	-	0.883 *** (0.014)
$\ln GDP$	3.017 *** (0.561)	0.597 ** (0.258)
$(\ln GDP)^2$	-0.185 *** (0.039)	-0.032 ** (0.015)
<i>REC</i>	-3.175 *** (0.527)	-1.454 *** (0.086)
<i>URB</i>	1.628 *** (0.988)	-1.113 *** (0.218)
<i>TRA</i>	-0.185 ** (0.099)	0.038 *** (0.016)
Constant	-12.392 *** (2.286)	-

Notes: *** and ** denote the level of significance at 1%, 5% and 10% respectively; numbers in parentheses are robust standard errors.

Table 4. Estimation Results for Nitrogen Oxide Emissions (NO_x).

	Fixed Effect Model	Dynamic Panel Model
$\ln NOX_{t-1}$	-	0.931 *** (0.010)
$\ln GDP$	1.275 *** (0.438)	0.225 *** (0.108)
$(\ln GDP)^2$	-0.071 *** (0.028)	-0.006 (0.006)
<i>REC</i>	-1.701 *** (0.308)	-0.551 *** (0.049)
<i>URB</i>	1.482 *** (0.751)	-0.241 *** (0.088)
<i>TRA</i>	-0.126 *** (0.053)	-0.008 (0.006)
Constant	-6.129 *** (1.788)	-

Notes: *** denotes the level of significance at 1%, 5% and 10% respectively; numbers in parentheses are robust standard errors.

Table 5. Estimation Results for Carbon Monoxide Emissions (CO).

	Fixed Effect Model	Dynamic Panel Model
$\ln CO_{t-1}$	-	0.829 *** (0.008)
$\ln GDP$	1.645 *** (0.431)	-0.132 (0.102)
$(\ln GDP)^2$	-0.095 *** (0.095)	0.017 *** (0.006)
<i>REC</i>	-0.785 *** (0.328)	-0.025 (0.044)
<i>URB</i>	1.126 *** (0.717)	0.062 (0.091)
<i>TRA</i>	-0.086 *** (0.059)	-0.017 *** (0.006)
Constant	-5.699 *** (1.783)	-

Notes: *** denotes the level of significance at 1%, 5% and 10% respectively; numbers in parentheses are robust standard errors.

Regarding the relationship between economic growth and air pollution (Tables 2–5), the results show that inverted U-shaped curve relationships exist between economic growth and the air pollutants PMA and SO₂. While the results of the fixed-effect model confirm the EKC for all the examined air pollutants, those of the dynamic panel model only confirm the existence of the EKC for PMA and SO₂. The different results obtained using the dynamic panel model can be attributed to the addition of the dynamic term and addressing the endogeneity problem, thus providing more rigorous estimates. In Tables 2 and 3, the results for PMA and SO₂ imply that more air pollutants are emitted as the economy grows until the GDP per capita reaches a certain level, after which emissions gradually improve. However, the results for NO_x and CO emissions show that these continue to increase with economic growth, a pattern which can be attributed to a continuous increase in the ownership automobiles, since vehicle engines are a major source of nitrogen oxide and carbon monoxide.

Using the peak of the inverted U-shaped curve, we determined the level of per capita GDP that correlated with a reduction in pollutant emissions. The per capita GDP level for peak PMA emissions was approximately USD 12,752.47, and that for SO₂ was approximately USD 11,249.74. The sources of particulate matter 2.5 are more diverse because they are formed in various combustion processes. However, sulfur dioxide is generated mostly by the burning of coal or oil in power plants and by factories that produce chemicals, paper, and steel. Most economies generally have a large number of factories reliant on burning coal and oil in their early stage of development, but tend to move away from resource-dependent manufacturing when they achieve sufficient economic growth.

Moreover, our results show that renewable energy consumption has negative effects on air pollution, which indicates that increasing renewable energy consumption can improve air quality. The use of renewable energy reduces SO₂ and NO_x emissions, but it is not associated closely with PMA and CO emissions. The use of renewable energy does not contribute to reducing PMA, a finding which can be attributed to the diversity of sources generating PMA emissions. CO emissions are related to the incomplete combustion of fuels. Although the use of renewable energy directly reduces the use of fossil fuels, their inefficient use still generates CO emissions. However, despite the limited evidence of any effect on PMA and CO emissions, the results show the potential contribution of renewable energy sources to improving air quality via the reduction of SO₂ and NO_x emissions.

The results indicate that urbanization tends to decrease SO₂ and NO_x emissions. This can be attributed to the fact that urbanization induces economies to move away from the industrial and manufacturing sectors. Urbanization also transforms rural energy structures dominated by solid fuels into urban energy structures dominated by clean fuels, a process which contributes to the reduction of SO₂ and NO_x emissions. Regarding trade openness, the results show that PMA and CO emissions improve as openness increases, but SO₂ emissions deteriorate. As discussed in [16,27,29], more frequent trade activities increase the intensity of production, and lead to a greater consumption of fossil fuels for transportation and trade, which increases SO₂ emissions. On the other hand, developed countries tend to gradually transfer their high-emission manufacturing activities to underdeveloped and developing countries. In addition, trade accelerates the exchange of technologies that can improve energy efficiency, thereby reducing the incomplete combustion of fossil fuels, which leads to reductions in PMA and CO emissions.

5. Discussion

The major findings are summarized in Figure 1. While NO_x and CO emissions continue to increase linearly and nonlinearly with economic growth, PMA and SO₂ emissions first increase mainly due to the industrialization, and then decline after economy achieves a certain level of income. The findings show that underdeveloped or developing countries can suffer from air pollution, but they can, at least, alleviate air pollution problems related to PMA and SO₂ emissions if their per capita GDP reaches about USD 11,000 to 12,000. Since the early stage of economic growth tends to require more combustion of coal, low-income

countries inevitably release high levels of air pollutants. As income grows, countries tend to improve energy efficiency and shift to nuclear generation, which generates less pollution in the form of PMA and SO₂ emissions. Moreover, consumers' demands for eco-friendly energy sources and products contribute to reductions in PMA and SO₂ emissions. However, the results for NO_x and CO emissions show that these pollutants continue to increase as economic growth continues, which can be attributed to a continuous increase in the use of automobiles, since combustion engines are the main source of nitrogen oxide and carbon monoxide. Technological improvements such as catalytic reduction and the more complete combustion of fuels are required to reduce NO_x and CO emissions as average incomes grow.

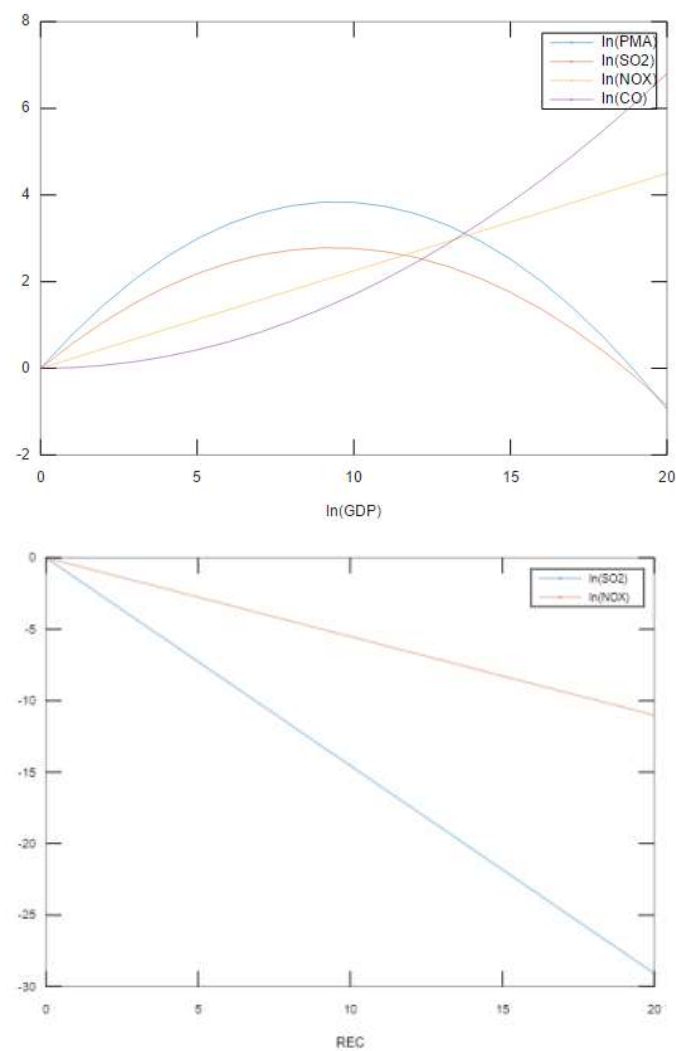


Figure 1. Cont.

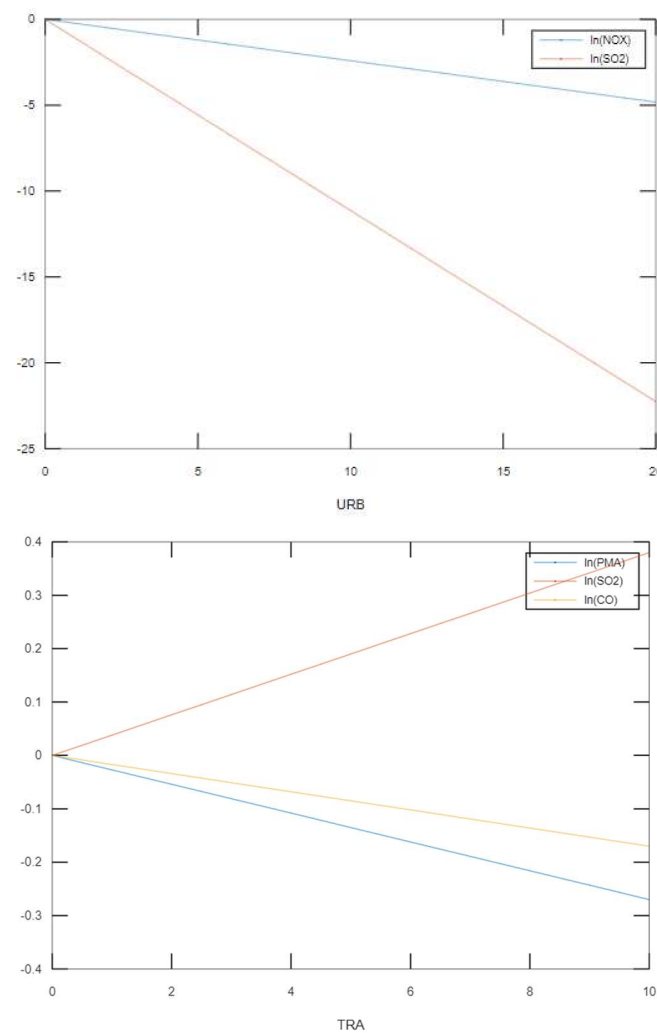


Figure 1. Graphical Summary of Results.

More importantly, the findings show that an increase in renewable energy consumption can be a way of alleviating air pollution problems effectively. The energy transition from fossil fuels to renewable energy sources can contribute to reductions in SO_2 and NO_x emissions. The findings on the impacts of economic growth and of renewable energy consumption on pollution suggest that we should not simply wait for economic growth to address air pollution problems. It can be seen that although low-income countries tend to suffer from air pollution, the implementation of active policy measures to increase the use of renewable energy can improve air quality, regardless of economic growth. Moreover, the use of renewable energy can help high-income countries reduce SO_2 and NO_x emissions. While the use of renewable energy can accelerate the speed at which SO_2 emissions reduce with economic growth, it can reduce NO_x emissions directly.

Some policy measures can be formulated to promote the consumption of renewable energy. Since high-income countries have more advanced renewable energy technology than low-income countries, they can diffuse these innovations, and the resultant improvements in air quality, to low-income countries. Moreover, strict regulations on energy sustainability can be imposed, and public awareness of the importance of renewable energy can be raised [25]. Governments can strengthen the measures used to control pollution and strictly enforce environmental legislation affecting industries which are highly polluting and consume high levels of energy. In addition, they can encourage and subsidize technological innovations that reduce the cost of renewable energy [52]. For consumers, they can also enhance public awareness of environmental protection, encourage residents to

use public transportation instead of private cars to travel, and encourage residents to use energy-saving or renewable energy appliances [51].

Our findings also show that urbanization tends to decrease SO₂ and NO_x emissions. In line with the findings of Lin and Zhu [62], urbanization reduces air pollutant concentrations due to the transition to advanced urban infrastructure and public transportation systems. The construction of urban rail transit can greatly reduce dependence on private cars and increase people's awareness of environmental protection. In addition, urban greening, low-carbon infrastructure, and green transportation systems can reduce the concentration of air pollutants [28]. For instance, advanced technology can be applied in civil architecture to improve energy efficiency and reduce emissions [66], and the use of solar lighting and new-energy vehicles can mitigate the dependence of the auto industry on petroleum [67]. Combined with the impact of renewable energy on SO₂ and NO_x emission indicated in our results, urbanization can contribute further to reductions in emissions.

Regarding the findings for trade openness, as discussed by Managi et al. [56], previous studies have been largely inconclusive with regard to the overall impact of trade on the environment. In theory, trade openness influences emissions through the composition effect, which includes environmental regulation and the capital–labor effects. If a country has less stringent environmental regulations and a high capital-to-labor ratio, it may produce more emissions. The relative size of the two effects will determine whether the composition effect is positive or negative [34,54,56]. Since our findings indicate that trade openness raises SO₂ emissions, more stringent environmental regulation should be formulated to force capital-intensive industries to reduce their emissions as income grows.

6. Conclusions

The main purpose of this paper is to study the nexus between air quality, economic growth and renewable energy consumption using dynamic analysis. Although there are many studies on the environmental Kuznets curve in the literature, few papers have examined the effects of both economic growth and renewable energy consumption on air pollution. In particular, many studies have demonstrated that the use of renewable energy mitigates carbon dioxide emissions, but few have studied the impact of renewable energy on air pollution. Accordingly, this paper contributes to a deeper understanding the dynamics of air pollution by examining the relationships between air pollution, economic growth, and renewable energy consumption.

A balanced panel of 145 countries, covering the period between 2000 and 2014, was utilized to estimate the dynamic panel model. The results of the fixed-effect model estimates indicated the existence of an EKC relationship between various air pollutants and income, but the estimation results of the dynamic panel model only confirmed the existence of an EKC relationship between PMA and SO₂ emissions and income. Our results also show that renewable energy consumption and air pollution have a statistically significantly inverse relationship, which indicates that increased renewable energy consumption contributes effectively to improving air quality. It was also found that urbanization tends to decrease SO₂ and NO_x emissions, while trade openness reduces PMA and CO emissions but is associated with higher SO₂ emissions.

The main findings indicate that air pollution is affected by both economic growth and renewable energy consumption. It is important to stimulate economic growth to address air pollution problems, since countries in the early stage of economic growth inevitably face air pollution problems due to economic activities that rely on fossil fuels. The findings are consistent with the EKC hypothesis, suggesting that economic growth should not be viewed as a threat to environmental quality. As raising per capita income is the most reliable way to solve environmental problems, it is possible to solve the negative external effects brought about by future economic growth when income increases [68]. Webber and Allen [69] also believe that economic growth will eventually lead to the improvement of the environment, while environmental protection policies will only slow down economic growth.

The findings also support the suggestion that degradation of air quality can be reversed if the economy encourages producers to adopt new technologies that reduce air pollution and if consumers demand more environmentally friendly products. Moreover, the findings suggest that countries can alleviate air pollution by increasing the use of renewable energy. Although countries in the early stages of economic growth tend to use fossil fuels more, the resultant degradation of air quality can be reduced via a significant transition from fossil fuels to renewable energy. As such, governmental policies that aim for economic growth alongside the use of renewable energy may be beneficial for addressing economic, social, and environmental problems related to air quality.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Literature Review.

Authors	Pollution	Regions and Periods	Findings	Methodology
Grossman and Krueger (1991) [10]	SO ₂ and smoke	42 countries (1977–1988)	Inverted U-shaped curve of SO ₂ and smoke	Random effect model
Shafik (1994) [12]	SO ₂ , SPM, CO ₂	149 countries (1960–1990)	Inverted U-shaped curve of SO ₂ , SPM; monotonically increasing CO ₂	OLS
Welsch (2004) [14]	SO ₂ , NO ₂ , SPM	106 countries (1980–2000)	Inverted U-shaped curve of CO ₂	OLS, SUR
Kacar (2014) [16]	SO ₂	20 countries (1951–2000)	Inverted U-shaped curve of SO ₂	OLS, Fixed effect model, Random effect model
Torras (1998) [18]	SO ₂ , smoke and heavy particles	58 countries (1977–1991)	N-shaped curve of SO ₂ and smoke; inverted N-shaped curve of heavy particles	OLS

Table A1. Cont.

Authors	Pollution	Regions and Periods	Findings	Methodology
Sulaiman (2013) [25]	CO ₂	Malaysia (1980–2009)	Inverted U-shaped curve; renewable energy consumption reduces CO ₂ emissions	ARDL model; VEC model
Bilgili et al. (2016) [26]	CO ₂	17 OECD countries (1977–2010)	Inverted U-shaped curve; renewable energy consumption reduces CO ₂ emission	FMOLS; DOLS
Jebli et al. (2016) [27]	CO ₂	25 OECD countries (1980–2010)	Inverted U-shaped curve; renewable energy consumption reduces CO ₂ emission	FMOLS; DOLS
Salim et al. (2017) [29]	CO ₂	86 Asian developing countries (1980–2010)	Inverted U-shaped curve; renewable energy consumption reduces CO ₂ emission	MG; CCEMG
Zhu et al. (2020) [30]	SO ₂ , NO _x , PM10	31 provinces in China (2011–2017)	Inverted U-shaped curve of SO ₂ ; renewable energy consumption reduces NO _x , PM10 emissions	Spatial econometric model
Panayotou (1993) [31]	Deforestation, SO ₂ , NO _x and SPM	68 countries for deforestation; 55 countries for SO ₂ , NO _x and SPM (1980)	Inverted U-shaped curve of deforestation, SO ₂ and NO _x	OLS
To et al. (2019) [32]	CO ₂	25 emerging markets and developing countries in Asia (1980–2016)	Inverted N-shaped curve	FMOLS; DOLS
Fang et al. (2019) [33]	CO ₂	30 provinces of China (1995–2016)	Inverted N-shaped curve	Fixed effect model, Random effect model
Tutulmaz (2015) [34]	CO ₂	Turkey (1968–2007)	Monotonically increasing; inverted U-shaped curve	Co-integration
Cole et al. (1997) [35]	SO ₂ , NO _x , CO and SPM	OECD countries (1960–1991)	Inverted U-shaped curve of SO ₂ , NO _x , CO and SPM	GLS
Xu and Lin (2015) [37]	CO ₂	China (2000–2012)	Inverted U-shaped curve of CO ₂	Dynamic nonparametric additive regression model
Sephton and Mann (2016) [38]	SO ₂ and CO ₂	UK (1830–2003)	Inverted U-shaped curve of SO ₂ and CO ₂	OLS
Och (2017) [39]	NO _x	Mongolia (1981–2012)	U-shaped curve	Co-integration and VECM model
Sapkota and Bastola (2017) [40]	CO ₂	14 Latin American countries (1980–2010)	Inverted U-shaped curve; U-shaped curve	Fixed effect model, Random effect model
Wang et al. (2017) [41]	CO ₂ , N ₂ O and methane	U.S. (1960–2010)	U-shaped curve of methane	Co-integration and correlation methods
Xie et al. (2019) [42]	PM2.5	249 Chinese cities (2015)	Inverted U-shaped curve	Semiparametric spatial autoregressive model
Haider et al. (2020) [43]	N ₂ O	31 countries (1981–2012)	Inverted U-shaped curve	Co-integration and correlation methods

Table A1. Cont.

Authors	Pollution	Regions and Periods	Findings	Methodology
Richmond and Kaufmann (2006) [44]	CO ₂	36 countries (1973–1997)	Monotonically increasing	OLS
Abdallah et al. (2013) [45]	CO ₂	Tunisia (1980–2010)	N-shaped curve	VECM model
Onafowora and Owoye (2014) [46]	CO ₂	8 countries (1971–2010)	Inverted U-shaped; Inverted N-shaped	ARDL model
Luo et al. (2014) [47]	PM10, SO ₂ , NO ₂	31 provincial capitals of mainland China	Monotonically increasing SO ₂ and PM10; Inverted U-shaped curve of NO ₂	OLS
Akpan (2015) [48]	CO ₂	47 countries (1970–2008)	Monotonically increasing; inverted U-shaped curve; N-shaped curve	OLS; GLS; 2SLS
Baek (2015) [49]	CO ₂	7 Arctic countries (1960–2010)	Inverted U-shaped curve; N-shaped curve	ARDL model

Note: OLS is ordinary least square; SUR is seemingly unrelated regression; ARDL is autoregressive distributed lag; VEC is vector error correction; FMOLS is fully modified OLS; DOLS is dynamic OLS; MG is mean group; CCEMG is common correlated effects mean group; GLS is generalized least square; 2SLS is two-stage least square.

References

- World Bank Group. *The Cost of Air Pollution: Strengthening the Economic Case for Action*; World Bank: Washington, DC, USA, 2016.
- Eze, I.C.; Schaffner, E.; Fischer, E.; Schikowski, T.; Adam, M.; Imboden, M.; Tsai, M.; Carballo, D.; von Eckardstein, A.; Künzli, N.; et al. Long-term air pollution exposure and diabetes in a population-based Swiss cohort. *Environ. Int.* **2014**, *70*, 95–105. [[CrossRef](#)]
- Madronich, S.; de Grujil, F.R. Skin cancer and UV radiation. *Nature* **1993**, *366*, 23. [[CrossRef](#)]
- Mo, Z.; Fu, Q.; Lyu, D.; Zhang, L.; Qin, Z.; Tang, Q.; Yin, H.; Xu, P.; Wu, L.; Wang, X.; et al. Impacts of air pollution on dry eye disease among residents in Hangzhou, China: A case-crossover study. *Environ. Pollut.* **2019**, *246*, 183–189. [[CrossRef](#)]
- Pope, C.A.; Burnett, R.T.; Thun, M.J.; Calle, E.E.; Krewski, D.; Ito, K.; Thurston, G.D. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. *JAMA* **2002**, *287*, 1132–1141. [[CrossRef](#)]
- Kurt, O.K.; Zhang, J.; Pinkerton, K.E. Pulmonary health effects of air pollution. *Curr. Opin. Pulm. Med.* **2016**, *22*, 138. [[CrossRef](#)]
- Manisalidis, I.; Stavropoulou, E.; Stavropoulos, A.; Bezirtzoglou, E. Environmental and health impacts of air pollution: A review. *Front. Public Health* **2020**, *8*, 14. [[CrossRef](#)] [[PubMed](#)]
- Bourdrel, T.; Bind, M.A.; Béjot, Y.; Morel, O.; Argacha, J.F. Cardiovascular effects of air pollution. *Arch. Cardiovasc. Dis.* **2017**, *110*, 634–642. [[CrossRef](#)] [[PubMed](#)]
- Glencross, D.A.; Ho, T.R.; Camina, N.; Hawrylowicz, C.M.; Pfeffer, P.E. Air pollution and its effects on the immune system. *Free Radic. Biol. Med.* **2020**, *151*, 56–68. [[CrossRef](#)] [[PubMed](#)]
- Grossman, G.M.; Krueger, A.B. *Environmental Impacts of a North American Free Trade Agreement*; Working paper 3914; NBER: Cambridge, MA, USA, 1991.
- Selden, T.M.; Song, D. Environmental quality and development: Is there a Kuznets curve for air pollution emissions? *J. Environ. Econ. Manag.* **1994**, *27*, 147–162. [[CrossRef](#)]
- Shafik, N. Economic development and environmental quality: An econometric analysis. *Oxf. Econ. Pap.* **1994**, *46*, 757–773. [[CrossRef](#)]
- Dinda, S.; Coondoo, D.; Pal, M. Air quality and economic growth: An empirical study. *Ecol. Econ.* **2000**, *34*, 409–423. [[CrossRef](#)]
- Welsch, H. Corruption, growth, and the environment: A cross-country analysis. *Environ. Dev. Econ.* **2004**, *9*, 663–693. [[CrossRef](#)]
- Dasgupta, S.; Hamilton, K.; Pandey, K.D.; Wheeler, D. Environment during growth: Accounting for governance and vulnerability. *World Dev.* **2006**, *34*, 1597–1611. [[CrossRef](#)]
- Kacar, S.B.; Kayalica, M.O. Environmental Kuznets curve and sulfur emissions: A comparative econometric analysis. *Ecol. Econ.* **2014**, *5*, 8–20.
- Carson, R.T.; Jeon, Y.; McCubbin, D.R. The relationship between air pollution emissions and income: US Data. *Environ. Dev. Econ.* **1997**, *2*, 433–450. [[CrossRef](#)]
- Torrás, M.; Boyce, J.K. Income, inequality, and pollution: A reassessment of the environmental Kuznets curve. *Ecol. Econ.* **1998**, *25*, 147–160. [[CrossRef](#)]
- List, J.A.; Gallet, C.A. The environmental Kuznets curve: Does one size fit all? *Ecol. Econ.* **1999**, *31*, 409–423. [[CrossRef](#)]

20. Millimet, D.L.; List, J.A.; Stengos, T. The environmental Kuznets curve: Real progress or misspecified models? *Rev. Econ. Stat.* **2003**, *85*, 1038–1047. [[CrossRef](#)]
21. Archibald, S.O.; Banu, L.E.; Bochniarz, Z. Market liberalisation and sustainability in transition: Turning points and trends in central and Eastern Europe. *Env. Polit.* **2004**, *13*, 266–289. [[CrossRef](#)]
22. Sinha, A. Trilateral association between SO₂/NO₂ emission, inequality in energy intensity, and economic growth: A case of Indian cities. *Atmos. Pollut. Res.* **2016**, *7*, 647–658. [[CrossRef](#)]
23. Dincer, I. Renewable energy and sustainable development: A crucial review. *Renew. Sustain. Energy Rev.* **2000**, *4*, 157–175. [[CrossRef](#)]
24. Boudri, J.C.; Hordijk, L.; Kroeze, C.; Amann, M.; Cofala, J.; Bertok, I.; Li, J.; Dai, L.; Zhen, S.; Hu, R.; et al. The potential contribution of renewable energy in air pollution abatement in China and India. *Energy Policy* **2002**, *30*, 409–424. [[CrossRef](#)]
25. Sulaiman, J.; Azman, A.; Saboori, B. The potential of renewable energy: Using the environmental Kuznets curve model. *Am. J. Environ. Sci.* **2013**, *9*, 103. [[CrossRef](#)]
26. Bilgili, F.; Koçak, E.; Bulut, Ü. The dynamic impact of renewable energy consumption on CO₂ emissions: A revisited environmental Kuznets curve approach. *Renew. Sustain. Energy Rev.* **2016**, *54*, 838–845. [[CrossRef](#)]
27. Jebli, M.B.; Youssef, S.B.; Ozturk, I. Testing environmental Kuznets curve hypothesis: The role of renewable and non-renewable energy consumption and trade in OECD Countries. *Ecol. Indic.* **2016**, *60*, 824–831. [[CrossRef](#)]
28. Dogan, E.; Ozturk, I. The influence of renewable and non-renewable energy consumption and real income on CO₂ emissions in the USA: Evidence from structural break tests. *Environ. Sci. Pollut. Res.* **2017**, *24*, 10846–10854. [[CrossRef](#)]
29. Salim, R.; Rafiq, S.; Shafiei, S. *Urbanization, Energy Consumption, and Pollutant Emission in Asian Developing Economies: An Empirical Analysis*; ADBI Working Paper; Asian Development Bank Institute: Tokyo, Japan, 2017.
30. Zhu, Y.; Wang, Z.; Yang, J.; Zhu, L. Does renewable energy technological innovation control China's air pollution? A spatial analysis. *J. Clean. Prod.* **2020**, *250*, 119515. [[CrossRef](#)]
31. Panayotou, T. *Empirical Tests and Policy Analysis of Environmental Degradation at Different Stages of Economic Development (No. 992927783402676)*; ILO: Geneva, Switzerland, 1993.
32. To, A.H.; Ha, D.T.-T.; Nguyen, H.M.; Vo, D.H. The Impact of foreign direct investment on environment degradation: Evidence from emerging markets in Asia. *Int. J. Environ. Res. Public Health* **2019**, *16*, 1636. [[CrossRef](#)]
33. Fang, D.; Hao, P.; Wang, Z.; Hao, J. Analysis of the influence mechanism of CO₂ emissions and verification of the environmental Kuznets curve in China. *Int. J. Environ. Res. Public Health* **2019**, *16*, 944. [[CrossRef](#)]
34. Tutulmaz, O. Environmental Kuznets curve time series application for Turkey: Why controversial results exist for similar models? *Renew. Sustain. Energy Rev.* **2015**, *50*, 73–81. [[CrossRef](#)]
35. Cole, M.A.; Rayner, A.J.; Bates, J.M. The environmental Kuznets curve: An empirical analysis. *Environ. Dev. Econ.* **1997**, *2*, 401–416. [[CrossRef](#)]
36. Kaika, D.; Zervas, E. The environmental Kuznets curve (EKC) theory—Part A: Concept, causes and the CO₂ emissions case. *Energy Policy* **2013**, *62*, 1392–1402. [[CrossRef](#)]
37. Xu, B.; Lin, B. What cause large regional differences in PM_{2.5} pollutions in China? Evidence from quantile regression model. *J. Clean. Prod.* **2018**, *174*, 447–461. [[CrossRef](#)]
38. Sephton, P.; Mann, J. Compelling evidence of an environmental Kuznets curve in the United Kingdom. *Environ. Resour. Econ.* **2016**, *64*, 301–315. [[CrossRef](#)]
39. Och, M. Empirical Investigation of the Environmental Kuznets Curve Hypothesis for Nitrous Oxide Emissions for Mongolia. *Int. J. Energy Econ. Policy* **2017**, *7*, 117–128.
40. Sapkota, P.; Bastola, U. Foreign direct investment, income, and environmental pollution in developing countries: Panel data analysis of Latin America. *Energy Econ.* **2017**, *64*, 206–212. [[CrossRef](#)]
41. Wang, S.; Yang, F.; En Wang, X.; Song, J. A microeconomics explanation of the environmental Kuznets curve (EKC) and an empirical investigation. *Pol. J. Environ. Stud.* **2017**, *26*, 1757–1764. [[CrossRef](#)]
42. Xie, Q.; Xu, X.; Liu, X. Is there an EKC between economic growth and smog pollution in China? New evidence from semiparametric spatial autoregressive models. *J. Clean. Prod.* **2019**, *220*, 873–883. [[CrossRef](#)]
43. Haider, A.; Bashir, A.; Husnain, M.I. Impact of agricultural land use and economic growth on nitrous oxide emissions: Evidence from developed and developing countries. *Sci. Total Environ.* **2020**, *741*, 140421. [[CrossRef](#)]
44. Richmond, A.K.; Kaufmann, R.K. Is there a turning point in the relationship between income and energy use and/or carbon emissions? *Ecol. Econ.* **2006**, *56*, 176–189. [[CrossRef](#)]
45. Abdallah, K.B.; Belloumi, M.; De Wolf, D. Indicators for sustainable energy development: A multivariate cointegration and causality analysis from Tunisian road transport sector. *Renew. Sustain. Energy Rev.* **2013**, *25*, 34–43. [[CrossRef](#)]
46. Onafowora, O.A.; Owoye, O. Bounds testing approach to analysis of the environment Kuznets curve hypothesis. *Energy Econ.* **2014**, *44*, 47–62. [[CrossRef](#)]
47. Luo, Y.; Chen, H.; Zhu, Q.; Peng, C.; Yang, G.; Yang, Y.; Zhang, Y. Relationship between air pollutants and economic development of the provincial capital cities in China during the past decade. *PLoS ONE* **2014**, *9*, e104013.
48. Akpan, U.F.; Abang, D.E. Environmental quality and economic growth: A panel analysis of the “U” in Kuznets. *J. Econ. Res.* **2015**, *20*, 317–339.
49. Baek, J. Environmental Kuznets curve for CO₂ emissions: The case of Arctic countries. *Energy Econ.* **2015**, *50*, 13–17. [[CrossRef](#)]

50. Adebayo, T.S.; Awosusi, A.A.; Oladipupo, S.D.; Agyekum, E.B.; Jayakumar, A.; Kumar, N.M. Dominance of fossil fuels in Japan's national energy mix and implications for environmental sustainability. *Int. J. Environ. Res. Public Health* **2021**, *18*, 7347. [[CrossRef](#)]
51. Panwar, N.L.; Kaushik, S.C.; Kothari, S. Role of renewable energy sources in environmental protection: A review. *Renew. Sustain. Energy Rev.* **2011**, *15*, 1513–1524. [[CrossRef](#)]
52. Elia, A.; Kamidelivand, M.; Rogan, F.; Gallachóir, B.Ó. Impacts of innovation on renewable energy technology cost reductions. *Renew. Sustain. Energy Rev.* **2020**, *138*, 110488. [[CrossRef](#)]
53. Davis, K.; Golden, H.H. Urbanization and the development of pre-industrial areas. *Econ. Dev. Cult. Chang.* **1954**, *3*, 6–26. [[CrossRef](#)]
54. Antweiler, W.; Copeland, B.R.; Taylor, M.S. Is free trade good for the environment? *Am. Econ. Rev.* **2001**, *91*, 877–908. [[CrossRef](#)]
55. Davis, J.C.; Henderson, J.V. Evidence on the political economy of the urbanization process. *J. Urban Econ.* **2003**, *53*, 98–125. [[CrossRef](#)]
56. Managi, S.; Hibiki, A.; Tsurumi, T. *Does Trade Liberalization Reduce Pollution Emissions?* Discussion papers 08-E-013; The Research Institute of Economy, Trade and Industry: Tokyo, Japan, 2008.
57. Kohler, M. CO₂ emissions, energy consumption, income and foreign trade: A South African perspective. *Energy Policy* **2013**, *63*, 1042–1050. [[CrossRef](#)]
58. Boutabba, M.A. The impact of financial development, income, energy and trade on carbon emissions: Evidence from the Indian economy. *Econ. Model.* **2014**, *40*, 33–41. [[CrossRef](#)]
59. Seker, F.; Ertugrul, H.M.; Cetin, M. The impact of foreign direct investment on environmental quality: A bounds testing and causality analysis for Turkey. *Renew. Sustain. Energy Rev.* **2015**, *52*, 347–356. [[CrossRef](#)]
60. Ertugrul, H.M.; Cetin, M.; Seker, F.; Dogan, E. The impact of trade openness on global carbon dioxide emissions: Evidence from the top ten emitters among developing countries. *Ecol. Indic.* **2016**, *67*, 543–555. [[CrossRef](#)]
61. Rafiq, S.; Salim, R.; Nielsen, I. Urbanization, openness, emissions, and energy intensity: A study of increasingly urbanized emerging economies. *Energy Econ.* **2016**, *56*, 20–28. [[CrossRef](#)]
62. Lin, B.; Zhu, J. Changes in urban air quality during urbanization in China. *J. Clean. Prod.* **2018**, *188*, 312–321. [[CrossRef](#)]
63. Anderson, T.W.; Hsiao, C. Formulation and estimation of dynamic models using panel data. *J. Econom.* **1982**, *18*, 47–82. [[CrossRef](#)]
64. Ahn, S.C.; Schmidt, P. Efficient estimation of models for dynamic panel data. *J. Econom.* **1995**, *68*, 5–27. [[CrossRef](#)]
65. Arellano, M.; Bond, S. Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *Rev. Econ. Stud.* **1991**, *58*, 277–297. [[CrossRef](#)]
66. Yong, C. Analysis on energy-saving technology of civil architecture. *Shanxi Archit.* **2010**, *23*, P263–P264.
67. Yuan, X.; Liu, X.; Zuo, J. The development of new energy vehicles for a sustainable future: A review. *Renew. Sustain. Energy Rev.* **2015**, *42*, 298–305. [[CrossRef](#)]
68. Beckerman, W. Economic growth and the environment: Whose growth? Whose environment? *World Dev.* **1992**, *20*, 481–496. [[CrossRef](#)]
69. Webber, D.J.; Allen, D.O. Environmental Kuznets curves: Mess or meaning? *Int. J. Sustain. Dev. World Ecol.* **2010**, *17*, 198–207. [[CrossRef](#)]