Southeast Asian Journal of Economics Vol.12(3), December 2024: 207-264
Received: January 5, 2023
Revision: April 16, 2023
Accepted: February 23, 2024

Re-assessing the Environmental Kuznets Curve for the Human Development Index: Evidence from Emerging Asian Economies

Titiksha Das
Department of Humanities and Social Sciences,
National Institute of Technology Durgapur, India
Corresponding author: td.20hs1101@phd.nitdgp.ac.in
Debasis Chakraborty
Department of Humanities and Social Sciences,
National Institute of Technology Durgapur, India

Abstract

Environmental Kuznets Curve (EKC) postulates an inverted U-shaped relationship between environmental degradation and measures of economic growth such as GDP per capita or income per capita. This study attempts to re-assess EKC with an indicator of human development instead of economic growth with a cubic specification. An empirical analysis was conducted for ten emerging Asian economies from 1990 to 2018. Using fixed effects and random effects regression models, we found an N-shaped curve for human development and environmental degradation. In a unique attempt, the study also determined the percentage of observations lying between the turning points. Deploying energy-efficient and renewable energy technologies will ensure that higher HDI scores are ecologically sustainable for developing economies. Framing policies that encourage higher percentages of renewable energy in the current energy mix will help to reduce pollution and facilitate the decoupling of human development from non-renewable energy consumption such that their positive relationship does not recur.

Keywords: environmental degradation, Environmental Kuznets Curve, human development, fixed effect, random effect.

1. Introduction

In 1992, the Earth Summit, held in Rio de Janeiro, Brazil, highlighted how anthropogenic activities are responsible for climate change-related disasters and threaten the existence of humankind. Rapid industrialisation since the twentieth century has caused pollution through excessive emission of greenhouse gases (GHGs), e.g., carbon dioxide, chlorofluorocarbons, methane, nitrous oxide, and sulphur dioxide, leading to global warming and climate change. In 2015, the United Nations Climate Change Conference (COP21) in Paris reached a landmark agreement to limit the rise in atmospheric temperatures to 1.5 degrees Celsius. For this, emissions must be reduced by 45% by 2030 and reach net zero emissions by 2050 (Intergovernmental Panel on Climate Change, 2018). In 2020, the top seven emitters contributing to approximately half of the GHG emissions were China, the USA, India, the European Union, Indonesia, the Russian Federation, and Brazil (United Nations Environment Programme, 2022). The developed nations have effectively transitioned towards renewable energy and energy-efficient practices. So, the onus to improve economic performance with environmental concerns lies with the developing economies. The direct correlation between energy consumption and human development indicators like income, health, and education (Ouedraogo, 2013) challenges the development strategy of the fossil-fuel-dependent developing economies. The emerging economies of Asia, excluding China, are responsible for an increase in emissions by 4.2% in 2022, which is higher than the emerging economies from any other region (International Energy Agency, 2022). Broadly, this study attempts to assess the impact of human development on pollution in the emerging economies of Asia.

Kuznets Theory (1955) has hypothesised that with increased income inequality in an economy, per capita income rises until a certain threshold level. Thereafter, income inequality contracts with further growth in per capita income, giving rise to an inverted U-shaped curve known as the Kuznets Curve. In other words, fuelling economic growth at all costs will alleviate income inequality. In the same vein, Grossman and Krueger (1991) made a definitive study that environmental pollution and income also share a non-linear relationship, which gives rise to an N-Shaped Curve. The study stated that the N-shaped pattern between pollution and income could be because of a recovery effect after the energy crisis of the 1970s or the outcome of a simple statistical result to adjust the cubic form of the model. Subsequently, many studies established an inverted U-shaped association between economic growth and environmental pollution (Cabanero, 2023; Weimin et al., 2022; Apergis & Ozturk, 2015; Bilgili et al., 2016; Holtz-Eakin & Selden, 1995; Sarkodie & Ozturk, 2020; Shafik & Bandyopadhyay, 1992). Panayotou (1993) flagged this inverted U-shaped curve as the Environmental Kuznets Curve (EKC) due to its analogy to Kuznets Curve. Acceptance of the inverted U-shaped EKC as an inevitable empirical reality suggests that pursuing economic growth will reduce the unfavourable impact on the environment in the long run. So, environmental deterioration is only a temporary phenomenon correlated with the early stages of development, i.e., until reaching the turning point. Nevertheless, ecological thresholds might be transgressed irreversibly before the turning point arrives (Panayotou, 1993). Therefore, the idea of improving environmental quality after achieving the turning point is a deceptive one. Several research explorations also concluded the presence of an N-shaped EKC, which highlights that after the second turning point, environmental degradation recurs at higher levels of economic growth (Allard et al., 2018; Gyamfi, 2021; Shaheen et al., 2022; Shehzad et al., 2022). In other words, low pollution levels cannot sustain high economic growth after a certain point. However, the last stretch after the second turning point could be simply a statistical result because of the absolute extreme in the data range reflecting high-income levels (Grossman & Krueger, 1995; Neumayer, 1998; Shafik, 1994; Torras & Boyce, 1998). Several studies also hinted at an inverted N-shaped EKC (Abbasi et al., 2023; Musolesi et al., 2010; Yaduma et al., 2015).

The EKC literature considers Gross Domestic Product (GDP) per capita as the most desirable indicator of economic growth. However, GDP records only the monetary valuation of an economy's aggregate output and does not capture social or human dimensions of development (Anand & Sen, 1994; Kelley, 1991; Kubiszewski et al., 2013). On the other hand, the Human Development Index (HDI), conceived by Pakistani economist Mahbub-ul-Haq and promoted by the United Nations Development Program (1990), gauges development not only with the help of income but also in terms of social capital like education and health. HDI is the geometric mean of three different normalised indices, i.e., health, as measured by life expectancy (LE) at birth; education, as measured by expected years of schooling (EYS) and mean years of Schooling (MYS); and standard of living as measured by Gross National Income (GNI) per capita. It is the most objective measure of social progress and development. This study works on the suggestions of Puzon (2012) and Jha (2003) to assess the EKC model with the help of HDI instead of GDP per capita. Replacing GDP per capita with HDI in the EKC model will help to investigate the impact of human development on the environment rather than accounting for the impact of income alone.

Very few studies have engaged HDI as an alternative to GDP per capita for evaluating the EKC model (Beyene, 2023; Hanif et al., 2020; Hussain & Dey, 2021). Hill and Magnani (2002) observed that although HDI includes an income-based index, EKC results are much different for HDI than for GDP. The EKC established by Beyene (2023) recommended that developing economies from Africa need to improve HDI with the help of low-carbon and eco-friendly technologies to have better environmental performance. Hanif et al. (2020) proved the presence of inverted-U-shaped EKC for non-renewable energy consumption and HDI but U-shaped EKC for renewable energy consumption and HDI in both OECD and non-OECD emerging countries. Similarly, Hussain and Dey (2021) established an inverted-U shaped EKC between HDI and carbon emissions for developed, developing, and emerging countries. However, studies have rarely used the cubic specification of HDI to explore the shape of EKC via carbon emissions. A cubic specification (N or inverted N shape) verifies the consistency of a quadratic specification (U or inverted U shape) in the long run. This study analyses the EKC model by replacing the cubic specification of GDP per capita with the cubic specification of HDI. The study's main contribution is to identify whether the quadratic specification of EKC holds strength in the long run when human development replaces GDP per capita. The study uses macroeconomic aspects of economic development like energy consumption, international trade, foreign investment, and urbanisation to address the omitted variable bias.

The rationale for studying emerging Asian economies is their impressive boost in economic performance and consistent rise in human development levels recorded in the 21st century. Asia is a significant emitter of GHGs, primarily due to its large population, rapid industrialisation, and high consumption of fossilised energy sources. Two of the most populous countries, i.e., India and China, are heavily reliant on coal for energy production and are the largest emitter of carbon dioxide from Asia (Crippa et al., 2021). The current energy mix of the Asian emerging economies has higher percentages of non-renewable energy (International Energy Agency, 2021). However, China and India have also been investing heavily in the renewable energy industry and taking steps to transition to a low-carbon economy.

The paper is structured as follows: Section 2 explains the theoretical background of EKC, Section 3 is a brief literature survey exploring the cubic and quadratic specifications of EKC, Section 4 discusses the variables and data selected for the empirical analysis, Section 5 explains the model and methodology adopted, Section 6 discusses the results obtained, and Section 7 concludes with policy recommendations.

2. Theoretical Framework of EKC

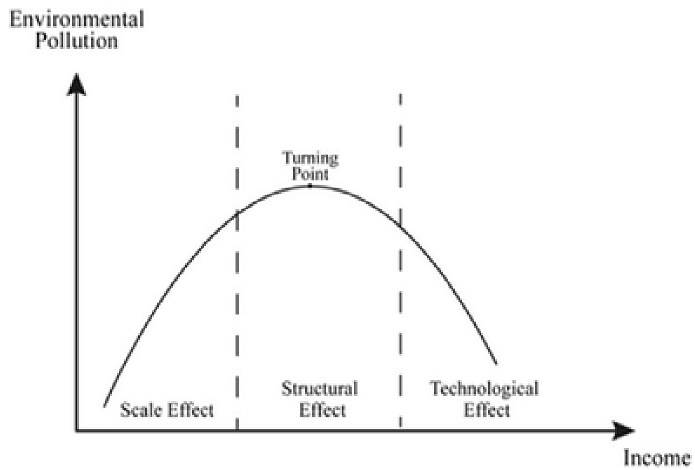
The theoretical underpinnings of the traditional inverted U-shaped EKC involve various reasons like an economy's supply and demand side factors, the market mechanism of natural resources, and macroeconomic determinants like international trade and flow of capital.

Scale effect, structural effect, and technological effect are the supply-side mechanisms influencing the inverted U-shaped association between economic growth and environmental damage (Grossman & Krueger, 1991; 1995). In the initial stages of development, the scale effect causes an increase in production and output, which in turn depends on natural resources and leads to environmental degradation. However, the strength and measure of environmental degradation is only restricted to extracting natural resources for subsistence economic activity. As a result of the structural or composition effect, the economy's structure changes from being primarily agricultural to industrial. Then, the economy prospers extensively, rapid industrialisation takes off, and the depletion rate of environmental capital exceeds nature's capacity for resource regeneration. Deterioration of natural capital continues until the threshold level is achieved, after which industries shift towards energy-efficient and cleaner technologies (Dinda, 2001). As the structural effect continues, economic prosperity positively affects the environment. With further economic progress, the technological effect leads to the predominance of knowledge-intensive industries rather than energy-intensive heavy industries. Investment in research and development activities brings efficient production processes and pollution-abating methods to the fore, prompting a gradual decline in pollution levels. De Bruyn et al. (1998) suggest that structural and technological changes have reduced emissions in industrialised nations such as the Netherlands, UK, USA, and Germany.

According to demand-side analysis, the shape of EKC is determined by the income elasticity of demand for environmental quality (Beckerman, 1992; Carson et al., 1997; McConnell, 1997). In the nascent stages of economic growth, the primary concern of people is to increase incomes, which raises demand for natural resources and causes environmental degradation. As income level elevates, the standard of living improves with a substantial need for better environmental quality. Moreover, high-income economies have governments with better institutional capacity to implement policies to check pollution and protect natural resources. Better education levels and environmental awareness facilitate the effective implementation of environmental regulations and pollution-abating technologies (Antle & Heidebrink, 1995; Hill & Magnani, 2002). The enhancement from poor to improved ecological standards is possible owing to the increased income elasticity of demand for environmental quality.

The market mechanism of natural resources also affects the shape of the EKC (Unruh & Moomaw, 1998). In the initial stages of an economy, natural resources are exploited to expand agriculture and the industrial sector. Given that the stock of natural resources is constant, economic progress results in higher demand for natural resources, which in turn raises their price level. In the later stages of economic growth, this price rise increases production costs and discourages manufacturers from consuming more natural resources. The shift towards resource-efficient or minimal resource-consuming mechanisms ultimately enhances the environmental quality (Duflou et al., 2012). Hence, the market for natural resources determines the inverted U-shape of EKC.

Figure 1. Inverted *u-s*haped Environmental Kuznets Curve



Source: Dinda, 2004

International trade and capital flight also govern the shape of EKC because industrialised nations take advantage of lenient environmental regulations in developing economies and import energy-intensive commodities from them (Stern et al., 1996; Suri & Chapman, 1998).

Outsourcing energy-intensive products contribute to the descending portion of EKC in high-income nations. Nevertheless, some studies implicate that the impact of trade policy orientation on EKC is environmentally conducive to low-income countries. Therefore, the argument of pollution-intensive activities being migrated to poorer countries is not strong (Jaffe et al., 1995; Lucas et al., 1992; Shafik & Bandopadhyay, 1992; Tobey, 1990).

3. A Brief Survey of Literature

Following the seminal work of Grossman and Krueger (1991), several studies have investigated the existence and shape of EKC for different countries and panels using various methodologies. Shahbaz and Sinha (2019) conducted an extensive literature survey of studies exploring CO2-induced EKC. Although CO2 emission is the most popular indicator of environmental degradation in the EKC literature, various other measures of environmental pressure such as deforestation, sulphur dioxide, methane, nitrous oxide, energy consumption, and ecological footprint have also been engaged in evaluating the shape of EKC (Al-Mulali et al., 2015; Cole, 2004; Cropper & Griffiths, 1994; Destek & Sinha, 2020; Hanif et al., 2020; Koop & Tole, 1999). However, the empirical results vary regarding the existence and shape of EKC and, consequently, their turning points. The outcome variation is attributed to the difference in model specification, methodologies used, the period for which the study is conducted, choice of sample, and explanatory variables. A varied range of explanatory variables has been used in EKC literature in a context specific to the research investigation. Some of these variables are foreign direct investment (Zhang et al., 2017; Pal & Mitra, 2017), crude oil prices (Balaguer & Cantavella, 2016), public budget in energy research (Álvarez-Herránz et al., 2017), population growth (Begum et al., 2015; Akpan & Abang, 2015), globalisation (Shahbaz et al., 2017), financial development (Dogan & Turkekul, 2016; Moghadam & Dehbashi, 2018), government effectiveness (Osabuohien et al., 2014), urbanisation (Farhani & Ozturk, 2015), economic liberalisation (Tiwari et al., 2013), fossil fuel energy consumption (Zoundi, 2017), renewable energy consumption (Zambrano-Monserrate et al., 2016; Gill et al., 2018), trade openness (Jebli et al., 2016; Li et al., 2016), democracy index (Mills & Waite, 2009), and institutional quality (Tamazian & Rao, 2010). Therefore, for any given context, results support either the presence or absence of the EKC hypothesis. The lack of agreement about the shape of EKC with different methodologies, study period, and panel are presented in Table 1.

Numerous studies have confirmed the existence of the traditional inverted U-shaped EKC (Al-Mulali & Ozturk, 2016; Cabanero, 2023; Jobert et al., 2012; Puzon, 2012; Weimin et al., 2022). This reflects that the economy is on the path of ecological sustainability and is switching from non-renewable energy sources to energy-efficient and environment-friendly ones. Some studies that invalidated the presence of EKC found a U-shaped relationship between measures of economic progress and environmental deterioration (Chakravarty & Mandal, 2016; Destek & Sinha, 2020; Dogan et al., 2017; Jebli et al., 2015; Zoundi, 2017). Such a relationship shows that an economy’s growth initially has a positive impact on the environment but damages it in the long run. An inverted-U-shaped or U-shaped EKC is obtained when the model has a quadratic specification of the economic growth variable.

Table 1. Literature review of EKC studies for economic growth and pollution

Study	Sample Countries and Study Period	Methodology	Shape of EKC
Bisset (2023)	41 Sub-Saharan African Countries (1996–2018)	3 Stage Simultaneous Equation Modelling	N
Cabanero (2023)	6 ASEAN States (1986–2018)	PMG and DFE	Inverted U
Shaheen et al. (2022)	High-income Countries (1976–2019)	ARDL	N
Weimin et al. (2022)	9 Globalised Countries (1990–2019)	FMOLS and DOLS	Inverted U
Pradhan et al. (2021)	BRICS Countries (1992–2014)	FMOLS and DOLS	Inverted N
Gyamfi (2021)	7 Emerging Countries (1995–2018)	PMG - ARDL	N
Awan and Azam (2021)	Five most influenced countries of G-20 (1993–2017)	DK Standard Errors for panel data estimation	N
Destek and Sinha (2020)	24 OECD Countries (1980–2014)	FMOLS and DOLS	U
Allard et al. (2018)	74 Countries	Quantile Regression	N
Alvarez-Herranz et al. (2017)	28 OECD (1990–2014)	Panel Regression with PCSE	N
Özokcu and Özdemir (2017)	26 OECD Countries and 52 Emerging Countries (1980–2010)	DK Standard Errors for FE and Robust Standard Errors for RE	Inverted N and N
Zoundi (2017)	25 African Countries (1980–2012)	System GMM	U
Zhang et al. (2017)	10 Newly Industrialised Countries (1971–2013)	OLS, FMOLS, DOLS	Inverted U
Sinha et al. (2017)	N11 Countries (1990–2014)	System GMM	N
Chakravarty and Mandal (2016)	BRICS (1997–2011)	GMM	U
Lorente and Álvarez-Herranz (2016)	17 OECD Countries (1990–2012)	Fixed Effects, Panel EGLS (Cross-Section Weights), 2SLS	N
Moutinho and Robaina (2016)	20 European Countries (1992–2010)	FMOLS and DOLS	Inverted U
Dogan and Seker (2016)	European Union (1980–2012)	DOLS	U
Akpan and Abang (2015)	47 Countries (1970–2008)	GLS	N

Alvarez-Herranz and Balsalobre-Lorente (2015)	28 OECD (1993–2010)	Fixed Effect and Panel EGLS (cross-section weights)	N
Apergis and Ozturk (2015)	14 Asian Countries (1990–2011)	GMM	Inverted U
Balsalobre et al. (2015)	28 OECD (1994–2010)	Fixed Effect and Generalised Least Square estimation	N
Dogan et al. (2017)	27 OECD Countries (1995–2010)	DOLS	U
Heidari et al. (2015)	5 ASEAN Countries (1980–2008)	Panel Smooth Transition Regression	Inverted U
Jebli et al. (2015)	24 Sub-Saharan African Countries (1980–2010)	OLS and FMOLS	U
Yaduma et al. (2015)	154 Countries (1960–2007)	Quantile Regression	Inverted N
Bölük and Mert (2014)	16 European Union Countries (1990–2008)	DK Standard Errors for FE	U
Lopez-Menendez et al. (2014)	27 European Countries (1996–2010)	Fixed Effect and Random Effect	N
Puzon (2012)	8 East Asian Countries (1980–2000)	Panel Data Regression Technique	Inverted U
Musolesi et al. (2010)	109 Countries (1959–2001)	Bayesian estimation	Inverted N
Halkos and Tzeremes (2009)	17 OECD Countries (1980–2002)	Fixed Effect and Random Effect	U
Lee et al. (2009)	89 Countries (1960–2000)	GMM	Inverted U and N
Markandya et al. (2006)	12 Western European Countries (1850–2001)	Fixed Effect and Random Effect	Inverted U
Vollebergh and Dijkgraaf (2005)	24 OECD (1960–1997)	Panel Regression	Inverted N
Vollebergh et al. (2005)	24 OECD (1960–2000)	Panel Regression (Parametric and Semi-Parametric)	Inverted N
Moomaw and Unruh (1997)	16 countries (1950–1992)	Fixed Effects and Cross-Sectional OLS	N

Note: 2SLS - Two Stage Least Square, DK - Driscoll Kraay, DOLS - Dynamic Ordinary Least Square, EGLS - Estimated Generalised Least Square, FE - Fixed Effect, FMOLS - Fully Modified Ordinary Least Square, GLS - Generalised Least Square, GMM - Generalised Method of Moments, OLS - Ordinary Least Square, PCSE - Panel Corrected Standard Errors, RE - Random Effect.

However, many studies have attempted to explore an extended version of the conventional EKC model where a cubic term of economic growth or development is included. The results implicate either an N-shaped EKC or an inverted N-shaped EKC. N-shaped EKC ideates that the reduction in environmental degradation is not definitive because very high levels of economic growth are ecologically unsustainable after a certain point (Bisset, 2023; Shaheen et al., 2022; Gyamfi, 2021; Lee et al., 2009). As income increases, the negative relationship between economic development and ecological damage becomes positive due to the weakening of technological effect (De Bruyn et al., 1998; Lazar et al., 2019; Torras & Boyce, 1998). Some studies have also interpreted that an N-shaped EKC arises when technology becomes expensive or the potential for its improvement is exhausted and economic growth results in net environmental degradation (Alvarez-Herranz et al., 2017; Balsalobre et al., 2015). Choi et al. (2010) highlight that environment-friendly technologies cannot help the environment for long, so it worsens again. Conversely, an inverted N-shaped EKC reflects that high economic growth is ecologically sustainable because the positive relationship between environmental damage and economic growth becomes negative after a certain point (Musolesi et al., 2010; Özokcu & Özdemir, 2017; Pradhan et al., 2022; Yaduma et al., 2015).

Few studies have explored EKC by using HDI as a replacement for GDP or income per capita. Beyene (2023) found a U-shaped curve for Environmental Performance Index and HDI for 38 African nations using SUR, 2SLS, 3SLS, and MVREG techniques. The results indicate that HDI improves with better environmental performance. Hussain and Dey (2021) used Panel Regression Models to conclude an inverted U-shaped EKC for developed, developing, and emerging economies by engaging HDI as the independent variable from 1990 to 2016. The results are implicative of the idea that HDI discourages environmental degradation. After reaching the threshold level, when the value of HDI improves, better education, consciousness for health, and increased income elasticity of demand for environmental quality reduce pollution. As structural effect dies out, the onset of knowledge-intensive technological effect brings energy efficient and renewable energy technologies to the forefront. Renewable energy consumption negates pollution (Sarkodie & Ozturk, 2020) and improves human development (Azam et al., 2023). Ouedraogo (2013) found a direct relationship between energy consumption and HDI for 15 developing countries from 1988 to 2008. This means improving each component of HDI involves a rise in emissions. As per capita income increases, there is access to better basic amenities, medical facilities, and education affordability (Youssef et al., 2015).

In one of the earliest studies involving HDI and pollution, Hill and Magnani (2002) studied a panel of 156 countries and found an N-shaped EKC for CO2 and NOx but an inverted N-shaped EKC for SO2. Jha and Murthy (2003) also confirmed the presence of an inverted N-shaped relationship between environmental pollution and HDI in 174 countries. They highlighted that environmental degradation is sensitive to levels of human development because a positive correlation exists between environmental degradation and HDI for high HDI countries, a negative correlation for low HDI countries, and a weak yet negative correlation for medium HDI countries. It is vital to explore whether the technological innovation that leads to low pollution levels in a quadratic specification of EKC is consistent enough at high levels of human development via a cubic specification.

Costantini and Monni (2008) employed genuine saving (GS) as a sustainability indicator instead of environmental degradation and HDI as the measure of progress in a generalised least square model specification of EKC. The results reflect an inverted N-shaped relationship between both variables and confirm that negative GS values are associated with low and medium values of HDI. On the other hand, Constantini and Martini (2006) found an N-shaped relationship for adjusted GS, which includes only depletion of natural capital, and modified form of HDI, which excludes the income component. Farhani et al. (2014) confirmed the presence of an inverted-U-shaped EKC using GS and HDI for MENA countries from 1990 to 2010 by deploying panel FMOLS and DOLS estimation methods. However, Chen et al. (2010) established a significant U-shaped relationship between ecological footprint per person and HDI, thereby refuting the presence of an EKC for 136 countries from 1996 to 2005. Hence, the shape of HDI-induced EKC is inconclusive due to differences in, the specification of variables, period of study, or choice of country or panel. However, hardly any study has used the cubic specification of HDI to explore the shape of EKC for emerging economies of Asia. The contribution of this study is to bridge that research gap.

4. Variables and Data

The panel for the study consists of 10 emerging Asian countries selected from upper middle income (UMI) and lower middle income (LMI) groups according to the classification of the United Nations Department of Economic and Social Affairs (2021). The countries from UMI are Malaysia, China, Indonesia, and Thailand, whereas Bangladesh, India, Pakistan, Philippines, Sri Lanka, and Vietnam are from LMI. Emerging economies experience rapid economic growth and development, often characterised by increasing industrialisation, urbanisation, and technological advancements (Allard et al., 2018). They are generally from the middle-income range as they have achieved a certain level of economic development but are still transitioning from low-income to high-income status. It is important to note that while these middle-income countries have made significant progress, they still face challenges such as income inequality, poverty reduction, and sustainable development. The period of the study is from 1990 to 2018. Of the total cumulative net carbon emissions from 1850 to 1989, 58% occurred between 1850 and 1989, but 42% occurred between 1990 and 2018 only (Intergovernmental Panel on Climate Change, 2022). This fact motivates the selection of the period of the study. It is crucial to examine how the heightened levels of human development in these emerging Asian economies have affected pollution during this period.

The study uses carbon dioxide emissions per capita (CO2e) to represent environmental degradation. As the series is measured in metric tons per capita, it adjusts for the effect of population growth on pollution levels. CO2e neither accounts for carbon emissions from imported goods nor deducts the same from exported goods and, therefore, is a production-based dependent variable for the EKC model. The study also uses methane emissions (CH4) as a proxy for environmental degradation (Adeel-Farooq et al., 2020). CH4 is measured annually as thousand metric tons of CO2 equivalent. Carbon dioxide and methane are identified as the GHGs with the highest contribution to global warming and climate change. More than half of carbon emissions are from the industry sector, which relies heavily on coal, and it has higher carbon intensity than oil or gas, whereas methane emissions are primarily associated with oil and gas production (BP Energy Outlook, 2023). Carbon dioxide is responsible for a majority of long-term climate change because of its high emissions and long atmospheric lifetime of hundreds of years. The Climate Pledge is a commitment to reach net zero carbon by 2040. However, methane, with only 12 years of atmospheric lifetime, causes 28 times more heat than carbon dioxide, resulting in a stronger influence on warming (International Energy Agency, 2023). The Global Methane Pledge, launched at COP26 in November 2021, is an initiative to catalyse action for reducing methane emissions. Therefore, using both carbon and methane emissions to evaluate EKC for the emerging Asian economies will help us understand the impact of the major GHGs.

Non-renewable energy consumption (NREC), trade openness (TROP), foreign direct investment (FDI), and urbanisation (URB) are used in the study as explanatory variables. The definition and sources of all the variables are listed in Table 2. NREC is measured in exajoules and is the sum of consumption from all non-renewable energy sources, namely coal, oil, natural gas, and nuclear. In an EKC model, energy consumption from fossilised sources explains the pollution from its combustion (Hussain et al., 2012; Moghadam & Dehbashi, 2018; Onafowora & Owoye, 2014; Shahbaz et al., 2017; Sinha et al., 2017). Asia's energy dependence on coal has exponentially increased in the last two decades (International Energy Agency, 2021). This led to increased carbon emissions from the region and justifies the inclusion of NREC in this model.

Table 2. Definition and source of variables

Variables and Abbreviations	**Unit of Measurement**	**Description**	**Source**
Carbon dioxide emissions per capita (CO2e)	Metric tons per capita	CO2 emissions produced due to burning of fossil fuels, consumption of solid, liquid, and gas fuels and gas flaring.	World Development Indicators
Foreign Direct Investment (FDI)	Net inflows (new investment inflows less disinvestment) calculated as a percent of GDP	Sum of equity capital, reinvestment of earnings, other long-term capital, and short-term capital from foreign investors.	World Development Indicators
Human Development Index (HDI)	Index measured on a scale of 0 to 1	Geometric mean of Life Expectancy Index, Education Index, and Income Index; each index is defined within a range of maximum and minimum values.	United Nations Human Development Report (2019)
Methane (CH4)	Thousand metric tons of CO2 equivalent	CH4 emissions from the production, handling, transmission, and combustion of fossil fuels and biofuels.	World Development Indicators
Non-Renewable Energy Consumption (NREC)	In Exajoules	Sum of consumption of oil, coal, gas, and nuclear in exajoules.	British Petroleum Statistical Review
Trade Openness (TROP)	Calculated as percent of GDP	Sum of exports and imports of goods and services measured as a share of GDP.	World Development Indicators
Urbanisation (URB)	Calculated as a percent of total population	Population of the nation living in urban areas.	World Development Indicators

TROP is the sum of exports and imports of goods and services measured as a share of GDP, and it is used to assess the impact of trade on environmental pollution. Empirical studies in the recent past have pursued the EKC model by including trade openness to deal with omitted variables (Dogan & Seker, 2016; Halicioglu, 2009; Jebli et al., 2016). The rationale for including Trade Openness is that the quantity of exports and imports of energy-intensive products have increased drastically in Asian countries in the 21st century (WDI, 2021).

URB measures the population of an economy living in urban areas and calculates it as a percentage of the total population. Urbanisation pressurises limited environmental resources because people relocate to urban areas for basic amenities and better facilities (Farhani & Ozturk, 2015; Martínez-Zarzoso & Maruotti, 2011). The trend of urbanisation in middle-income Asian economies has witnessed an exponential increase in the last three decades (World Bank, 2019). Therefore, it is crucial to analyse the impact of urbanisation on environmental pollution for the panel in question.

The net inflow of FDI used in the analysis is calculated as a share of GDP in percentage. The logic for including FDI in the EKC model is that the prevalence of lenient environmental regulations in developing countries attracts foreign investments for pollution-intensive industries (Cole & Elliott, 2005; Fredriksson & Svensson, 2003; Hassaballa, 2014). Stringent environmental laws in developed economies increase the cost of production and lead to the outflow of investment to the capital-scarce economies (Pradhan & Hiremath, 2020).

5. Model and Methodology

The EKC model with a cubic term of GDP per capita or income has been popularly used to determine whether the conventional inverted U-shaped EKC is sustainable in the long run (Lazar et al., 2019; Dinda, 2004; Yang et al., 2015; Dogan & Seker, 2016). The cubic form of the EKC model can be written as follows:

$$Y_{it} = \alpha_{it} + \beta_1 X_{it} + \beta_2 {X_{it}}^2 + \beta_3 {X_{it}}^3 + \beta_4 Z_{it} + U_{it} \quad (1)$$

In Eq. (1), Y is a representation of environmental degradation. X represents economic growth in the form of income or GDP per capita, Z represents other control variables, U_{it} is the conventional error term, i symbolises groups of the panel, and t is time. The signs of coefficients of

$\beta_1, \beta_2,$ and β_3 determine the shape of the EKC. Table 3 explains how the shape of EKC changes as the sign of $\beta_1, \beta_2,$ and β_3 varies, and Figure 2 shows how each case gives rise to an EKC of a different shape.

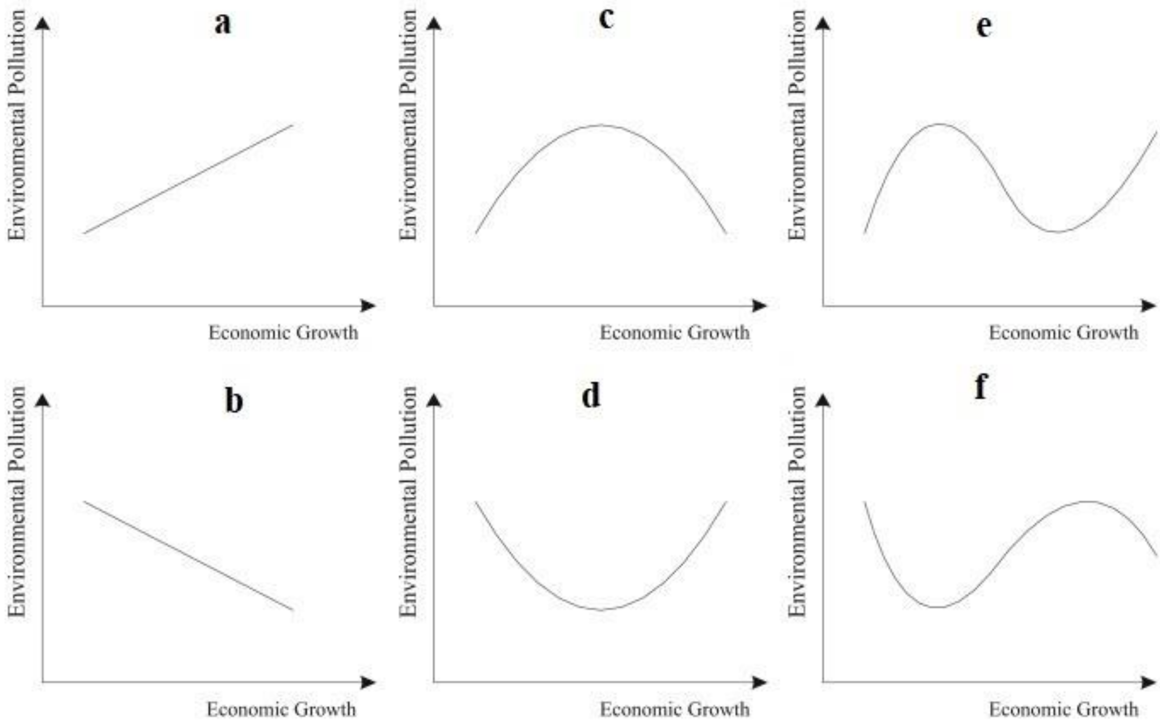
A monotonically increasing curve implies that the environment worsens as income rises, but a monotonically decreasing curve implies that the environment improves with increased income. The inverted U-shaped EKC reveals that pollution increases with a rise in income until the turning point, and the pollution level reduces with a further increase in income. U-shaped EKC is the mirror image of an inverted-U-shaped EKC, where environmental pollution and economic growth have a negative relationship until the turning point; after that, their relationship has a positive association. The case of an N-shaped curve signifies that the inverted U relationship extends to a second turning point, after which the positive association between environmental degradation and economic growth is renewed. An inverted N-shaped graph is the reverse of an N-shaped curve, where the environmental quality improves with increased income after reaching the second turning point.

Table 3. Coefficient specification for different shapes of EKC

a- Monotonically Increasing	b- Monotonically Decreasing	c- Inverted-U Shaped	d- U Shaped	e- N Shaped	f- Inverted N Shaped
$\beta_1 > 0$	$\beta_1 < 0$	$\beta_1 > 0$	$\beta_1 < 0$	$\beta_1 > 0$	$\beta_1 < 0$
$\beta_2 = \beta_3 = 0$	$\beta_2 = \beta_3 = 0$	$\beta_2 < 0$	$\beta_2 > 0$	$\beta_2 < 0$	$\beta_2 > 0$
		$\beta_3 = 0$	$\beta_3 = 0$	$\beta_3 > 0$	$\beta_3 < 0$

Source: Lopez-Menendez et al., 2014

Figure 2. Different shapes of EKC



Note: Adapted from Dinda (2004).

The models used to investigate the shape of EKC for the selected middle-income Asian economies are as follows:

$$CO2e = \beta_0 + \beta_1 HDI + \beta_2 HDI^2 + \beta_3 HDI^3 + \beta_4 NREC + \beta_5 TROP + \beta_6 FDI + \beta_7 URB + u_{it} \quad (2)$$

$$CH4 = \alpha_0 + \alpha_1 HDI + \alpha_2 HDI^2 + \alpha_3 HDI^3 + \alpha_4 NREC + \alpha_5 TROP + \alpha_6 FDI + \alpha_7 URB + \varepsilon_{it} \quad (3)$$

The study attempts to assess Model 1, i.e., Eq. (2), and Model 2, i.e., Eq. (3), with the help of fixed effect (FE) and random effect (RE) regression techniques. The definitions and abbreviations of the variables involved in both models are listed in Table 3. The choice between pooled OLS and RE is made by the Breusch-Pagan Lagrange Multiplier (LM) test, whereas the Hausman test is used to decide between FE and RE models. However, panel estimation through the RE and FE models is not free from cross-sectional dependence, serial correlation, and heteroskedasticity. Pesaran's cross-sectional dependence test checks the correlation of residuals across panels (Torres-Reyna, 2007).

Modified Wald and likelihood ratio tests are used to detect heteroskedasticity in FE and RE models, respectively (Özokcu & Özdemir, 2017). The Woolridge test is used to check autocorrelation in both models (Park, 2011). Driscoll–Kraay standard errors are the natural extension of the Newey–West standard errors (Driscoll & Kraay, 1998), and they outperform common standard errors in the presence of cross-sectional dependence, autocorrelation, and heteroskedasticity for FE estimation (Bölük & Mert, 2014; Garmann, 2014; Hoechle, 2007). Therefore, Driscoll–Kraay standard errors are used for the FE model. Robust standard errors are used for the RE model to account for cross-sectional dependence, serial correlation, and heteroskedasticity (Özokcu & Özdemir, 2017).

A cubic model of EKC has two turnaround points (X_1 and X_2), which are calculated by the authors using Eq. (4) and Eq. (5) for Model 1 (Shahbaz & Sinha, 2019; Lopez-Menendez et al., 2014).

$$X_1 = \frac{-\beta_2 - \sqrt{\beta_2^2 - 3\beta_1\beta_3}}{3\beta_3} \qquad (4)$$

$$X_2 = \frac{-\beta_2 + \sqrt{\beta_2^2 - 3\beta_1\beta_3}}{3\beta_3} \qquad (5)$$

Similarly, the two turnaround points for Model 2 are also calculated using slope coefficients of Eq. (3).

6. Results and Discussion

Table 4 shows the descriptive statistics of all the variables in the study. The maximum and minimum values of CH4, NREC, TROP, and URB reflect a wide range. On the other hand, CO2e, FDI, and HDI have a smaller range. Standard deviation reveals that CH4, NREC, TROP, and URB have a larger variation than CO2e, FDI, and HDI. Table 5 shows the unit root tests for all the variables. The unit root tests used are Levin, Lin, and Chu (LLC) (2002) and Im, Pesaran, and Shin (IPS) (2003). All the variables are stationary in their first order difference (FOD) values for both unit root tests.

Table 4. Descriptive statistics of the variables

Variable	Mean	Standard Deviation	Minimum	Maximum	Skewness	Kurtosis
CO2e	1.953	1.973	0.102	7.757	1.565	4.461
FDI	2.325	2.068	-2.757	11.939	1.368	5.552
HDI	0.615	0.101	0.394	0.805	-0.261	2.176
CH4	64531.59	142799.8	1460	746030	3.394	14.372
NREC	10.132	22.904	0.055	121.035	3.395	14.274
TROP	74.605	49.438	15.506	220.407	1.178	3.461
URB	37.002	13.703	18.196	76.036	0.777	3.168

Table 5. Results of unit root test

Variable	LLC-level	IPS-level	LLC-FOD	IPS-FOD
CO2e	3.140 (0.999)	5.231 (1.000)	-3.40415 (0.000)	-5.492 (0.000)
FDI	-2.689 (0.004)	-4.292 (0.000)	-9.650 (0.000)	-10.383 (0.000)
HDI	-3.053 (0.001)	1.362 (0.914)	-4.469 (0.000)	-5.330 (0.000)
CH4	-5.132 (0.000)	-1.523 (0.064)	-6.768 (0.000)	-3.902 (0.000)
NREC	4.267 (1.000)	8.245 (1.000)	-2.438 (0.008)	-4.963 (0.000)
TROP	-0.204 (0.419)	0.742 (0.771)	-7.076 (0.000)	-7.565 (0.000)
URB	-3.306 (0.000)	-0.386 (0.350)	-4.043 (0.000)	-1.670 (0.000)

Note: Values in the parenthesis are p-values. Source: Author's Calculation

The results of the study are summarised in Table 6. The decision for model selection went against pooled OLS when the null hypothesis of the Bruesch Pagan LM test for RE was rejected (Chi-square = 993.89, p-value = 0.000). However, the Hausman Test showed that FE is appropriate for Model 1. The cubic FE model clearly illustrates that $\beta_1 > 0$, $\beta_2 < 0$, and

$\beta_3 > 0$. This is indicative of an N-shaped relationship between HDI and CO2e. The F-statistic is significant, and an R-square value of 89% demonstrates that the model is a good fit. NREC, TROP, and URB have a significantly positive impact on CO2 emissions. However, the effect of FDI is insignificant. The diagnostic tests detect the presence of serial correlation, heteroskedasticity, and cross-sectional dependence. So, the FE model is re-assessed with Driscoll-Kraay standard errors. The N-shape of Model 1 is retained. Moreover, NREC, TROP, and URB continue to have a significantly positive impact, while the effect of FDI remains insignificant. This is implicative of the robustness of the results. The F-statistic is also statistically significant, and the R-square value increases to 91%. Hence, the fitted model is relevant and well-explained.

Similarly, for Model 2, the decision for model selection went against pooled OLS when the null hypothesis of the Bruesch Pagan LM test for RE was rejected. The Chi-square test statistic of the Hausman Test found a score of 10.46 with a p-value of 0.063, and the RE model was selected as appropriate. The cubic RE model shows that $\beta_1 > 0$, $\beta_2 < 0$, and $\beta_3 > 0$. This means that the cubic RE model agrees with the cubic FE model, and the N-shaped association between HDI and pollution is sustained for CH4 induced EKC model. The F-test statistic is significant, and the R-square value of 98% demonstrates that Model 2 is well explained. The impact of NREC and TROP on CH4 is positive and statistically significant. The effect of URB and FDI is statistically insignificant for Model 2. Diagnostic tests detect the presence of serial correlation, heteroskedasticity, and cross-sectional dependence in the RE model; therefore, Model 2 is re-assessed with robust standard errors. The N-shape is re-affirmed, and the explanatory variables sustain their effect even with robust standard errors for RE. The F-test statistic remains statistically significant, and the R-square value is retained at 98%.

Table 6. FE and RE results

	Model 1		Model 2	
Coefficients	FE	DK-FE	RE	Robust RE
HDI	105.665 (0.000)	105.665 (0.000)	4418826 (0.000)	4418826 (0.010)
HDI^2	-205.023 (0.000)	-205.023 (0.000)	-8044399 (0.000)	-8044399 (0.010)
HDI^3	127.765 (0.000)	127.765 (0.000)	4642546 (0.000)	4642546 (0.011)
NREC	0.037 (0.000)	0.037 (0.000)	5970.114 (0.000)	5970.114 (0.000)
TROP	0.007 (0.000)	0.007 (0.000)	193.2 (0.000)	193.2 (0.061)
FDI	-0.011 (0.395)	-0.011 (0.533)	-1049.903 (0.104)	-1049.903 (0.183)
URB	0.067 (0.000)	0.067 (0.000)	-259.000 (0.291)	-259.000 (0.579)
Constant	-18.888 (0.000)	-18.888 (0.000)	-757282.3 (0.000)	-757282.3 (0.012)
Relationship	N	N	N	N
F stat	431.36 (0.000)	3012.25 (0.000)	6367.99 (0.000)	15199.37 (0.000)
R Square	0.8936	0.9171	0.9800	0.9800
Adjusted R-sq	0.8022	0.8839	0.9022	0.9346

Note: Values in the parentheses are P-values. Source: Author's Calculation

The main finding of the study is that an N-shaped relationship exists between human development and pollution levels in the selected middle-income Asian economies from 1990 to 2018. The positive relationship between HDI and pollution becomes negative after the first turnaround point and continues until the second turning point. However, the relationship again becomes positive after the second turning point. So, as HDI improves, environmental degradation reduces and then rises. Few studies have established a similar N-shaped relationship between environmental degradation and human development (Costantini & Martini, 2010; Hill & Magnani, 2002). On the contrary, Jha and Murty (2003) spotted the presence of an inverted N-shaped EKC for the Environmental Degradation Index and HDI. The result also contrasts studies that have established an inverted U-shaped EKC for HDI and environmental degradation (Hanif et al., 2019; Hussain & Dey, 2021). Environmental degradation does not die out after achieving better levels of HDI; rather, it recurs after a certain point. Nevertheless, hardly any recent study has concluded an N-shaped association between HDI and pollution in emerging Asian economies from the middle-income group. Improving human development components in these countries primarily depends upon fossilised energy sources. The region between the first and the second turning point is characterised by increasing technological returns from environment-friendly technologies. After the second turning point, the lack of consistency in technological innovation causes decreasing technological returns, forcing the economies back into a state of environmental destruction (Alvarez-Herranz & Balsalobre-Lorente, 2015). The validity of the N-shaped EKC can be checked by the fulfilment of the following two conditions (Sinha et al., 2019):

1 – First Order Necessary Condition: β_1 and β_3 must be greater than zero, whereas β_2 must be less than zero in the case of Model 1. Similarly, for Model 2, α_1 and α_3 must be greater than zero, whereas α_2 must be less than zero.

2 – Second Order Sufficient Condition: For Model 1, $\beta_2^2 - 3\beta_1\beta_3 > 0$, and for Model 2, $\alpha_2^2 - 3\alpha_1\alpha_3 > 0$.

The results satisfy both conditions and reaffirm the existence of N-shaped EKC for the investigated dataset.

The calculated turning points for both models are presented in Table 7, and the diagrammatic occurrence of turning points in an N-shaped curve is illustrated in Figure 3. As a post-estimation strategy, the study observes that for Model 1, 4.48% of the observations occur before the first turning point, and 49.31% of the observations lie between the first and second turning point, whereas 46.20%[1] of the observations are after the second turning point. Similarly, for Model 2, it is observed that 7.59% of the observations occur before the first turning point, 71.37% of the observations lie between the first and the second turning point, and 21.03%[2] of the observations are after the second turning point. For both models, a significant number of observations lie after the second turning point, which ensures that the last stretch of the N-shaped curve is not driven by only a few high HDI scores towards the end of the distribution. Studies have established that the last region after the second turning point in an N-shaped curve is simply a statistical result to adjust the polynomial curve and occurs because of a few extreme values at the end of the distribution (Grossman & Krueger, 1995; Neumayer, 1998; Shafik, 1994; Torras & Boyce, 1998). This study is one of the few to identify the percentage of observations distributed across the N-shaped curve and does not merely state the shape of the polynomial curve with the help of signs of the coefficients.

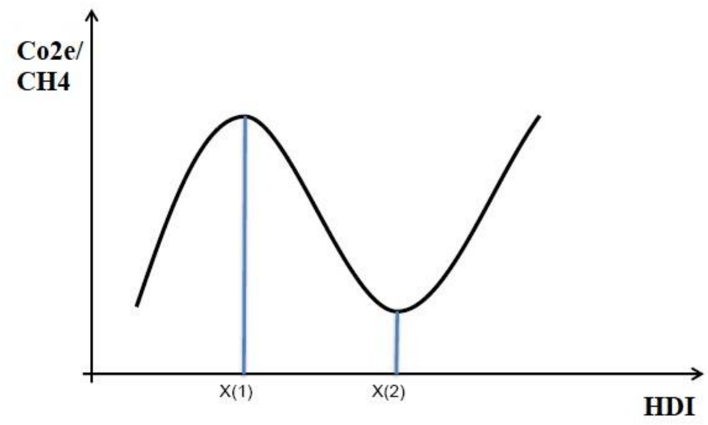
[1] 46.20% of the observations after the second turning point are found for the following countries: China, India, Indonesia, Malaysia, Philippines, Sri Lanka, Thailand, and Vietnam.
[2] 21.03% of the observations after the second turning point are found for the following countries: China, Indonesia, Malaysia, Philippines, Sri Lanka, and Thailand.

Table 7. Calculation of turning points

	Model 1		Model 2	
Turning Points	FE	DK-FE	RE	Robust RE
X1	0.433	0.433	0.450	0.450
X2	0.637	0.637	0.704	0.704

Source: Author's Calculation

Figure 3. Occurrence of turning points in an N-shaped graph



Source: Alvarez-Herranz and Balsalobre-Lorente (2015)

The first turning point for Model 1 is 0.433, whereas X_2 or the second turning point is 0.637. The turning points for Model 2 are 0.450 and 0.704, respectively. This means that CO2e starts declining only after the HDI score is approximately 0.433 and again increases after the second turning of 0.637 is attained. Similarly, CH4 decline occurs between the HDI threshold values of 0.450 and 0.704. Enhancing human development levels between the two turning points may be interpreted as environment-friendly and ecologically sustainable. If HDI > 0.637 for Model 1 and HDI > 0.704 for Model 2, there will be deterioration of the environment with a rise in the emission of pollutants. Nevertheless, complete decoupling of the process of economic growth and development from carbon emissions is possible by switching from non-renewable to renewable energy (Jacobson & Deluchhi, 2011). This will undoubtedly help to improve HDI without aggravating pollution levels.

The direct relationship between energy consumption and HDI (Ouedraogo, 2013) implies that improving the components of HDI involves non-renewable energy, which explains the rise in CO2/CH4 emissions until the first turning point. The growing per capita income ensures better access to medication and education affordability, leading to an increased per capita energy consumption (Youssef et al., 2015). After the first turning point, the standard of living improves, and the income elasticity of demand for environmental quality increases. Better education and health also improve environmental consciousness. The increasing returns from innovation in renewable energy technologies prove effective and cause pollution to decline, improving health outcomes by increasing life expectancy (Polcyn et al., 2023). Renewable energy consumption enhances human development (Azam et al., 2023, Wang et al., 2020). However, with the arrival of the second turning point, the positive relationship between HDI and pollution recurs. Improved health outcomes encourage population expansion and productivity of the labour force, which further increases per capita energy consumption (Youssef et al., 2015). However, the lack of continuous improvement in renewable energy technology and energy efficiency causes decreasing technological returns (Alvarez-Herranz & Balsalobre-Lorente, 2015). So, the increase in per capita energy consumption leads to an increase in consumption from non-renewable sources. Therefore, after the second turning point, decreasing technological returns lead to the recurrence of scale effect and environmental degradation (Awan & Azam, 2021), even though the levels of human development are high. Similarly, another study estimated that developing countries from Africa with higher HDI and higher GDP per capita have a lower share of renewable energy in the national grid (Ergun et al., 2019). Targeting high HDI without decoupling the components from non-renewable energy sources is ecologically unsustainable for emerging Asian economies. Investing in R&D of cleaner technologies will continuously increase technological returns and ensure efficiency in the long run. The study also confirms the inference that HDI and pollution are positively correlated on a linear curve (Hickel, 2020). Further, the study demonstrates that the positive correlation between pollution and income is stronger than for life expectancy and education (Annexure).

As expected, the impact of TROP is significantly positive for the levels of pollution (Li et al., 2016; Munir & Ameer, 2018). Allard et al. (2018) showed that trade positively impacts environmental degradation for middle-income countries in the presence of an N-shaped EKC for economic growth and environmental degradation. Globalisation and trade liberalisation attract investors to developing countries with lax environmental regulations whose energy consumption relies heavily on non-renewable energy sources (Pradhan et al., 2022; Guzel & Okumus, 2020). On the contrary, some studies argue that trade openness improves environmental quality by encouraging innovations and stringent environmental policies to bring industry standards at par with developed nations (Frankel, 2009; Sobrinho, 2005). URB also has a significantly positive impact on environmental deterioration in an EKC model (Al-Mulali & Ozturk, 2016; Dogan & Turkekul, 2016; Sultana et al., 2021). This is in accordance with the conventional argument that urbanisation creates pressure on environmental resources due to the rise in population and per capita energy consumption in the well-facilitated urban zones. However, urbanisation also leads to improved educational standards, expansion of the service sector, and, therefore, large-scale implementation of green technology (Wan & Kahn, 2014). NREC also affects pollution in a significantly positive manner (Rahman & Velayutham, 2019; Kais & Sami, 2016; Li et al., 2016). Hardly any study has argued that consumption from non-renewable energy sources does not lead to pollution.

The results of this study should be perceived as an addition to the existing empirical research despite invalidating the presence of conventional EKC in the long run. The contribution of this study is two-fold. Firstly, it is a rare study to establish an N-shaped relationship between HDI and pollution in emerging Asian economies. Secondly, very few studies have estimated how the observations are distributed across the cubic relationship as a post-estimation analysis to validate that the last stretch of the curve is not the statistical result of a few high-end observations. However, increased human development, non-renewable energy consumption, trade openness, and urbanisation cannot be the only variables thoroughly explaining environmental degradation. It is a complex issue and can also be affected by qualitative factors, e.g., institutional capacity and environmental regulation.

7. Conclusion and Policy Recommendation

The theory of the Environmental Kuznets Curve has been repeatedly investigated in various contexts to understand the impact of economic growth on pollution. Several studies challenged the conventional inverted U-shaped EKC by demonstrating U-shaped EKC or the non-existence of EKC. Research explorations have also analysed the EKC model in a cubic framework to conclude the existence of an N-shaped or inverted N-shaped EKC. The cubic framework of EKC checks whether the parabolic trend of the quadratic model is sustainable enough in the long run at high levels of development. Very little EKC literature has explored the relationship between human development and environmental degradation in a cubic framework considering human development as a better indicator than economic growth. Human Development Index (HDI) is an internationally accepted objective measure of human development that includes income, education, and health. The United Nations Development Program records it annually for all the countries based on life expectancy at birth, expected years of schooling, mean years of schooling, and gross national income per capita. The direct correlation between non-renewable energy consumption and human development indicators leads to increased levels of pollution in developing economies.

This study analyses EKC for HDI instead of GDP per capita in the cubic framework for ten emerging Asian economies selected from the middle-income group from 1990 to 2018. The indicators of environmental degradation used are carbon dioxide emissions and methane emissions, which have the highest contribution as pollutants to climate change and global warming. The methodological framework for the CO2-induced EKC model is fixed effects regression with Driscoll–Kraay Standard Errors. On the other hand, random effects regression with robust standard errors is applied for the CH4-induced EKC model. Both models reveal the presence of an N-shaped curve. This implies that as the human development score improves, environmental degradation decreases after the first turning point and then increases after the second.

After the first turning point, pollution reduction is due to the environment-friendly technologies involving renewable energy sources. Improved income, health, and education create awareness for better environmental quality. However, the lack of continuous technological innovation causes increasing technological returns to cease in the long run.

After the second turning point, decreasing technological returns surface and scale effect recurs to bring back the phenomena of rising environmental destruction. Improving the HDI score involves enhancing each component of HDI, i.e., education, health, and income, which increases per capita energy consumption. Lack of investment for continuous technological innovation in renewable energy technologies causes increased energy consumption from non-renewable energy sources in these largely fossil-fuel-dependent economies. The results imply that the emerging Asian economies from middle-income group must target human development levels between the first and second turning points to stay ecologically sustainable. However, the economies need to target levels of human development beyond the second turning point and remain environmentally sustainable at the same time. Higher investment in research and development will improve the resilience and reliability of renewable energy technologies. Continuous technological innovation will ensure increasing technological returns that are not outweighed by decreasing technological returns. Therefore, deploying energy-efficient and renewable energy technologies will ensure that pursuing higher HDI is ecologically sustainable for developing economies.

Framing policies that encourage higher percentages of renewable energy in the current energy mix and disincentivise non-renewable sources will help to reduce pollution. COP21 discusses strategies to increase climate financing and outsourcing financial resources from developed to developing countries to achieve net zero emissions. Mobilising financial resources to support renewable energy infrastructure in developing countries will also improve the efficiency of energy consumption. Such policy measures will enhance the process of decoupling non-renewable energy consumption from economic and human development. Moreover, reframing HDI such that it internalises the pollution caused by economic activities involving income, health, and education will help assess human development within ecologically sustainable standards. It is a rare study to establish an N-shaped relationship between HDI and pollution for emerging Asian economies and validate the observations' distribution across the cubic relationship as a post-estimation analysis. The study also found that macroeconomic determinants like non-renewable energy consumption, trade openness, and urbanisation substantially contribute to environmental degradation in the selected countries.

Addressing environmental degradation via pollution requires a comprehensive and coordinated approach. This includes promoting renewable energy, improving energy efficiency, enhancing public transportation, implementing carbon pricing mechanisms, and adopting sustainable agricultural practices. Although many countries in the region recognise the importance of transitioning to low-carbon economies, the implementation of pollution reduction strategies and disincentivising non-renewable energy sources is not aggressive enough. Time-bound treaties at the international, national, and local levels must be designed to address climate change on an urgent note. Raising environmental awareness with the help of households, individuals, corporate firms, and non-governmental organisations are the micro-level initiatives that the government should make accountable to facilitate the decoupling of development and non-renewable energy consumption. The execution of policies meant to lower the release of pollutants should not wait until the threshold limit in the EKC is reached. It is of primary essence that the developing countries restructure their human development trends such that the potential EKC is flattened out and does not cause permanent ecological damage.

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Appendix

Figure 4. Correlation between CO2e and HDI

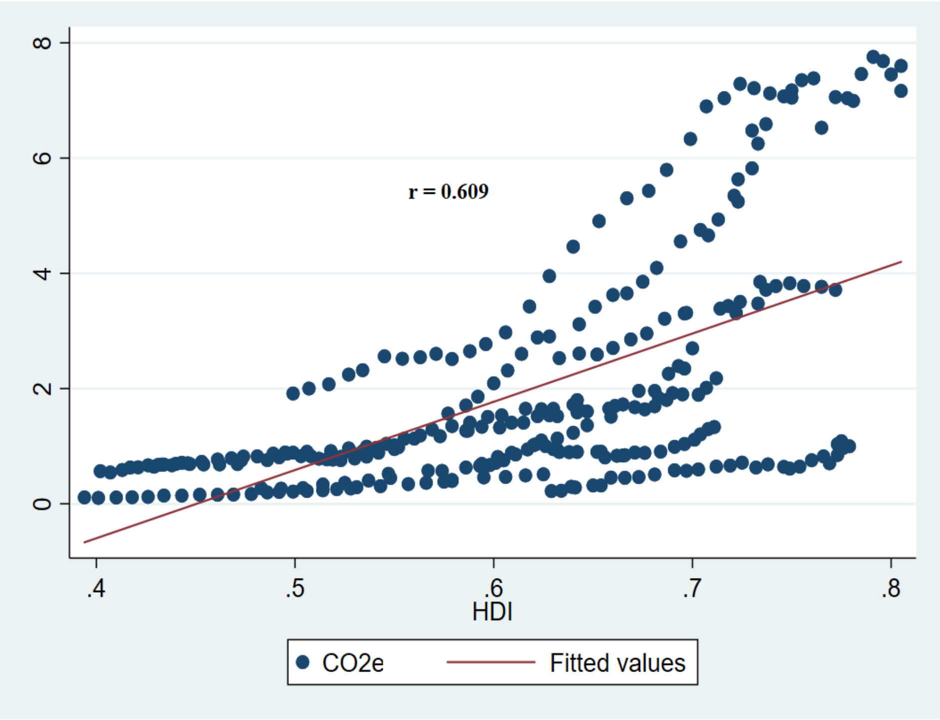

Figure 5. Correlation between Methane and HDI

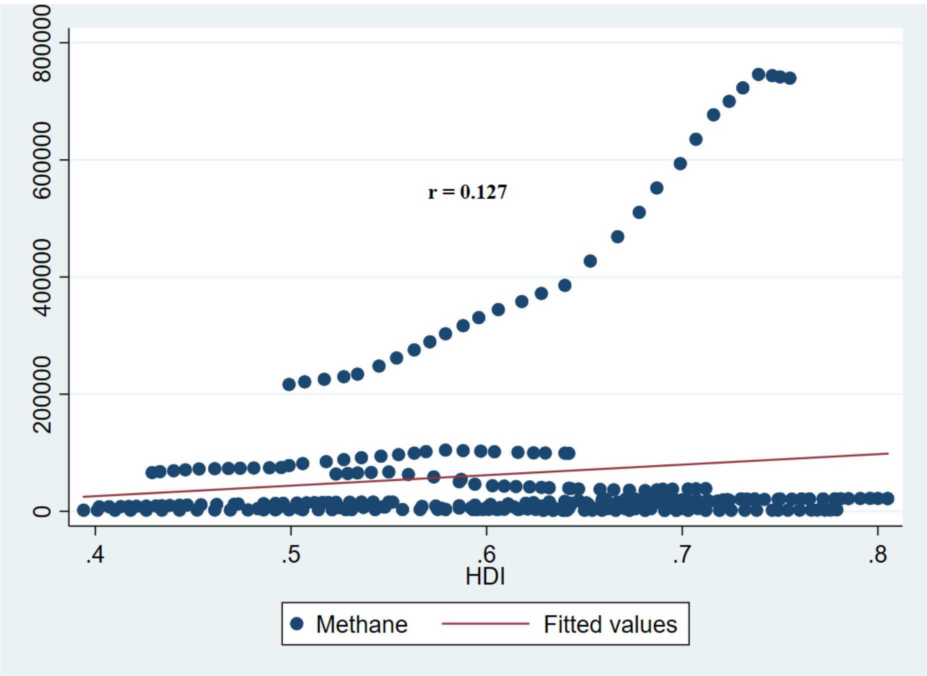

Figure 6. Correlation between CO2e and Gross National Income per capita

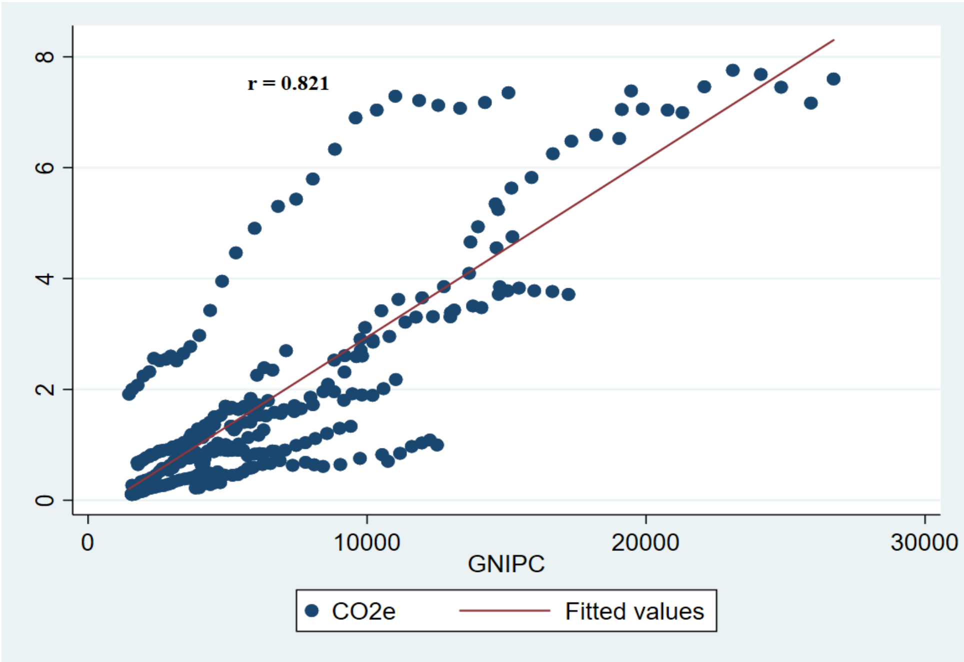

Figure 7. Correlation between Methane and Gross National Income per capita

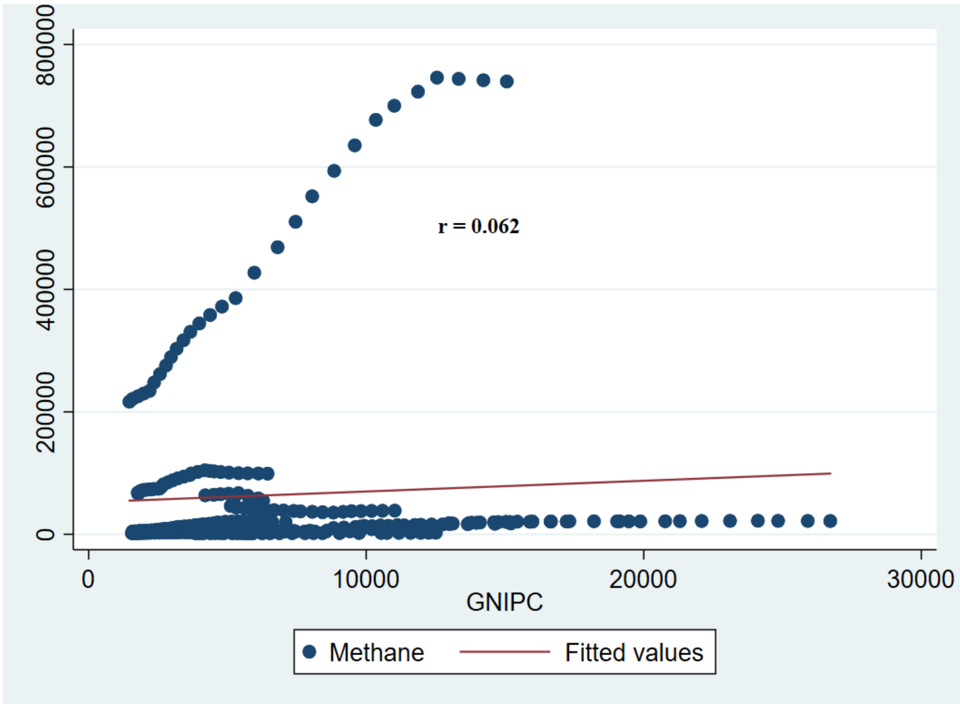

Figure 8. Correlation between CO2e and LE

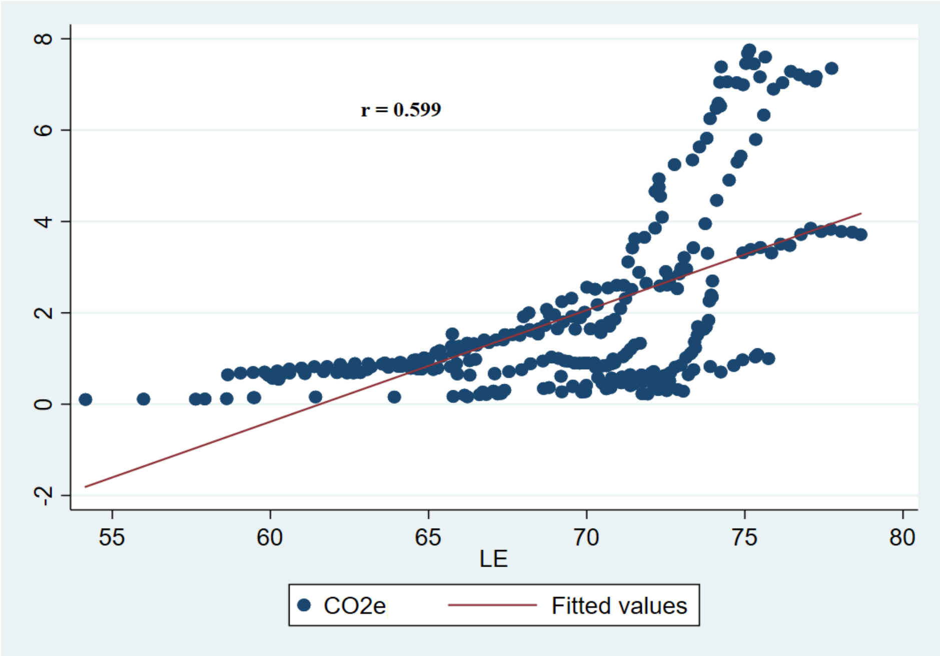

Figure 9. Correlation between Methane and LE

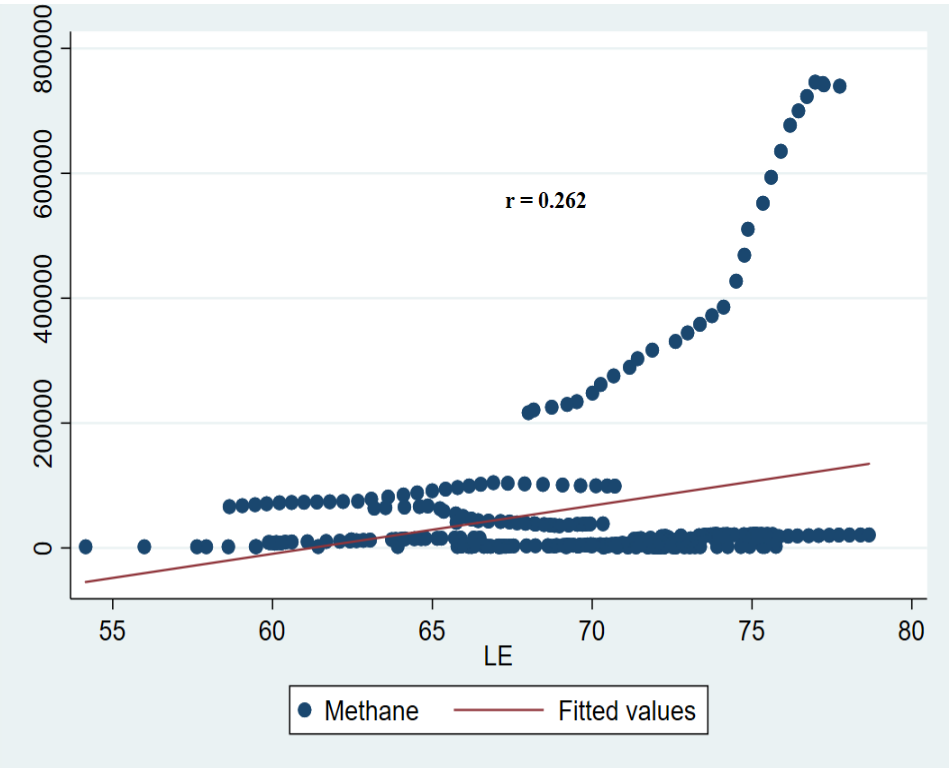

Figure 10. Correlation between CO2e and Expected Years of Schooling

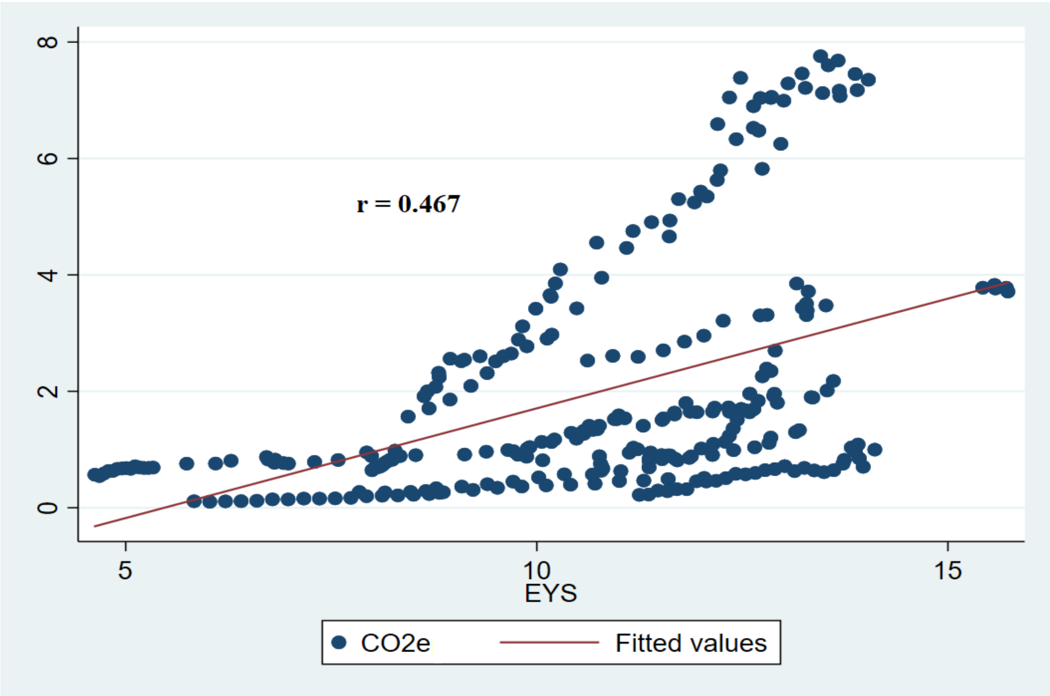

Figure 11. Correlation between Methane and Expected Years of Schooling

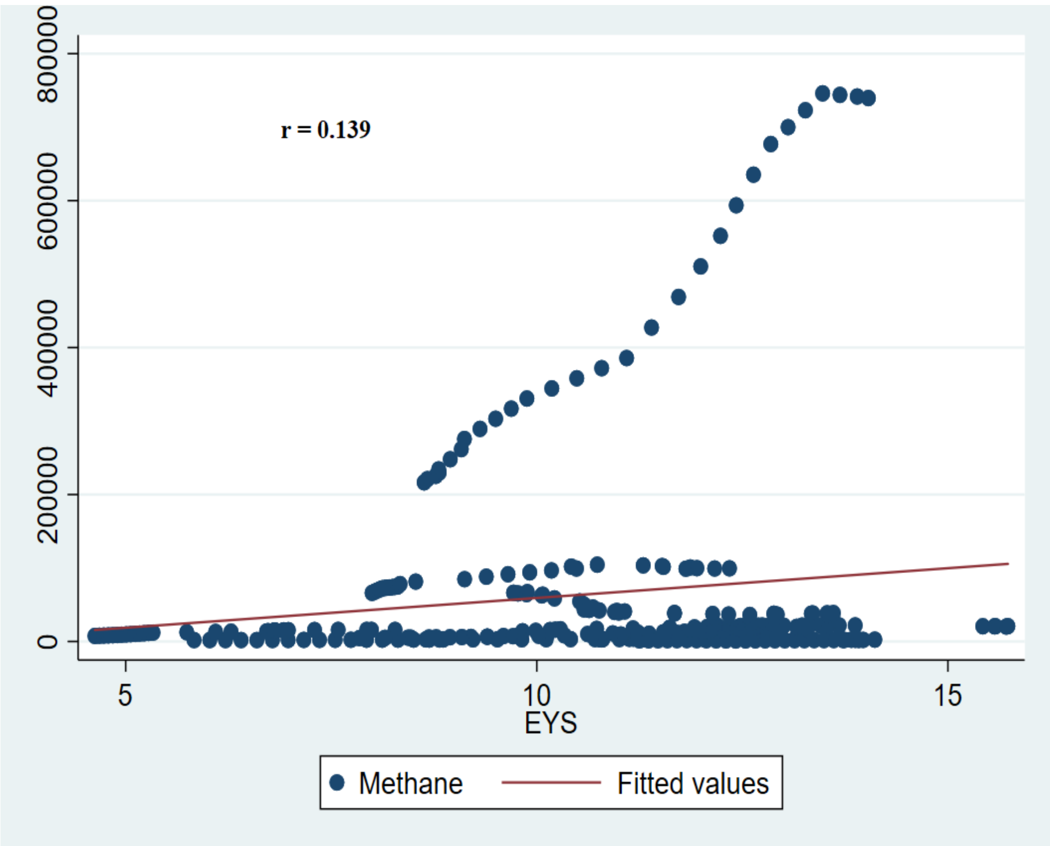

Figure 12. Correlation between CO2e and Mean Years of Schooling

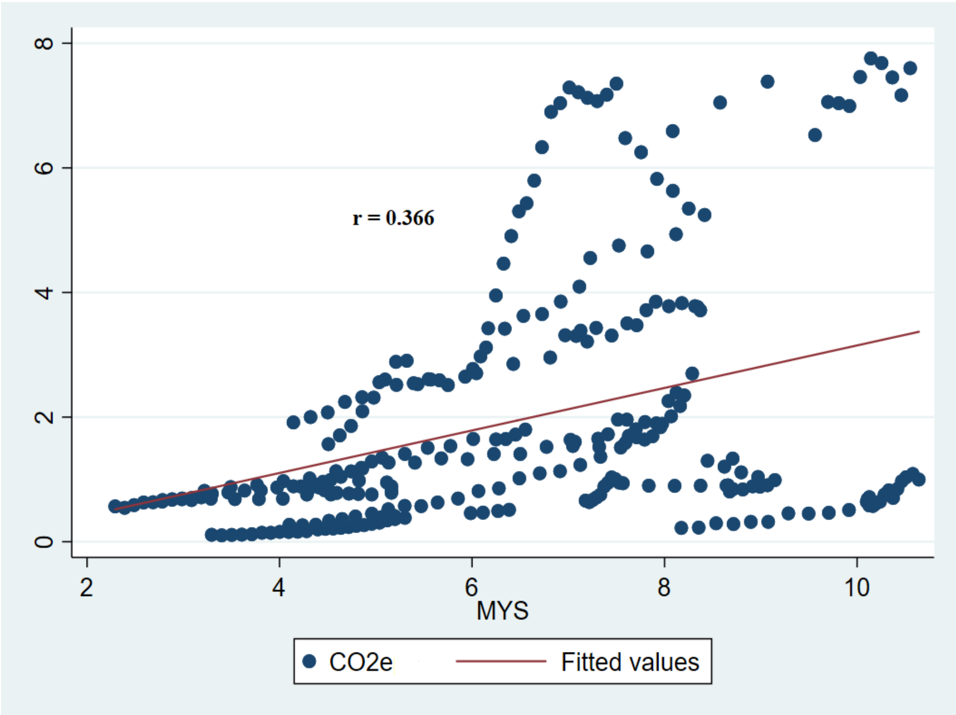

Figure 13. Correlation between Methane and Mean Years of Schooling