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Growth, Emission, and Mitigation Aid in Developing Countries

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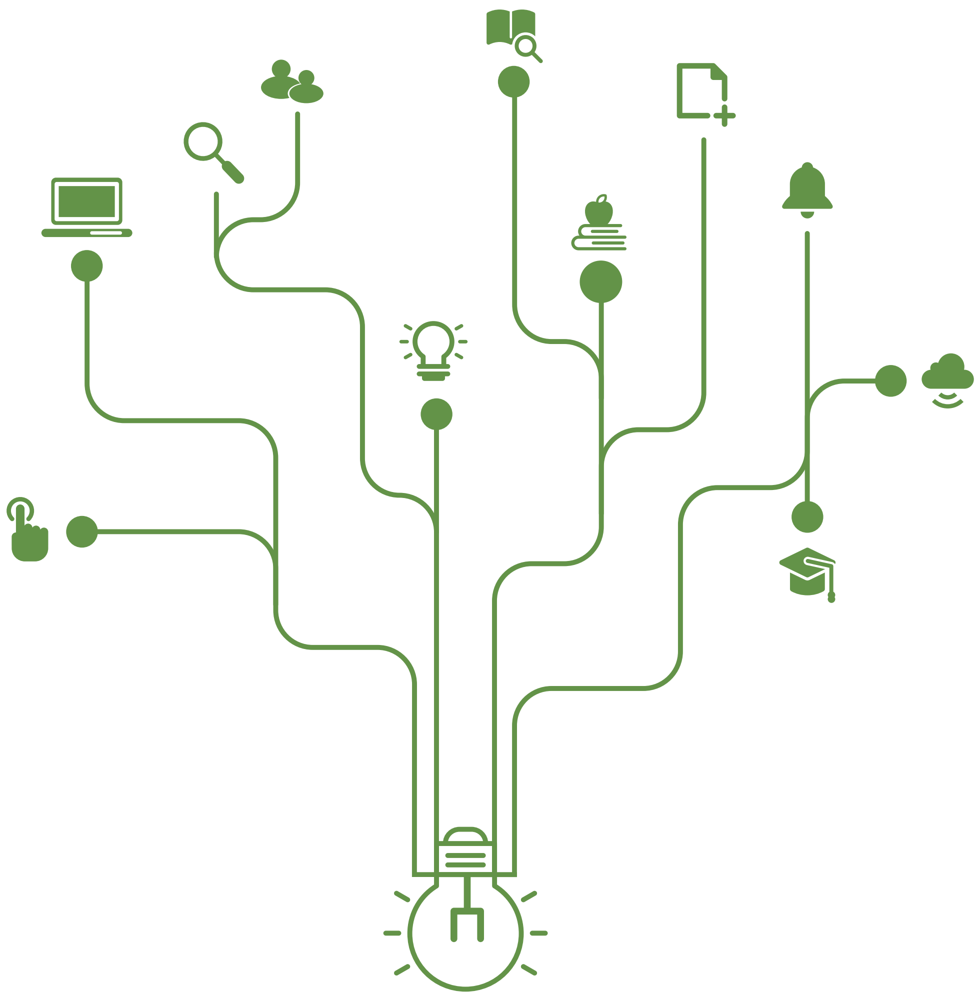

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Summary

This paper aims to examine the relationship between growth and pollution, especially in developing countries that struggle with adverse effects caused by the climate crisis. By using the Environmental Kuznets Curve (EKC) framework, the effect of GDP on four air pollutants was investigated with a panel data of 91 countries for 10 years. Only carbon dioxide without control variables showed EKC and climate change mitigation aid was significantly negative to only greenhouse gas emission.

Introduction

Recognizing an unquestionable fact of climate change, the international community has made numerous efforts to decelerate global warming. Devoted countries specified their ambitious goals to fight against climate change in Nationally Determined Contribution or Intended Nationally Determined Contribution, and announced their commitment to carbon neutrality. Private sector also actively participated in or led the global efforts through launching initiatives such as RE100 or producing environmental-friendly products. Many of the endeavors targeted to reduce carbon dioxide emission because it has been singled out as the largest contributor to greenhouse gas emission which is one of the main accelerators of global warming.

According to Intergovernmental Panel on Climate Change (2021), “[h]uman influence has warmed the climate at a rate that is unprecedented in at least the last 2000 years (p.7),” which brought visible impacts of climate change in diverse aspects including global pandemic, frequent natural disasters, melting glaciers, rising sea level, and extreme weather. All of these threaten the lives of people on earth, however, it has been reported that the most affected population is in developing countries and in vulnerable groups (Hallegatte et al. 2016; Mendelsohn, Dinar, and Williams 2006; Tol et al. 2004; Ward and Shively 2012). Even though advanced economies are the ones that have largely deteriorated the global environment while they rapidly grew, developing countries and vulnerable groups are the ones that have suffered from the negative aftermath of it. Lack of facilities and capacities to deal with climate risks worsen the situation in developing countries. Due to the unequal consequence, some view this issue as climate justice (Bond 2012; Furlan and Mariano 2021; Newell and Mulvaney 2013) and urge responsible actions to developed countries.

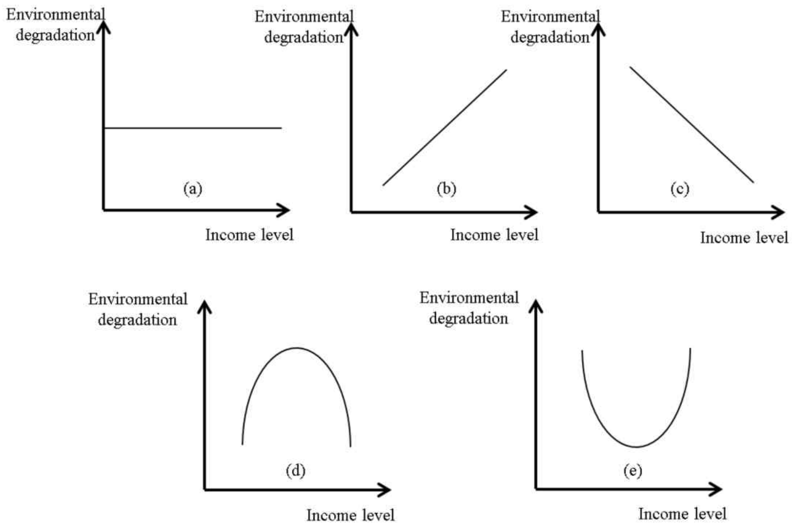
In order to alleviate the problem, developed countries have been asked and have voluntarily committed to support developing countries, revolving around the famous principle of common but differentiated responsibilities codified in Article 3 and 4 of United Nations Framework Convention on Climate Change (United Nations 1992). Nevertheless, a wide gap between investment needs in developing countries and actual investment from developed countries has remained. Narrowing the opinion gap between the two groups of countries on climate actions seems to be difficult as well. A case in point is regarding divestment from fossil fuel. For developing countries, the conventional energy source is necessary to promote rapid economic growth since it is relatively cheap and easy to use compared to renewable energy which is encouraged in climate change discourse. However, under the name of reducing carbon dioxide emission, developed countries which are the historical culprits of the emission have advantage over this transition of energy source and even experience benefit from technological superiority.

Considering the aforementioned circumstances, this paper aims to examine the relationship between growth and pollution, especially in developing countries that struggle with adverse effects caused by the climate crisis. Economy-environment nexus has been studied over three decades using the Environmental Kuznets Curve (EKC) framework. This study is in line with EKC literature, and it will contribute to the existing EKC studies by focusing on developing countries and questioning whether the international support for developing countries is effective. Due to data availability, a panel data of 91 developing countries over the year 2002 to 2012 will be a study sample, and gross domestic product (GDP) per capita and four main air pollutants per capita will be main variables to analyze. As a proxy of the international supports for developing countries, climate change mitigation aid will be incorporated which is given to facilitate mitigation actions in developing countries.

Environmental Kuznets Curve

The EKC test has been the most widely used framework to investigate the relationship between growth and environment. Scholars found out that the two had an inverted U shaped curve, and they named it EKC inspired by the Kuznets Curve (Kuznets, 1955) which demonstrated the identical shape between income and income equality. One of the main assumptions of the EKC is that economic growth will naturally lead to environmental improvement. That is to say, during the early stage of development, environmental degradation increases with the rise of GDP, but after the threshold, environmental quality will be enhanced while economic growth continues. Among the patterns that can be displayed by income and pollution, a bell shaped curve, which is (d) in Figure 1, is generally regarded as EKC. Some studies expanded the boundary to N-shape (e.g. Akbostancı, Türüt-Aşık, and Tunç 2009; Kang, Zhao and Yang 2016) or M-shape (e.g. Destek et al. 2020; Hasanov, Hunt, and Mikayilov 2021), however, an inverted U curve is a well-known EKC.

Figure 1 The Relationship between Income Level and Environmental Degradation



Note: Each figure presents that pollution and growth have (a) no relationship, (b) positive monotonic relationship, (c) negative monotonic relationship, (d) inverted U relationship, i.e. Environmental Kuznets Curve, and (e) U relationship.

Source: Adapted from Sarkodie and Strezov (2019)

Seminal piece of EKC literature is known as Grossman and Krueger (1991), which analyzed the effect of the North American Free Trade Agreement on the environment. They also proposed three effects that can explain the inverted U relationship. Firstly, scale effect is related to an upward slope of EKC, indicating the increase of environmental degradation with the beginning of economic growth. Second, the composition effect is realized in the process of restructuring the economy. In general, countries develop from agriculture to heavy industry or manufacturing and to service sector. Heavy industry tends to bring more pollution, whereas the level of environmental degradation caused by service sector is mostly lower than that of manufacturing. Lastly, the technique effect occurs when green and clean technology is developed and productivity is improved, which results in reducing environmental pollution and plots the right side of an inverted U curve.

EKC has been tested with diverse variables, methodologies, sample countries, and time periods. For the dependent variable representing environmental quality, a number of indicators were employed including carbon dioxide, greenhouse gas, sulfur dioxide, ecological footprint, water quality, and solid waste management. In addition, different sets of control variables were adopted as determinants of environmental degradation. For example, since increasing greenhouse gas emission or worsening environmental pollution is largely attributed to the energy sector, quite a lot of research includes energy consumption as an important variable in the EKC framework (Lorente and Álvarez-Herranz 2016; Özokcu and Özdemir 2017; Sarkodie and Strezov 2018; Zoundi 2017). Regarding empirical strategy, panel vector error correction model, generalized method of moments, fixed effects, random effects, or ordinary least squares regression are some of the examples. With regard to study area, diverse locations were considered. For instance, there were papers on a single country case (e.g., Brazil, China, India, Italy, Malaysia, Tunisia, or USA) or on a group of or groups of countries (e.g., OECD countries, ASEAN countries, middle income countries, or African countries). The concerned period was also differ by research.

Even with or because of numerous estimations performed under the EKC framework, the relationship between growth and pollution remains mixed. For instance, Shafik and Bandyopadhyay (1992) analyzed the effect of GDP per capita on carbon dioxide emission per capita in 149 countries between the year 1961 and 1986, and they found out monotonically increasing relationship. In the work by Apergis and Ozturk (2015), they also considered GDP per capita and carbon dioxide emission per capita but for 14 Asian countries from 1990 to 2011, and the test resulted the inverted U shape curve. Destek and Sarkodie (2019) investigated the relationship between ecological footprint and GDP per capita for 11 newly industrialized countries over 1977 to 2013, and EKC was found.

Data and Methodology

To investigate the effects of the growth on the environment in developing countries, the EKC hypothesis will be revisited. Below are the model specification in a reduced form and the interpretations of the relationships, which is mostly used in the existing literature on EKC. In the Equation (1), Y denotes emission of pollutants, X means income level, and Z represents control variables.

$$Y_{it} = \alpha_{it} + \beta_1 X_{it} + \beta_2 X_{it}^2 + \beta_3 Z_{it} + u_{it} \ \ldots\ldots (1)$$

- β_1=β_2=β_3=0, then X and Y have no relationship
- β_1> 0, β_2=β_3=0, then X and Y have a positive monotonic relationship
- β_1< 0, β_2=β_3=0, then X and Y have a negative monotonic relationship
- β_1> 0, β_2< 0, β_3=0, then X and Y have an inverted U-shape relationship
- β_1< 0, β_2> 0, β_3=0, then X and Y have a U-shape relationship

To identify the existence of EKC in developing countries with reference to the effectiveness of international support, a panel data of 91 countries from the year 2002 to 2012 will be tested. The most recent data were gathered, and then, considering data availability and outliers, the number of countries and years were limited. The selected countries belong to upper middle (from 4,046 to 12,535 USD), lower middle (from 1,036 to 4,045 USD), and low income (1,035 USD or less) groups based on World Bank (2020) criteria and are recipients of climate change mitigation aid which will be further described below. The list of the countries is provided in the Appendix 1. Variables were selected referring to major preceding research on EKC, collected from World Bank Open Data (2021) and Organisation for Economic Co-operation and Development (OECD)'s Creditor Reporting System (2021), and converted into the logarithm form. The name and source of the variables is summarized in Table 1, and detailed explanation on each variable will be given in the latter part of the chapter. All of the variables were log-transformed to reduce outliers and skewness.

Table 1 Name and Source of Variables

Variables	Source
CO_2 emissions (metric tons per capita)	World Bank (2021)
Total greenhouse gas emissions (kt of CO_2 equivalent)	
Methane emissions (kt of CO_2 equivalent)	
Nitrous oxide emissions (thousand metric tons of CO_2 equivalent)	
GDP per capita (current USD)	
Population density (people per sq. km of land area)	
Renewable energy consumption (% of total final energy consumption)	
Urban population (% of total population)	
Merchandise exports (current USD)	
Climate change mitigation aid (Rio marker, current USD)	OECD (2021)

Equation (2) is derived to analyze the effects of GDP per capita on four air pollutants reflecting the influence from control variables. As dependent variables, four air pollutants are chosen because they are considerable contributors to the greenhouse effect which facilitates climate change. According to Intergovernmental Panel on Climate Change (2014), carbon dioxide, methane, nitrous oxide, and fluorinated gases are main four components of greenhouse gases. In addition, the data is publicly available at the World Bank (2021). The equation below is applied to each pollutant respectively, and to identify the effectiveness of international assistance, climate change mitigation aid is incorporated.

$$lnpollutants_{it} = \alpha_{it} + \beta_1 lngdp_{it} + \beta_2 lngdpsq_{it} + \beta_3 lnpod_{it} + \beta_4 lnrec_{it} + \beta_5 lnupr_{it} + \beta_6 lnmex_{it} + \beta_7 lnaidm_{it} + u_{it} \;\ldots\ldots (2)$$

In the Equation (2), $lnpollutants_{it}$ represents four dependent variables which are the logarithm of carbon dioxide (*lncde*)[1], greenhouse gas (*lngge*)[2], methane (*lnmee*)[3], and nitrous oxide (*lnnoe*)[4] emission per capita of country *i* in the year *t*. For carbon dioxide, the original data has decimals, thus, the values were multiplied by 1,000 before converting into logarithmic form in order to make the adjusted numbers positive. This modification does not disturb statistical significance, which aligns with the methods applied in Oh and Yun (2014). Similarly, the number 10 was multiplied with nitrous oxide, considering decimals in the raw data. In addition, except carbon dioxide emission per capita, other three dependent variables exhibited the total amount. Hence, the three were divided by total population, and multiplied by 10,000 with greenhouse gas and methane emission and by 100,000 with nitrous oxide emission prior to log-transformation to make positive values.

Independent variables are $lngdp_{it}$ and $lngdpsq_{it}$ denoting the logarithm of GDP per capita (current USD)[5] of country *i* in the year *t* in a linear term and a quadratic term, respectively. Adding the square of GDP per capita is a conventional rule in EKC to figure out whether the income-pollution nexus shows an inverted U shape curve. Current USD is considered in order to ensure comparability with other two variables which also have a unit of current USD, i.e. merchandise exports and climate change mitigation aid. Other than the unit, independent variables in EKC literature do not have much variances. Most of the studies employed GDP per capita as their independent variable.

All the control variables are also in logarithm forms as the letter *ln* shows. First, logarithm of population density[6] of country *i* in the year *t* is displayed as $lnpop_{it}$. This is

1) “Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring (World Bank 2021).”

2) “Total greenhouse gas emissions in kt of CO_2 equivalent are composed of CO_2 totals excluding short-cycle biomass burning (such as agricultural waste burning and savanna burning) but including other biomass burning (such as forest fires, post-burn decay, peat fires and decay of drained peatlands), all anthropogenic CH4 sources, N2O sources and F-gases (HFCs, PFCs and SF6) (World Bank 2021).”

3) “Methane emissions are those stemming from human activities such as agriculture and from industrial methane production (World Bank 2021).”

4) “Nitrous oxide emissions are emissions from agricultural biomass burning, industrial activities, and livestock management (World Bank 2021).”

5) “GDP per capita is gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in current U.S. dollars (World Bank 2021).”

6) “Population density is midyear population divided by land area in square kilometers. Population is based on the de facto definition of population, which counts all residents regardless of legal status or citizenship--except for refugees not permanently settled in the country of asylum, who are generally considered part of the population of their country of origin. Land area is a country's total area, excluding area under inland water bodies, national claims to continental shelf,

one of the oft-used control variables, however, some works (e.g. Panayotou 1997) concluded that it had an increasing effect on emission and others (e.g. Selden and Song 1994) argued the opposite. Secondly, logarithm of renewable energy consumption[7] of country *i* in the year *t* is indicated as $lnrec_{it}$. Energy consumption is one of the important indicators utilized in EKC literature because traditional energy sector is known as one of the main negative contributor on environmental quality. However, the usage of renewable energy is relatively less studied, even though it receives a lot of attention as an environmentally friendly energy these days. Expected sign of this variable is negative since most preceding papers (e.g., Yao, Zhang, and Zhang 2019) employing it reported that it was correlated with the decrease in emissions. Third, urban population[8] of country *i* in the year *t* is put as $lnupr_{it}$. Rapid urbanization is known as one of the serious developmental problems faced by developing countries. Previous papers yielded confronting results on the direction of its effect on the environment. This may relate to management or governance issues in a country since, if poorly managed, populated urban areas might turn into slums and, if well controlled, a structured system might bring benefits to more people. Fourth, logarithm of merchandise exports[9] of country *i* in the year *t* is written as $lnmex_{it}$. The variable is included because of the pollution haven hypothesis which points out that a country with less strict environmental regulation has an advantage in trade but this will eventually lead to fostering pollution-intensive sectors. The pollution haven hypothesis is particularly relevant to developing countries since developed countries often have tighter policies and this results in relocating the polluting factories from developed to developing countries.

Fifth, $lnaidm_{it}$ signifies the amount of climate change mitigation aid committed (current USD) to country *i* in the year *t*, which is added as a proxy of international supports from developed to developing countries against climate change, specifically climate change mitigation[10]. When using bilateral aid data, disbursement is often preferred, however, for this variable, only the amount of commitment is available. $lnaidm_{it}$ is constructed by

and exclusive economic zones. In most cases the definition of inland water bodies includes major rivers and lakes (World Bank 2021)."

7) "Renewable energy consumption is the share of renewables energy in total final energy consumption (World Bank 2021)."

8) "Urban population refers to people living in urban areas as defined by national statistical offices. The data are collected and smoothed by United Nations Population Division (World Bank 2021)."

9) "Merchandise exports show the free on board value of goods provided to the rest of the world valued in current U.S. dollars (World Bank 2021)."

10) Climate activities can be divided into two groups depending on its purpose. The first is mitigation which is mainly focusing on reducing or removing greenhouse gas in the atmosphere, and the second is adaptation which addresses vulnerability and enhances resilience to climate risks.

gathering the amount of aid marked as climate change mitigation among four Rio Markers, and then, by summing up the amount of climate change mitigation aid classified as principal and significant. Biodiversity, climate change mitigation, climate change adaptation, and desertification are four Rio Markers, and each marker is scored as principal, significant[11], screened not targeted, and not screened, based on the Rio Marker manual. In addition, the number 1,000,000 is multiplied due to decimals, accordingly, the values with logarithmic form become positive.

Below is a table of descriptive statistics on each variable. The variables named *clngdp* and *clngdpsq* are mean-centering values of *lngdp* and *lngdpsq*, respectively, which was needed to suppress high variance inflation factors (VIFs). When VIFs are over 10, it signifies high correlation among explanatory variables. This leads to multicollinearity which may bring inaccurate or unreliable statistical results. The means of mean centered variables are supposed to be zero, however, due to rounding issues, the numerical values are near to zero. In addition, scatterplots and fitted values of the income-pollution nexus is shown in Figure 2 to observe whether the relationships are exhibited in non-linear shapes.

Table 2 Summary Statistics of Variables

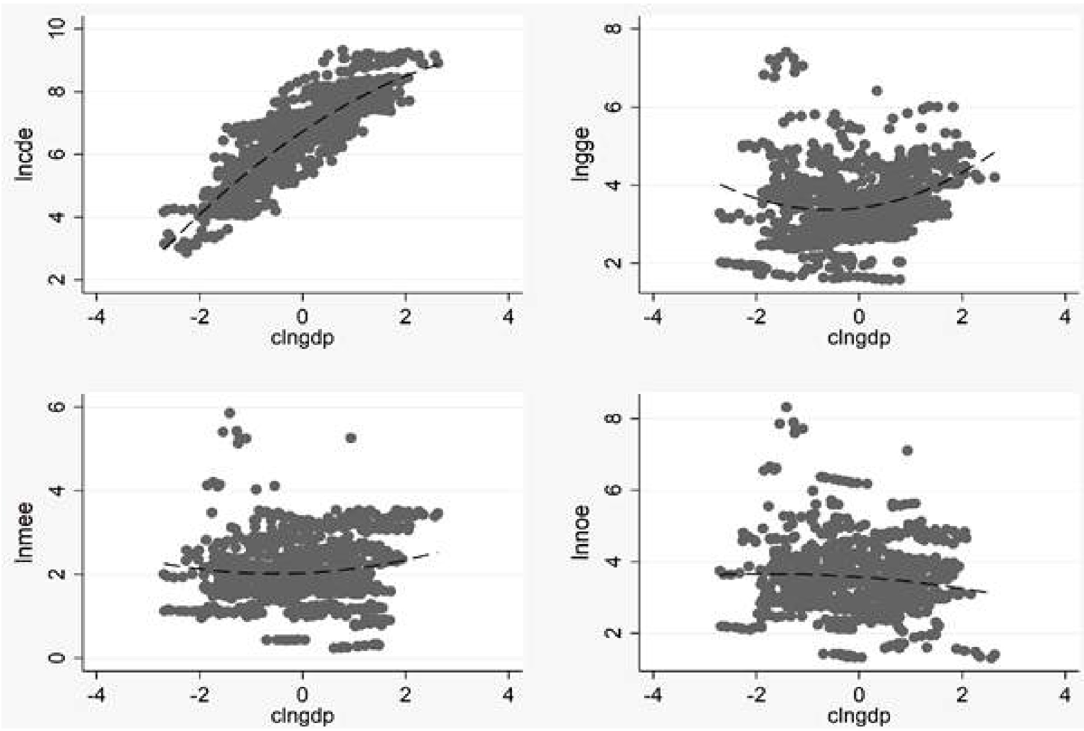
Variable	Observations	Mean	Standard Deviation	Min	Max
lncde	910	6.613319	1.352626	2.866385	9.324024
lngge	880	3.575941	0.9267177	1.579493	7.412533
lnmee	910	2.091742	0.7611576	0.2361053	5.862026
lnnoe	910	3.544671	0.9487297	1.308526	8.32225
clngdp	910	-1.17E-08	1.050387	-2.69521	2.627695
clngdpsq	910	1.1021	1.213902	4.07E-07	7.264135
lnpod	910	6.412188	1.293735	3.294114	9.44803
lnrec	910	10.34377	1.128739	6.907755	11.5056
lnupr	910	3.699581	0.500446	2.161252	4.51075
lnaidm	799	15.30841	2.732521	5.049856	21.77283

Empirical strategies implemented by this study are fixed effects (FE) and random effects (RE) models, which is commonly used in panel regression. The results from two approaches will be presented in the next chapter, and the most suitable estimation for each

11) "Principal (2) when the objective (climate change mitigation or adaptation) is explicitly stated as fundamental in the design of, or the motivation for, the activity. Significant (1) when the objective (climate change mitigation or adaptation) is explicitly stated but it is not the fundamental driver or motivation for undertaking it. (OECD 2018)"

dependent variable will be determined by relevant statistical tests which will be elaborated in the next chapter. Due to identified heteroscedasticity, White-corrected standard errors will be addressed in all of the estimations. STATA 14.2 is used for the panel regression.

Figure 2 Schematic Diagrams of Income-Pollution Nexus



Findings and Analysis

Table 3 shows the empirical results of the relationship between economic growth and environmental quality using four air pollutants which are carbon dioxide, greenhouse gas, methane, and nitrous oxide emission per capita. To see if EKC is demonstrated, both the linear and the quadratic terms of GDP per capita are regressed with each dependent variable. Among the four pollutants, only carbon dioxide emission per capita exhibits supporting evidence on EKC hypothesis, i.e. the coefficient of *clngdp* is significantly and positively correlated to carbon dioxide emission and that of *clngdpsq* is significantly and negatively correlated with the emission. The square terms of GDP per capita in greenhouse gas emission columns indicate significant results, but the signs of the coefficients are opposite to those in the carbon dioxide emission columns. With regard to methane emission per capita, even though the signs are identical to the EKC relationship, all of the coefficients are insignificant. In terms of nitrous oxide emission per capita, the quadratic terms of income variable had a significantly negative effect on the emission, whereas significance level is not found in the linear terms.

Table 3 Empirical Results on EKC Relationship (1)

	lncde		*lngge*		*lnmee*		*lnnoe*	
	FE	RE	FE	RE	FE	RE	FE	RE
clngdp	0.203***	0.249***	0.00518	0.0139	0.0361	0.0365	0.0376	0.0305
	(0.0304)	(0.0301)	(0.0390)	(0.0377)	(0.0423)	(0.0399)	(0.0504)	(0.0476)
clngdpsq	-0.0301*	-0.0327**	0.0524***	0.0547***	-0.0229	-0.0215	-0.0422*	-0.0418*
	(0.0157)	(0.0163)	(0.0150)	(0.0150)	(0.0175)	(0.0171)	(0.0227)	(0.0222)
Observations	910	910	880	880	910	910	910	910
R^2	0.246		0.026		0.013		0.022	
Adjusted R^2	0.244		0.024		0.011		0.020	

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Note: FE denotes fixed effects model, and RE represents random effects model. Heteroscedasticity is addressed with White-corrected standard errors, and GDP variable is mean-centered to deal with multicollinearity.

Table 4 displays the results after incorporating control variables. Interestingly, EKC disappears in carbon dioxide emission, while it appears in methane emission with FE. For greenhouse gas and nitrous oxide emission, the quadratic terms of GDP are still significant with the same signs as Table 3, and the linear terms of it remain insignificant. According to a test of overidentifying restrictions (Schaffer and Stillman 2006), FE is favored over RE in carbon dioxide emission, and RE is preferred in greenhouse gas, methane, and nitrous oxide emission. By narrowing down the interpretation on the favored estimation, EKC is not supported in Table 4.

Regarding control variables, population density is negatively significant to pollution in the case of greenhouse gas, methane, and nitrous oxide emission at the 1% level, but not in carbon dioxide emission. In terms of renewable energy consumption, it is significantly correlated with the reduction of emission in carbon dioxide, however, it has a significantly positive effect on the emission of nitrous oxide emission. When it comes to urban population ratio, both carbon dioxide and greenhouse gas emission are positively and significantly affected by higher level of urbanization. The increase in merchandise export is found to be significantly positive to only carbon dioxide emission, which supports the pollution haven hypothesis. Table 4 indicates that each pollutant has different sets of determinants, which highlights the need of examining unique features of environmental indicators in the process of developing mitigation policies or climate actions.

Table 4 Empirical Results on EKC Relationship (2)

	lncde		*lngge*		*lnmee*		*lnnoe*	
	FE	RE	FE	RE	FE	RE	FE	RE
clngdp	0.0566	0.0566	0.0506	0.000146	0.127*	0.0720	0.0919	0.0965
	(0.0412)	(0.0361)	(0.0698)	(0.0531)	(0.0737)	(0.0567)	(0.0799)	(0.0660)
clngdpsq	-0.0365*	-0.0394*	0.0427**	0.0547***	-0.0370**	-0.0222	-0.0492*	-0.0421*
	(0.0190)	(0.0203)	(0.0187)	(0.0162)	(0.0184)	(0.0178)	(0.0261)	(0.0238)
lnpod	-0.215	-0.0766	-0.820***	-0.449***	-0.260	-0.401***	-0.0608	-0.399***
	(0.259)	(0.0675)	(0.288)	(0.0604)	(0.245)	(0.0483)	(0.361)	(0.0755)
lnrec	-0.458***	-0.554***	-0.0896	-0.00739	-0.162	0.0516	-0.0812	0.151***
	(0.117)	(0.0713)	(0.0786)	(0.0580)	(0.101)	(0.0523)	(0.112)	(0.0572)
lnupr	0.644**	0.751***	0.447	0.336*	-0.161	-0.0139	-0.0677	-0.0314
	(0.259)	(0.170)	(0.423)	(0.195)	(0.290)	(0.167)	(0.384)	(0.204)
lnmex	0.0591**	0.0498**	0.0177	0.0339	-0.0551	0.0229	-0.0448	0.00775
	(0.0297)	(0.0210)	(0.0316)	(0.0241)	(0.0420)	(0.0208)	(0.0460)	(0.0255)
Observations	900	900	870	870	900	900	900	900
R^2	0.379		0.045		0.034		0.026	
Adjusted R^2	0.375		0.039		0.027		0.020	

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Note: FE denotes fixed effects model, and RE represents random effects model. Heteroscedasticity is addressed with White-corrected standard errors, and GDP variable is mean-centered to deal with multicollinearity.

In Table 5, climate change mitigation aid is added as a proxy to figure out whether the support from developed to developing countries facilitates the achievement of climate goals in developing countries. A test of overidentifying restrictions (Schaffer and Stillman 2006) suggests FE is the proper model for carbon dioxide emission, and RE is more suitable to greenhouse gas, methane, and nitrous oxide emission, same as the case in Table 4. Considering the preferred models, the inverted U relationship is not demonstrated in Table 5. Population density, renewable energy consumption, and urban population produced the same signs and significance level with Table 4, but for merchandise exports, the significance level is reduced in the column of carbon dioxide and is increased in the column of greenhouse gas emission.

Moreover, climate change mitigation aid, which is a variable of interest in the table below, is found to be negatively significant to only greenhouse gas emission. Even though the value of the coefficient is not big, a unit change in *lnaidm* is significantly associated with the decrease of greenhouse gas emission by 0.991% at the 10% significance level. For other pollutants, all exhibit negative signs although insignificant. Since the purpose of mitigation aid is to reduce greenhouse gas emission, it seems that the international support is effective. Nevertheless, statistical significance only appears with greenhouse gas emission as a whole, but not with the elements of it.

By incorporating mitigation aid variable, the number of observations is reduced, however, the values of R^2 and *adjusted* R^2 become higher compared to Table 4. This signifies that the regression model with mitigation aid fits the observed data better than the regression model without mitigation aid. Although just a slight increase of R^2 and *adjusted* R^2 is identified and the significant results of individual coefficients are known as more important than explanatory power of the model in panel regression, it may be inferred from the results that official bilateral mitigation aid from developed countries is in some level significantly influencing the reduction of main air pollutants in developing countries. Thus, when it comes to analyzing EKC relationship in developing countries, mitigation aid would be a good additional control variable to explain the situation in developing countries. At the same time, international community should pay more attention to the effectiveness of mitigation measures for developing countries. Not only increasing the amount of aid flows to developing countries but also the role of it should be more carefully considered.

Table 5 Empirical Results on EKC Relationship (3)

	lncde		*lngge*		*lnmee*		*lnnoe*	
	FE	RE	FE	RE	FE	RE	FE	RE
clngdp	0.0423	0.0639*	0.0726	0.0236	0.145*	0.0676	0.128	0.105
	(0.0441)	(0.0382)	(0.0655)	(0.0472)	(0.0851)	(0.0622)	(0.0863)	(0.0709)
clngdpsq	-0.0278	-0.0315*	0.0320**	0.0450***	-0.0401**	-0.0246	-0.0537**	-0.0457*
	(0.0175)	(0.0181)	(0.0148)	(0.0127)	(0.0187)	(0.0187)	(0.0262)	(0.0242)
lnpod	-0.198	-0.0551	-0.868***	-0.440***	-0.314	-0.402***	-0.207	-0.406***
	(0.280)	(0.0659)	(0.308)	(0.0617)	(0.297)	(0.0495)	(0.405)	(0.0777)
lnrec	-0.437***	-0.539***	-0.101	-0.0112	-0.160	0.0597	-0.0670	0.163***
	(0.117)	(0.0705)	(0.0750)	(0.0579)	(0.103)	(0.0543)	(0.111)	(0.0593)
lnupr	0.791***	0.821***	0.374	0.279*	-0.0780	-0.000374	0.0389	-0.0277
	(0.250)	(0.162)	(0.334)	(0.151)	(0.335)	(0.173)	(0.425)	(0.209)
lnmex	0.0715*	0.0574**	0.0350	0.0448*	-0.0750	0.0224	-0.0617	0.00127
	(0.0360)	(0.0234)	(0.0317)	(0.0248)	(0.0507)	(0.0242)	(0.0523)	(0.0284)
lnaidm	-0.00268	-0.00630**	-0.00846*	-0.00991*	-0.00117	-0.00156	-0.00521	-0.00340
	(0.00287)	(0.00274)	(0.00497)	(0.00538)	(0.00440)	(0.00378)	(0.00560)	(0.00499)

Observations	791	791	765	765	791	791	791	791
R^2	0.394		0.051		0.039		0.034	
Adjusted R^2	0.388		0.042		0.031		0.026	

Standard errors in parentheses
$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$
Note: FE denotes fixed effects model, and RE represents random effects model. Heteroscedasticity is addressed with White-corrected standard errors, and GDP variable is mean-centered to deal with multicollinearity.

Conclusion

To investigate the relationship between growth and environment in developing countries, the EKC hypothesis was revisited in this study. Considering the fact that the greenhouse effect accelerates global warming and ultimately climate change, three main elements of greenhouse gas and greenhouse gas emission as a whole were employed as indicators to represent environmental quality. Moreover, by reflecting climate justice discourse, a proxy variable on official assistance from developed to developing countries was incorporated into the EKC model. Specifically, international support related to climate change mitigation was examined. The sample panel data composed of 91 countries over the period of 2002 to 2012 was dictated by data availability and outlier.

By carrying out panel regressions using FE and RE with heteroscedasticity-robust standard errors, the inverted U relationship was found only in the estimation on carbon dioxide emission with no control variables. There was not a strong evidence of EKC and the patterns between income and pollution are not consistent across the four air pollutants. Additionally, in general, population density and renewable energy were associated with the reduction of emission, while urban population and merchandise exports had increasing effects on emission variables. However, different characteristics of air pollutants should be considered since the significance levels and the signs of control variables varied by different combinations of the indicators. Especially in the case of renewable energy consumption, it was significantly negative to carbon dioxide emission, however, opposite result was yielded in nitrous oxide emission. For merchandise exports, the pollution haven hypothesis was supported, even though it was only found in carbon dioxide emission. Regarding climate change mitigation aid, significantly negative effects on emission were only observed in the estimation with greenhouse gas emission as a whole. This partly showed the accomplishment of expected results of mitigation aid, and also called attention to more careful and thorough design of international supports for developing countries.

To provide further explanations on economy-environment nexus, more data should become available, specifically for developing countries. As suggestions for future study, adding qualitative analysis onto the key findings in this study would enable in-depth understanding of the mechanism behind the regression models. In addition, the methodological approach taken in this paper was limited to discover the correlation among variables, however, using more sophisticated econometric methods would allow the interpretation of the results from the viewpoint of causal relationship.

Appendix: List of 91 Countries

Country	Regional Classification	Income Classification
Albania	Europe & Central Asia	Upper middle income
Algeria	Middle East & North Africa	Lower middle income
Angola	Sub-Saharan Africa	Lower middle income
Argentina	Latin America & Caribbean	Upper middle income
Bangladesh	South Asia	Lower middle income
Belize	Latin America & Caribbean	Upper middle income
Benin	Sub-Saharan Africa	Lower middle income
Bhutan	South Asia	Lower middle income
Bolivia	Latin America & Caribbean	Lower middle income
Botswana	Sub-Saharan Africa	Upper middle income
Brazil	Latin America & Caribbean	Upper middle income
Burkina Faso	Sub-Saharan Africa	Low income
Burundi	Sub-Saharan Africa	Low income
Cabo Verde	Sub-Saharan Africa	Lower middle income
Central African Republic	Sub-Saharan Africa	Low income
Chad	Sub-Saharan Africa	Low income
China	East Asia & Pacific	Upper middle income
Colombia	Latin America & Caribbean	Upper middle income
Comoros	Sub-Saharan Africa	Lower middle income
Congo, Dem. Rep.	Sub-Saharan Africa	Low income
Congo, Rep.	Sub-Saharan Africa	Lower middle income
Costa Rica	Latin America & Caribbean	Upper middle income
Côte d'Ivoire	Sub-Saharan Africa	Lower middle income
Cuba	Latin America & Caribbean	Upper middle income
Djibouti	Middle East & North Africa	Lower middle income
Dominica	Latin America & Caribbean	Upper middle income
Dominican Republic	Latin America & Caribbean	Upper middle income
Ecuador	Latin America & Caribbean	Upper middle income
Egypt, Arab Rep.	Middle East & North Africa	Lower middle income
El Salvador	Latin America & Caribbean	Lower middle income
Equatorial Guinea	Sub-Saharan Africa	Upper middle income
Eswatini	Sub-Saharan Africa	Lower middle income
Ethiopia	Sub-Saharan Africa	Low income
Fiji	East Asia & Pacific	Upper middle income
Gabon	Sub-Saharan Africa	Upper middle income
Gambia, The	Sub-Saharan Africa	Low income
Ghana	Sub-Saharan Africa	Lower middle income
Grenada	Latin America & Caribbean	Upper middle income

Guatemala	Latin America & Caribbean	Upper middle income
Guinea	Sub-Saharan Africa	Low income
Guinea-Bissau	Sub-Saharan Africa	Low income
Guyana	Latin America & Caribbean	Upper middle income
Haiti	Latin America & Caribbean	Low income
Honduras	Latin America & Caribbean	Lower middle income
India	South Asia	Lower middle income
Indonesia	East Asia & Pacific	Upper middle income
Jamaica	Latin America & Caribbean	Upper middle income
Jordan	Middle East & North Africa	Upper middle income
Kenya	Sub-Saharan Africa	Lower middle income
Kiribati	East Asia & Pacific	Lower middle income
Lao PDR	East Asia & Pacific	Lower middle income
Lebanon	Middle East & North Africa	Upper middle income
Lesotho	Sub-Saharan Africa	Lower middle income
Libya	Middle East & North Africa	Upper middle income
Madagascar	Sub-Saharan Africa	Low income
Malawi	Sub-Saharan Africa	Low income
Malaysia	East Asia & Pacific	Upper middle income
Maldives	South Asia	Upper middle income
Mali	Sub-Saharan Africa	Low income
Mauritania	Sub-Saharan Africa	Lower middle income
Mexico	Latin America & Caribbean	Upper middle income
Morocco	Middle East & North Africa	Lower middle income
Nepal	South Asia	Lower middle income
Nicaragua	Latin America & Caribbean	Lower middle income
Nigeria	Sub-Saharan Africa	Lower middle income
Pakistan	South Asia	Lower middle income
Papua New Guinea	East Asia & Pacific	Lower middle income
Paraguay	Latin America & Caribbean	Upper middle income
Peru	Latin America & Caribbean	Upper middle income
Philippines	East Asia & Pacific	Lower middle income
Rwanda	Sub-Saharan Africa	Low income
Samoa	East Asia & Pacific	Upper middle income
Senegal	Sub-Saharan Africa	Lower middle income
Sierra Leone	Sub-Saharan Africa	Low income
Solomon Islands	East Asia & Pacific	Lower middle income
South Africa	Sub-Saharan Africa	Upper middle income
Sri Lanka	South Asia	Lower middle income
St. Lucia	Latin America & Caribbean	Upper middle income
St. Vincent and the Grenadines	Latin America & Caribbean	Upper middle income

Tanzania	Sub-Saharan Africa	Lower middle income
Thailand	East Asia & Pacific	Upper middle income
Togo	Sub-Saharan Africa	Low income
Tonga	East Asia & Pacific	Upper middle income
Tunisia	Middle East & North Africa	Lower middle income
Turkey	Europe & Central Asia	Upper middle income
Tuvalu	East Asia & Pacific	Upper middle income
Uganda	Sub-Saharan Africa	Low income
Vanuatu	East Asia & Pacific	Lower middle income
Yemen, Rep.	Middle East & North Africa	Low income
Zambia	Sub-Saharan Africa	Lower middle income
Zimbabwe	Sub-Saharan Africa	Lower middle income

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