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A Dynamic Panel Analysis of Human Development and Environmental Sustainability in Indonesia

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Abstract

As decentralized emerging economies navigate the complex trade-offs between rapid industrialization and ecological preservation, understanding the nuanced drivers of environmental sustainability becomes critically imperative. This study investigates the dynamic interplay between human development and environmental quality across 34 Indonesian provinces from 2013 to 2020. Recognizing that regional ecological trajectories are highly path-dependent and that traditional static panel models frequently yield biased estimates, we employ a System Generalized Method of Moments (GMM) approach. This methodological framework rigorously addresses the inherent endogeneity and reverse causality between macroeconomic expansion and environmental outcomes. The model incorporates Foreign Direct Investment (FDI), physical capital, economic growth, and population as control variables, all of which exhibit negative coefficients, suggesting that current macroeconomic expansion and demographic pressures pose significant challenges to regional environmental quality. Despite these pressures, the research novelty reveals that human development dimensions particularly education and welfare—act as critical countervailing forces. Our findings confirm that while industrial and population scaling currently degrade the environment, qualitative improvements in human capital can catalyze a transition toward green growth. Policy implications suggest that Indonesia must shift from a 'grow first, clean up later' strategy toward selective FDI screening and 'green-weighted' development metrics to decouple economic progress from ecological decline.

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INTRODUCTION

Indonesia is among the countries with the poorest environmental quality worldwide. According to the Environmental Performance Index (EPI), Indonesia has consistently ranked below 100th place out of 180 countries in recent years (Wolf et al., 2022). Within the Association of Southeast Asian Nations (ASEAN), Indonesia ranks only above Vietnam and Myanmar, placing it among the three lowest-performing countries in the region. Furthermore, Indonesia is one of the world's largest contributors to greenhouse gas emissions (Eko Cahyono et al., 2022; Dunne, 2019).

Poor environmental quality has profound socioeconomic consequences, including reduced life expectancy, higher infant mortality (Majeed & Ozturk, 2020), lower labor productivity (Chung, 2020), and increased income inequality and poverty (Ehigiamusoe et al., 2022). Consequently, understanding the determinants of environmental quality has become increasingly important, particularly in supporting the achievement of the Sustainable Development Goals (SDGs), especially those related to climate action and environmental sustainability.

To monitor environmental conditions, Indonesia employs the Environmental Quality Index (EQI), which integrates concepts from the Environmental Performance Index (EPI) with national environmental indicators to evaluate environmental quality at both national and provincial levels (KLHK, 2020). The EQI is a composite index consisting of three primary dimensions: water quality, air quality, and land-cover quality. More broadly, environmental quality assessment considers multiple environmental domains, including air, water, land, the built environment, and sociodemographic conditions, to provide a comprehensive understanding of ecological conditions (EPA, 2020). The national EQI represents the aggregate environmental quality of all Indonesian provinces and serves as an important tool for environmental monitoring and policy formulation.

Water quality is evaluated using chemical, physical, and microbiological indicators. Chemical parameters include pH, dissolved oxygen, biochemical oxygen demand, nitrate, and phosphate concentrations, whereas physical indicators include turbidity and total suspended solids (TSS). Microbiological quality is assessed through coliform contamination, which reflects the extent of fecal pollution in water bodies. Air quality is primarily measured by particulate matter and gaseous pollutants such as carbon monoxide (CO), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2), with NO_2 and SO_2 serving as key indicators of pollution from transportation and industrial activities. Land-cover quality is also an essential component of environmental quality because changes in land use directly affect ecosystem sustainability. Therefore, periodic monitoring of land cover is necessary to support spatial planning while maintaining environmental sustainability.

One important factor influencing environmental quality is human development. Recent studies increasingly recognize human development as a more comprehensive measure of societal well-being than gross domestic product (GDP) per capita (van den Bergh & Botzen, 2018). Similarly, Tenaw and Beyene (2021) argue that the Human Development Index (HwDI) better captures improvements in welfare. As welfare increases, individuals generally seek better education, higher living standards, and healthier environmental conditions (Li & Xu, 2021). Health, as one of the three dimensions of the HDI, encourages greater demand for cleaner environments to improve quality of life and increase life expectancy. Likewise, rising income levels increase public awareness of environmental quality and strengthen demand for cleaner and healthier surroundings. Education, another key dimension of HDI, enhances environmental awareness by improving individuals' understanding of environmental conservation and sustainable resource management. Consequently, regions with higher levels of human development are generally expected to place greater emphasis on environmental protection.

Despite extensive research, the empirical literature examining the determinants of environmental quality remains fragmented. Broadly, previous studies can be classified into three strands: studies reporting positive environmental effects, studies reporting adverse effects, and studies reporting insignificant or mixed relationships. For example, Yao et al. (2020) in OECD countries, Balaguer and Cantavella (2018) in Australia, Chankrajang and Muttarak (2017) in Thailand, and Bano et al. (2018) in Pakistan reported that improvements in human capital or education reduce carbon emissions. Conversely, Sarkodie et al. (2020) found that increasing human capital may accelerate environmental degradation by stimulating greater economic activity and carbon emissions. However, these studies remain limited in scope. Similarly, Dedeoğlu et al. (2021) for the Americas and Williamson (2017) across 181 countries found no significant relationship between human development and environmental quality. In contrast, Sapkota and Bastola (2017) reported that the impact of human capital varies across income groups in Latin America.

As Nayak (2008) argues, human development cannot be adequately represented solely by human capital or educational attainment. Moreover, most previous studies examining human capital and environmental degradation rely exclusively on carbon emissions as the environmental indicator. Such an approach provides only a partial representation of environmental degradation because environmental sustainability encompasses multiple dimensions beyond greenhouse gas emissions (Opoku et al., 2022). Accordingly, this study examines the relationship between human development and environmental quality using a broader and more comprehensive environmental indicator.

Within the Indonesian context, previous studies have primarily relied on national-level data and focused on single environmental indicators, particularly carbon emissions (Sugiawan & Managi, 2016; Nikensari et al., 2019; Fajar & Hariyanto, 2021; Prasetyanto & Sari, 2021). However, environmental quality cannot be adequately represented by a single pollutant because it reflects the combined condition of multiple environmental components, including air, water, and land quality (Esty et al., 2005). Consequently, relying solely on carbon emissions may underestimate the complexity of regional environmental conditions.

Another important limitation concerns the econometric approach adopted in previous Indonesian studies. Most analyses investigating the relationship between human development and environmental quality have employed static panel models while paying limited attention to endogeneity issues, including reverse causality and unobserved heterogeneity (Bariesta & Asyiawati, 2016; Prawesti, 2021; Ramadhantie et al., 2021). Environmental quality evolves cumulatively over time, implying that those of previous periods inherently influence current environmental conditions. Consequently, dynamic panel models that incorporate lagged dependent variables are more appropriate for capturing these temporal dynamics. Conventional pooled ordinary least squares (OLS), fixed-effects, and random-effects estimators are likely to produce biased and inconsistent estimates when applied to dynamic panel data. Therefore, the System Generalized Method of Moments (System GMM) is employed because it effectively addresses endogeneity, heteroscedasticity, autocorrelation, and dynamic persistence simultaneously (Elhorst, 2014).

Despite the growing literature examining the nexus between human development and environmental quality, empirical evidence in Indonesia remains fragmented and inconclusive. This inconsistency largely reflects several methodological shortcomings. First, previous studies predominantly rely on unidimensional environmental indicators, particularly carbon emissions, which fail to capture the multidimensional nature of environmental quality. Second, existing regional analyses generally overlook the inherent endogeneity, reverse causality, and dynamic persistence associated with environmental and macroeconomic variables. Consequently, estimates derived from static econometric models are susceptible to bias and inconsistency.

Accordingly, the central research problem addressed in this study is the limited capacity of existing empirical approaches to provide robust evidence on the influence of human development on multidimensional environmental quality in a rapidly developing, decentralized economy. To address these limitations, this study employs a dynamic System GMM framework that explicitly accounts for endogeneity, reverse causality, and dynamic persistence. By moving beyond carbon emissions as the sole environmental indicator and adopting a comprehensive measure of environmental quality, this study contributes both methodologically and empirically to the literature on regional environmental sustainability in Indonesia. The findings provide a more robust empirical foundation for aligning regional human development policies with long-term environmental sustainability objectives.

Building upon this methodological framework, this study formulates three interconnected hypotheses. First, it hypothesizes that human development is a key driver of environmental sustainability, in which improvements in human development contribute to reducing environmental degradation. Second, it proposes that the individual dimensions of human development—education, health, and welfare—exert distinct and heterogeneous effects on environmental quality. Finally, considering Indonesia's substantial regional disparities, the study hypothesizes that the beneficial effect of human development on environmental quality remains significant across provinces. However, its magnitude differs between Java and the Outer Java regions.

RESEARCH METHODS

Panel data covering the period from 2013 to 2020 across 33 provinces in Indonesia were employed in this study. The 2013–2020 observation period was deliberately selected to ensure longitudinal consistency and uniform institutional measurement across provinces. By ending the analysis in 2020, this study intentionally avoids the substantial structural disruptions and nonlinear economic shocks associated with the post-pandemic recovery period. This approach enables the System Generalized Method of Moments (System GMM) model to capture stable long-term regional dynamics rather than temporary fluctuations, thereby enhancing the robustness of the estimated relationships and the reliability of the resulting policy implications.

Data on the Human Development Index (HDI), population, foreign direct investment (FDI), gross regional domestic product (GRDP) per capita, and gross fixed capital formation (GFCF) were obtained from Statistics Indonesia (BPS). Data on the Environmental Quality Index (EQI) were collected from the Ministry of Environment and Forestry (KLHK).

The dependent variable in this study is the Environmental Quality Index (EQI). Compared with single-pollutant indicators, such as carbon emissions, the EQI provides a more comprehensive measure of environmental quality because it incorporates multiple environmental dimensions, including water quality, air quality, and land-cover quality. Consequently, the EQI better captures the multidimensional nature of environmental conditions at the regional level.

The primary explanatory variable is the Human Development Index (HDI). The HDI is widely regarded as a more comprehensive measure of social welfare than income-based indicators alone because it reflects multiple dimensions of human well-being (Tenaw & Beyene, 2021). Specifically, the HDI consists of three dimensions: health, education, and standard of living, and is calculated as the geometric mean of these three components.

To isolate the effect of human development on environmental quality, this study controls for four variables: foreign direct investment (FDI), population, physical capital, and economic growth. Data for these variables were also obtained from Statistics Indonesia

(BPS). FDI is included because foreign investment may facilitate the transfer of advanced technologies and production processes that improve resource efficiency and potentially enhance environmental quality. However, in developing economies, FDI may also stimulate environmentally intensive production activities. Population is incorporated because demographic expansion has frequently been identified as a major driver of environmental degradation (Martínez-Zarzoso et al., 2007). An increase in population generally intensifies demand for natural resources, energy, and land use, thereby increasing environmental pressure. Conversely, if population growth is accompanied by improvements in environmental awareness and resource efficiency, its environmental impact may be mitigated.

The remaining control variables are physical capital and economic growth. Physical capital is measured by gross fixed capital formation (GFCF) as a percentage of gross regional domestic product (GRDP). At the same time, the annual growth rate of GRDP per capita represents economic growth. Economic growth may adversely affect environmental quality when expansion is driven primarily by increased production and resource exploitation without corresponding improvements in environmental efficiency. Under such conditions, greater industrial activity generates higher levels of pollution and environmental degradation (Opoku et al., 2021).

The selection of variables and their expected relationships are theoretically grounded in the Environmental Kuznets Curve (EKC), Endogenous Growth Theory, and the Pollution Haven Hypothesis. These theoretical perspectives suggest a fundamental structural trade-off during the development process of emerging regional economies. On one hand, rapid economic expansion and demographic growth generate substantial environmental pressures. According to the EKC scale effect, increases in production and capital accumulation initially intensify resource extraction, energy consumption, and pollution. Likewise, capital accumulation may reinforce resource-intensive industrialization during the early stages of development, while population growth further intensifies environmental pressure by increasing demand for land, energy, and natural resources.

Foreign direct investment may further intensify these environmental pressures. Consistent with the Pollution Haven Hypothesis, multinational firms may relocate environmentally intensive production to developing regions with less stringent environmental regulations. Consequently, FDI may contribute to regional environmental degradation despite its potential to transfer technology and managerial expertise.

Conversely, the three dimensions of human development are expected to function as critical counterbalancing mechanisms that gradually shift regional economies toward a more sustainable development path. According to Environmental Literacy Theory, improvements in educational attainment enhance environmental awareness, strengthen pro-environmental behavior, and accelerate the adoption of cleaner technologies. The income and composition effects of the Environmental Kuznets Curve complement this educational effect. As household welfare and purchasing power improve, societies increasingly shift from resource-intensive consumption toward cleaner production technologies and environmentally sustainable consumption patterns while simultaneously demanding stronger environmental regulations.

Furthermore, improvements in health and life expectancy contribute to environmental sustainability through the Long-Term Utility Hypothesis. Individuals with better health and longer life expectancy tend to place greater value on environmental quality because they expect to benefit from long-term environmental improvements. Nevertheless, the environmental benefits associated with improved public health may emerge only gradually and therefore may require a longer period before becoming empirically observable.

Taken together, these theoretical perspectives suggest although macroeconomic expansion and demographic growth continue to impose substantial environmental pressures, investments in human development provide an essential foundation for long-term environmental sustainability. Accordingly, this study expects human development to mitigate environmental degradation. In contrast, economic growth, physical capital accumulation, population growth, and environmentally intensive foreign investment are expected to exert downward pressure on environmental quality.

Table 1. Research variables and sources

Variable	Description	Source	Unit	Expected Sign	Theoretical Justification	References
EQI	The quality index ranges from 1 to 100; the higher the index value, the better the quality.	Ministry of Environment and Forestry	Index			Maulida (2021)
HDI	The quality index ranges from 1 to 100; the higher the index value, the better the quality.	Statistics Indonesia (BPS)	Index	+	Environmental Literacy Theory; Long-Term Utility Hypothesis; EKC (Income/Composition Effect)	Opoku et al. (2022)
Foreign Direct Investment (FDI)	Investment by foreigners	Statistics Indonesia (BPS)	Million US$	-	Pollution Haven Hypothesis	Opoku et al. (2022)
Population	Total population in a region	Statistics Indonesia (BPS)	Million people	-	Anthropogenic Pressure	Opoku et al. (2022)
Physical Capital	Percentage of Gross Fixed Capital Formation to GDP	Statistics Indonesia (BPS)	Percentage	-	Capital-Resource Complementarity	Malik (2021)
Growth economy	The growth rate of GDP per capita	Statistics Indonesia (BPS)	Percentage	-	EKC (Scale Effect)	Kais & Sami (2016)

The analysis of the relationship between human development and environmental quality may be subject to endogeneity problems. The first potential issue is dynamic endogeneity. Several previous studies have employed fixed-effects or random-effects models to estimate this relationship. However, these estimation methods are susceptible to problems such as heteroscedasticity and endogeneity arising from the correlation between explanatory variables and the error term (Roodman, 2009), thereby limiting their ability to accurately estimate the relationship between human development and environmental quality. Halkos (2003) also argues that these methods are prone to model misspecification and estimation bias. Moreover, fixed-effects and random-effects models generate static estimates, whereas most socioeconomic variables, including environmental quality, exhibit dynamic behavior (Opoku et al., 2022). In other words, environmental quality in the current period is likely to be influenced by its level in previous periods. Conventional estimation methods, such as Pooled Least Squares (PLS) and fixed-effects models, cannot adequately capture this dynamic process. When a lagged dependent variable is included in these models, the resulting estimates become inconsistent and biased (Wooldridge, 2012). Therefore, a dynamic panel data approach is more appropriate for this study.

A second potential issue is reverse causality between human development and environmental quality, which may lead to simultaneity bias. Another concern is unobserved heterogeneity, arising from omitted variables that influence both human development and environmental quality but are not explicitly included in the model. The Generalized Method of Moments (GMM) framework is well-suited to address these sources of endogeneity, including unobserved heterogeneity, simultaneity, and dynamic endogeneity (Wintoki et al., 2012). Therefore, this study adopts a GMM-based estimation approach.

The dynamic panel GMM estimator was originally developed by Arellano and Bond (1991) and later extended by Blundell and Bond (1998) to model causal relationships that evolve over time. This estimation technique incorporates the lagged dependent variable, $EQI_{i,t-1}$, as an explanatory variable. The lagged dependent variable serves as an internal instrument to control for endogeneity (Roodman, 2006).

The GMM approach addresses endogeneity by internally transforming the data. Specifically, the transformation removes unobserved individual effects by expressing variables in terms of their changes over time rather than their original levels (Roodman, 2006). Although this transformation improves estimation efficiency, it also reduces the number of usable observations (Wooldridge, 2012). Two principal GMM estimators are commonly employed: Difference GMM and System GMM. However, the first-difference transformation used in Difference GMM may result in substantial information loss, particularly when the panel is relatively short (Roodman, 2009). To mitigate this limitation, Arellano and Bover (1995) introduced an extended framework that improves estimation efficiency through additional moment conditions, which later formed the basis of the System GMM estimator.

Although Difference GMM is generally efficient, Blundell and Bond (1998) demonstrated that System GMM provides more efficient and reliable estimates, particularly when the time dimension (T) is relatively small. System GMM combines two sets of moment conditions—those based on first-difference and level equations—thereby improving estimation efficiency and reducing the weak-instrument problem commonly associated with Difference GMM. Accordingly, this study employs the System GMM estimator.

To ensure the structural validity and statistical consistency of the dynamic panel estimates, a series of diagnostic tests specifically designed for the GMM framework was conducted. First, the validity of the internal instruments was evaluated using Hansen's J-test for overidentifying restrictions (Hansen, 1982). The null hypothesis states that the instruments are exogenous and uncorrelated with the error term. In this study, the resulting p-value exceeded the conventional significance level of 0.05, indicating that the null hypothesis cannot be rejected. This result confirms that the selected instruments are valid and that the model does not suffer from overidentification bias, thereby supporting the consistency and efficiency of the System GMM estimator.

In addition, the Arellano–Bond serial correlation test was conducted to examine autocorrelation in the idiosyncratic error term. Although first-order serial correlation (AR(1)) is expected in first-differenced residuals, the validity of the System GMM estimator fundamentally depends on the absence of second-order serial correlation (AR(2)). The results indicate that the p-value for the AR(2) test is statistically insignificant at the 5% significance level. Therefore, the null hypothesis of no second-order serial correlation cannot be rejected. This finding confirms that the error terms in the original level equation are not serially correlated and validates the use of lagged endogenous variables as appropriate instruments. Consequently, the estimated coefficients can be considered robust to dynamic misspecification and endogeneity.

Environmental quality is inherently a dynamic, time-dependent socioeconomic variable (Li et al., 2016). To capture this dynamic behavior, the empirical model incorporates the lagged dependent variable as an explanatory variable. Accordingly, the baseline empirical specification used in this study is presented as follows:

$$EQI_{i,t} = \alpha + \beta_0(EQI_{i,t-1}) + \beta_1(HDI_{i,t}) + \gamma X_{i,t} + \mu_i + \varepsilon_{i,t} \quad \text{....................(1)}$$

where EQI is the environmental quality index; EQI_{t-1} is The first-order lagged environmental quality index; HDI is the human development index; $X_{i,t}$ represents the control variables (natural logarithm of FDI, physical capital, economic growth, and population); α is a constant term; μ_i is the regional-specific effect that controls for provincial conditions, varying across provinces but not across time; $\varepsilon_{i,t}$ is the idiosyncratic error; subscript i equals provincial region, and subscript t represents period.

This study aims to validate the analysis findings by conducting several robustness checks, as outlined in Tenaw & Beyene (2021). First, the dependent variable was replaced with the air quality index, and the other fixed variables were included. Second, given the diverse economic structures across Indonesian regions, it is crucial to assess how regression results vary with natural resource endowment levels. To address this, the regions are classified into two groups: Java Island and regions outside Java Island.

RESULTS AND DISCUSSION

Increases in 33 provinces generally drove the growth in environmental quality during the 2013-2020 period. However, four provinces still experienced a decline in environmental quality during 2013-2020. Some provinces that experienced a decline in environmental quality were Central Sulawesi, North Maluku, West Papua, and Papua. The province with the highest rate of decline in environmental quality is Papua Province, with a decrease of 3,7 percent; this should serve as an alert for the Government to pay closer attention to environmental issues, especially in provinces experiencing a downward trend in environmental quality.

One factor that can improve environmental quality is human development. The highest increase in environmental quality growth is DKI Jakarta Province, reaching 65,7 percent, and it is the province with the highest human development ranking. This indicates that human development can be a solution to environmental conservation efforts.

Table 2. Descriptive statistics of research variables

Variable	**Obs**	**Mean**	**SD**	**Min**	**Max**
EQI	264	66,839	10,247	35,660	91,500
HDI	264	69,426	4,278	56,250	80,770
FDI	264	745,701	1748,973	6,000	16787
Physical capital	264	32,215	7,170	17,948	60,009
Growth	264	3,117	3,922	-20,134	20,203
Population	264	7,867	10,879	0,828	49,023

Source: Data processed, 2025

Table 2 shows descriptive statistics of the research variables. The average environmental quality during the study period was 66,839, which was categorized as good. Meanwhile, the average human development was 69,426, which is categorized as moderate. This average is still slightly below the global average human development, which was 70,950 during the same period.

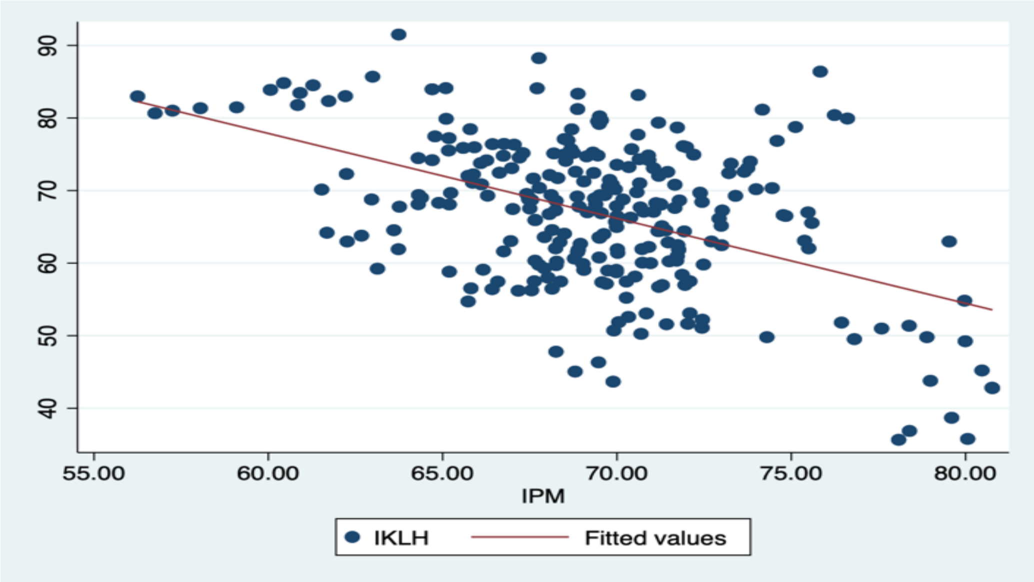

Figure 1. Scatter plot of environmental quality indicators against HDI

Source: Data processed, 2025

An early indication of the relationship between environmental quality and human development is shown in Figure 4.1, which shows a relatively negative correlation. This relationship only provides preliminary information and is limited because it has not controlled for other vital factors/variables. Therefore, the researcher used regression for further analysis at a later stage.

The environmental quality index model estimates for Indonesia from 2013 to 2020 are shown in Table 3. Table 3 presents the empirical estimations detailing the impact of disaggregated human development dimensions and macroeconomic controls on regional environmental sustainability. While baseline static models (Pooled OLS and Fixed Effects) are reported for preliminary comparative purposes, the System Generalized Method of Moments (GMM) is explicitly designated as the primary and definitive analytical model for this study. Traditional static estimators suffer from inherent Nickell bias and fail to capture reverse causality, often yielding spurious or inconsistent coefficients. By introducing instrumental variables and accounting for unobserved regional heterogeneity, the System GMM framework effectively eliminates these preliminary methodological inconsistencies, yielding robust and unbiased parameter estimates.

In model 1, the PLS estimation does not include lagged environmental quality variables or control variables. PLS is a fundamental regression method, but has not overcome the problems of omitted-variable bias (OVB) and reverse causality. As a result, in model 1, the effect of human development on environmental quality is negative, with a coefficient of -1,171.

Furthermore, model 2 incorporates a lagged environmental quality variable into the PLS model, and the results show a negative relationship with a coefficient of -0,287. In model 2, there is a bias due to the correlation between the lag variable and the error. The bias leads to an upward bias. In Model 3, the control variable is included; the results still show a negative effect with a coefficient of -0,195, meaning that the control variable reduces the coefficient. Model 4 estimates fixed effects by including lag and control variables. Estimation using fixed effects can minimize OVB bias, but there remains bias due to the correlation between the lag and the error. The estimation results show a positive effect of human development on environmental quality with a coefficient of 1,534. This illustrates that bias from unobserved factors not only alters the coefficient but also reverses the direction of the estimated effect of human development on environmental quality. The change in direction is indicated because it minimizes OVB-induced bias. In this study, OVB is caused by important variables not included in the model. Based on several previous studies, one possible cause is energy consumption. Energy consumption has a positive correlation with development and a negative correlation with environmental quality. The relationship between energy consumption and physical capital is also close because physical capital requires energy for its use, causing the two variables to move together. Therefore, the physical capital variable explains the correlation between energy consumption, human development, and environmental quality.

Furthermore, columns 4 and 5 use the GMM estimation method, which can overcome the correlation between lag and error, unobserved heterogeneity, and reverse causality. Column 5 is the difference GMM model, yielding positive effect estimates with a coefficient of 1,282. These results indicate an upward bias due to the correlation between lagged variables and errors, as well as reverse causality. However, the difference GMM has a weakness, namely, weak instruments, so it was developed to overcome this with system GMM. The GMM results indicate that human development positively affects environmental quality, with a coefficient of 1,121. To be more confident that the bias is due to differences in estimation, the researcher provides the estimation results with the same number of observations in Appendix Table 1. Based on Appendix Table 1, the results are almost similar, and it can be concluded that the changes in bias are more likely to lead to differences in estimation techniques.

Table 3 shows the results of post-estimation tests assessing autocorrelation and instrument validity. The AR(2) test, also known as the Arellano-Bond test, examines second-order autocorrelation in first-differenced errors and ensures the consistency of estimates under the null hypothesis of no autocorrelation. Additionally, the Sargan test is used to assess the instrument's validity. The Sargan test assesses the instrument's validity by comparing the number of estimated parameters with the number under the null hypothesis that the instrument is valid. The expected result is not to reject the null hypothesis, so the model specification is valid and consistent. Then, the rule of thumb is that the GMM-dependent lag variable lies between the dependent lag value in PLS and the fixed effect, with the former as the upper limit and the latter as the lower limit. Table 3 shows that the GMM system dynamic model specification is good.

Table 3. Model Estimation of Indonesia's Environmental Quality Index, 2013-2020

	Dependent variable: EQI					
Variable	**PLS (1)**	**PLS (2)**	**PLS (3)**	**Fixed Effect (4)**	**Diff GMM (5)**	**Sys GMM (6)**
L.EQI		0,775***	0,697***	0,026	0,082	0,183**
		(0,041)	(0,044)	(0,068)	(0,081)	(0,087)
HDI	-1,171***	-0,287***	-0,195*	1,534***	1,282**	1,121***
	(0,142)	(0,099)	(0,104)	(0,452)	(0,507)	(0,400)
Ln(FDI)			-0,719*	-2,083***	-2,541***	-2,945***
			(0,387)	(0,699)	(0,986)	(0,811)
Physical Capital			-0,011	-0,037	-0,259	-0,397***
			(0,048)	(0,081)	(0,178)	(0,131)
growth			-0,121	0,131	0,048	-0,075
			(0,085)	(0,121)	(0,134)	(0,121)

	Dependent variable: EQI					
Variable	**PLS (1)**	**PLS (2)**	**PLS (3)**	**Fixed Effect (4)**	**Diff GMM (5)**	**Sys GMM (6)**
Ln(population)			-0,753	5,132	15,107**	-0,044
			(0,547)	(11,885)	(7,507)	(3,514)
Constant	148,117***	35,411***	40,066***	-36,858*	-28,108	6,274
	(9,746)	(8,821)	(8,448)	(20,943)	(29,428)	(26,853)
r2	0,239	0,733	0,750	0,108		
N	264	231	231	231	198	231
AR(2)					-1,101	-0,737
Sargan					30,897*	31,918

Note: Robust Standard errors in parentheses * p < .1, ** p < .05, *** p < .01
Source: Data processed, 2025

This research uses various estimation methods: PLS, fixed effects, two-step GMM, and system GMM two-step. Almost all estimation methods indicate that human development improves environmental sustainability, including the System GMM method. Based on the System GMM estimation results, a one-point increase in human development increases environmental quality by 1.121 points. This means that educated, healthy people who live properly can access environmentally friendly energy, becoming more efficient in their energy use and more aware of the importance of environmental sustainability. In economic terms, a one standard deviation increase in human development corresponds to a 46,8 standard deviation increase in environmental quality. In line with the research by Gouvea et al. (2018), increasing HDI is important to ensure environmental sustainability. Increasing HDI encourages people to demand a cleaner environment (Mukherjee & Chakraborty, 2009).

The lag variable of environmental quality shows a positive relationship at the 5 percent significance level. This finding establishes a long-run relationship between the estimated variable and the data. The value of the environmental quality lag (0,183) indicates that 0,183 points per year correct the change from short-term to long-term environmental quality. The long-term effect of human development on environmental quality ($\beta\_1/(1-\beta\_0$)) is 1,373, meaning that the long-term effect of human development is greater than the short-term effect due to the correction of environmental quality lag.

This finding is still below the coefficient reported by Opoku et al. (2022) in OECD countries, which was 1,914 points. However, compared to the economic magnitude, the researcher's findings have a greater impact than those of Opoku et al. (2022), which found that a one-standard-deviation increase in human development is associated with a 7.74 percentage-point increase in environmental quality. This could be because the economic magnitude in OECD countries is greater than in Indonesia, so the impact on the economy is smaller there. In addition, based on the dependent lag, it is known that Indonesia is on a positive trend toward environmental sustainability, whereas the previous period favored it.

The relationship between environmental quality and foreign direct investment (FDI) is negative and statistically significant. A US$1 million increase in foreign direct investment decreases environmental quality by 0.029 points. This finding supports the pollution haven hypothesis, which states that, with globalization and greater openness to investment, multinational companies from developed countries relocate "dirty" production to developing countries. This occurs because developing countries often have weaker environmental regulations and require investment to support their economic development (Adams & Opoku, 2020). In addition, physical capital has a negative and statistically significant relationship with environmental quality. A one percent increase in physical capital reduces environmental quality by 0.397 points. This indicates that the physical capital used so far continues to degrade the environment. The use of machinery, vehicles, and equipment that make up capital is still not environmentally friendly, resulting in increased emissions and air pollution that degrade the environment. This follows Parr (2016), who states that capital can degrade the environment through carbon emissions, thereby decreasing environmental quality through air pollution. Population and economic growth generally have negative coefficients, although they are not statistically significant.

Table 4. Effect of Human Development on Environmental Quality (GMM system)

Dependent variable: EQI				
Variable	**(1)**	**(2)**	**(3)**	**(4)**
L.EQI	0,183**	0,148**	0,267**	0,225**
	(0,087)	(0,073)	(0,114)	(0,099)
HDI	1,121***			
	(0,400)			
Educ		6,398***		
		(2,082)		
health			0,182	
			(1,087)	
welfare				0,002**
				(0,001)
Control Var	yes	yes	yes	yes
N	231	231	231	231

Note: Robust Standard errors in parentheses * p < .1, ** p < .05, *** p < .01
Source: Data processed, 2025

The dimensional analysis presented in Table 4 indicates that improvements in education and living standards primarily drive the positive influence of human development on environmental sustainability. Specifically, the significant effect of the education dimension, measured by average and expected years of schooling, suggests that higher levels of cognitive capacity and environmental literacy enable individuals to adopt more sustainable consumption patterns and support environmentally oriented public policies.

The education dimension represents the strongest contributor to environmental sustainability. A one-point increase in the education index is associated with a 6.39-point increase in environmental quality. This finding suggests that individuals with higher educational attainment are generally more aware of the importance of environmental conservation and are more likely to engage in environmentally responsible behaviors. Consistent with the findings of Ahmed et al. (2020) and Zafar et al. (2019) in the G7 countries and the United States, higher educational attainment increases public awareness of environmental issues and encourages active participation in environmental protection. These results emphasize the critical role of human capital development in promoting environmental sustainability. From a theoretical perspective, the significant education coefficient supports the argument that enhanced cognitive abilities and environmental literacy fundamentally reshape consumption patterns and strengthen institutional demand for sustainable development policies.

The living standards dimension also has a positive and statistically significant effect on environmental quality. Specifically, a one-point increase in the living standards index improves environmental quality by 0.002 points. This finding empirically supports the income and composition effect proposed by the Environmental Kuznets Curve (EKC) hypothesis. As purchasing power increases, households are more likely to invest in environmentally friendly technologies and demand stricter environmental regulations. Individuals with higher living standards generally have greater access to cleaner technologies and environmentally sustainable products, contributing to improvements in environmental quality. Zen et al. (2014) argue that higher levels of education and income strengthen individuals' commitment to environmental protection through activities such as recycling and waste reduction. They further suggest that education enhances people's ability to understand complex environmental challenges, enabling them to respond more effectively to issues such as global warming and ecological degradation. Similarly, Opoku et al. (2022) report that higher living standards increase public appreciation of environmental quality and strengthen demand for cleaner surroundings. As one of the key dimensions of the Human Development Index (HDI), income provides the financial resources necessary to adopt more sustainable lifestyles, while education equips individuals with the knowledge required to protect natural resources effectively.

In contrast, the health dimension shows a positive coefficient but is not statistically significant. Although the estimated effect is positive, the lack of statistical significance suggests that improvements in health and life expectancy may take longer to produce measurable environmental outcomes. This result is consistent with the study's theoretical expectations, indicating that the environmental benefits of better public health are likely to emerge gradually rather than immediately. Healthier populations tend to recognize the close relationship between environmental quality and human well-being. They are therefore more likely to adopt environmentally responsible behaviors, including energy conservation, recycling, and waste reduction. Opoku et al. (2022) similarly argue that populations with higher levels of human development are more likely to support initiatives to improve environmental quality. However, during the study period, these long-term behavioral changes have not yet translated into statistically significant improvements in environmental quality.

Table 5. Robustness Check

Variable	EQI	AQI
HDI	1,121***	1,274**
	(0,400)	(0,645)
Control Variable	yes	yes
N	231	231
AR(2)	-0,6728	1,0942
Sargan	31,91766	30,64863

Note: Robust Standard errors in parentheses * p < .1, ** p < .05, *** p < .01
Source: Data processed, 2025

To evaluate the results, robustness and heterogeneity checks were performed by replacing the dependent variable with the air quality index. Table 5 shows that the results are similar to those of the research. Human development improves air quality (as measured by the AQI). This aligns with the research of Opoku et al. (2022), who found that human development also contributes to improving air quality. These results support the robustness of this study. Second, by clustering the Java and Outer Java regions, the results in Table 6 also show that human development promotes environmental sustainability in both regions. Although human development is not significant in the Java region, this finding is similar to Omri et al. (2019), who found that human development does not contribute to environmental sustainability. This is possible because human development in the Java region is already relatively high, so the sensitivity is lower than in areas outside Java. In areas outside Java, each increase in human development increases human sustainability by 0.962 point.

Table 6. Estimation of Heterogeneity of Java and Outer Java Regions

Variable	Java	Outside Java
HDI	0.426	0.962**
	(0.836)	(0.396)
Control var	yes	yes
N	42	189

Note: Robust Standard errors in parentheses * p < .1, ** p < .05, *** p < .01
Source: Data processed, 2025

CONCLUSION

This study contributes to the literature by examining the influence of human development on environmental quality in Indonesia using a dynamic panel approach. The analysis employs the System Generalized Method of Moments (System GMM) estimator to address potential endogeneity arising from reverse causality, unobserved heterogeneity, and the dynamic nature of environmental quality. Based on panel data from Indonesian provinces for 2013–2020, the findings reveal a positive, statistically significant relationship between human development and environmental quality. The results indicate that improvements in human capital contribute to environmental sustainability by encouraging greater environmental awareness and more sustainable resource management.

These findings are consistent with previous studies by Ahmed et al. (2020), Yao et al. (2019), Khan et al. (2021), Li et al. (2021), and Opoku et al. (2022), which suggest that improvements in human development promote environmental sustainability. By employing the System GMM estimator, this study provides more reliable empirical evidence by explicitly accounting for endogeneity and dynamic relationships that are often overlooked in conventional static panel models. The results reinforce the importance of investing in human development as a long-term strategy for improving environmental quality in developing economies.

The dynamic panel estimates further indicate that physical capital accumulation, population growth, and foreign direct investment (FDI) exert significant negative effects on environmental quality. These findings are consistent with the Pollution Haven Hypothesis and the scale effect of the Environmental Kuznets Curve (EKC), suggesting that rapid economic expansion without adequate environmental safeguards may increase ecological degradation. In contrast, human development acts as an important mitigating factor. The disaggregated analysis shows that the education and living standards dimensions significantly improve environmental quality by encouraging environmentally responsible behavior, increasing demand for cleaner technologies, and promoting more sustainable consumption patterns. Furthermore, the regional analysis demonstrates that although the magnitude of these effects differs between Java and Outer Java, the positive contribution of human development remains statistically significant across both regions.

This study also addresses several limitations of previous research in Indonesia. Earlier studies generally relied on static panel estimation methods and focused primarily on single environmental indicators, such as carbon emissions. By employing a dynamic panel framework and a multidimensional measure of environmental quality, this study provides a more comprehensive understanding of how human development influences environmental sustainability. Moreover, the regional heterogeneity analysis reveals that the positive effect of human development is stronger in Outer Java than in Java, suggesting that improvements in human capital may yield greater environmental benefits in less developed regions.

Accordingly, this research makes three main contributions to the environmental economics literature. First, it contributes methodologically by applying the System GMM estimator to overcome endogeneity, dynamic panel bias, and unobserved heterogeneity in the analysis of environmental quality. Second, it contributes empirically by examining the individual dimensions of human development—education, health, and living standards—rather than relying solely on the aggregate Human Development Index (HDI). Third, it contributes contextually by comparing the effects of human development across Java and Outer Java, thereby providing evidence on regional differences in the human development–environment relationship within a decentralized developing country.

The findings also have important policy implications. Rather than adopting a "grow first, clean up later" approach, policymakers should integrate human development objectives into environmental management strategies. Given the significant role of education, governments should strengthen environmental education through formal curricula, digital learning platforms, and community-based environmental literacy programs. In addition, investment policies should place greater emphasis on environmental quality by incorporating green investment screening mechanisms that encourage environmentally responsible foreign investment and facilitate the transfer of cleaner technologies. Such policies would help reduce the environmental costs associated with economic expansion while promoting sustainable regional development.

Despite these contributions, several limitations should be acknowledged. First, the analysis is based on a balanced panel of Indonesian provinces spanning 2013–2020. Consequently, the results reflect medium-term environmental dynamics and do not capture the structural changes associated with the post-pandemic recovery period. Furthermore, because the analysis uses provincial administrative boundaries, it may not fully represent ecological processes that extend across provincial borders.

Second, the explanatory variables represent macro-level indicators of human development. Although these indicators effectively capture broad socioeconomic conditions, they may not fully reflect individual environmental behavior or community-level environmental awareness. Likewise, although the Environmental Quality Index provides a more comprehensive measure than carbon emissions alone, it may not adequately capture localized environmental problems, such as soil contamination or watershed-specific pollution.

Finally, although the System GMM estimator substantially reduces bias arising from endogeneity, reverse causality, and unobserved time-invariant heterogeneity, omitted variable bias cannot be eliminated. Institutional factors—such as the effectiveness of environmental regulations, governance quality, and local environmental enforcement—as well as sociocultural attitudes toward environmental conservation, were not explicitly incorporated into the model. Future research should integrate these institutional and behavioral dimensions while extending the observation period to examine the long-term stability of the relationship between human development and environmental quality.

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REFERENCES

Adams, S., & Opoku, E. E. O. (2020). Trade and environmental pollution in Africa: accounting for consumption and territorial-based emissions.

Environmental Science and Pollution Research, *27*(35), 44230–44239. https://doi.org/10.1007/s11356-020-10328-8

Ahmed, Z., Zafar, M.W., Ali, S., 2020. Linking urbanization, human capital, and the ecological footprint in G7 countries: an empirical analysis. Sustain. Cities Soc. 55, 102064

Arellano, M., & Bond, S. (1991). Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations. *The Review of Economic Studies*, *58*(2), 277. https://doi.org/10.2307/2297968

Arellano, M., & Bover, O. (1995). Another look at the instrumental variable estimation of error-components models. *Journal of Econometrics*, *68*(1), 29–51. https://doi.org/10.1016/0304-4076(94)01642-D

Balaguer, J., & Cantavella, M. (2018). The role of education in the Environmental Kuznets Curve. Evidence from Australian data. *Energy Economics*, *70*, 289–296. https://doi.org/10.1016/j.eneco.2018.01.021

Bano, S., Zhao, Y., Ahmad, A., Wang, S., & Liu, Y. (2018). Identifying the impacts of human capital on carbon emissions in Pakistan. *Journal of Cleaner Production*, *183*, 1082–1092. https://doi.org/10.1016/j.jclepro.2018.02.008

Bariesta, A. K., & Asyiawati, Y. (2016). *Kajian Pengaruh Indeks Pembangunan Manusia Terhadap Kondisi Lingkungan Di Kecamatan Cariu Kabupaten Bogor*.

Blundell, R., & Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics*, *87*(1), 115–143. https://doi.org/10.1016/S0304-4076(98)00009-8

Eko Cahyono, W., Parikesit, Joy, B., Setyawati, W., & Mahdi, R. (2022). Projection of CO2 emissions in Indonesia. *Materials Today: Proceedings*, *63*, S438–S444. https://doi.org/10.1016/j.matpr.2022.04.091

Chankrajang, T., & Muttarak, R. (2017). Green Returns to Education: Does Schooling Contribute to Pro-Environmental Behaviors? Evidence from Thailand. *Ecological Economics*, *131*, 434–448. https://doi.org/10.1016 /j.ecolecon.2016.09.015

Chung, S. hun. (2020). The impact of regional environmental amenity on skill aggregation across regions in developing countries: evidence from air pollution in China. *Asia-Pacific Journal of Regional Science*, *4*(1), 27–53. https://doi.org/10.1007/s41685-019-00125-8

Dedeoğlu, M., Koçak, E., & Uucak, Z. Ş. (2021). The impact of immigration on human capital and carbon dioxide emissions in the USA: an empirical investigation. *Air Quality, Atmosphere & Health*, *14*(5), 705–714. https://doi.org/10.1007/s11869-020-00973-w

Dunne, D. (2019, June 6). *Profil Carbon Brief: Indonesia*. Carbon Brief.

Ehigiamusoe, K. U., Majeed, M. T., & Dogan, E. (2022). The nexus between poverty, inequality, and environmental pollution: Evidence across different income groups of countries. *Journal of Cleaner Production*, *341*. https://doi.org/10.1016/j.jclepro.2022.130863

Elhorst, J. P. (2014). Matlab Software for Spatial Panels. *International Regional Science Review*, *37*(3), 389–405. https://doi.org/10.1177/0160017612452429

EPA (2020). Environmental Quality Index - Technical Report, 2006-2010. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-20/367

Esty, D. C., Levy, M., Srebotnjak, T., & De Sherbinin, A. (2005). Environmental sustainability index: benchmarking national environmental stewardship. *New Haven: Yale Center for Environmental Law & Policy*, *47*, 60.

Halkos, G. E. (2003). Environmental Kuznets Curve for sulfur: evidence using GMM estimation and random coefficient panel data models. *Environment and Development Economics*, *8*(4), 581–601. https://doi.org/10.1017/S1355770X0300317

Huang, C., Zhang, X., Liu, K., 2021. Effects of human capital structural evolution on carbon emissions intensity in China: A dual perspective of spatial heterogeneity and nonlinear linkages. Renew. Sust. Energ. Rev. 135, 110258

Kuang, H., Liang, Y., Zhao, W., & Cai, J. (2023). Impact of natural resources and technology on economic development and sustainable environment – analysis of resources-energy-growth-environment linkages in BRICS. *Resources Policy*.

Li, X., & Xu, L. (2021). Human development associated with environmental quality in China. *PLoS ONE*, *16*(2 February). https://doi.org/10.1371/journal.pone.0246677

Majeed, M. T., & Ozturk, I. (2020). Environmental degradation and population health outcomes: a global panel data analysis. *Environmental Science and Pollution Research*, *27*(13), 15901–15911. https://doi.org/10.1007/s11356-020-08167-8

Martínez-Zarzoso, I., Bengochea-Morancho, A., & Morales-Lage, R. (2007). The impact of population on CO2 emissions: evidence from European countries. *Environmental and Resource Economics*, *38*(4), 497–512. https://doi.org/10.1007/s10640-007-9096-5

Muhammad Fajar, & Hariyanto. (2021). Pengujian Eksistensi Environmental Kuznets Curve Di Indonesia. *Jurnal Lebesgue : Jurnal Ilmiah Pendidikan Matematika, Matematika Dan Statistika*, *2*(1), 62–68. https://doi.org/10.46306/lb.v2i1.56

Nayak, P. (2008). *Human Development: Concept and Measurement*.

Nickell, S. (1981). *Biases in dynamic models with fixed effects.* Econometrica.

Nikensari, S. I., Destilawati, S., & Nurjanah, S. (2019). STUDI ENVIRONMENTAL KUZNETS CURVE DI ASIA: SEBELUM DAN SETELAH MILLENNIUM DEVELOPMENT GOALS. *Jurnal Ekonomi Dan Pembangunan*, *27*.

Omri, A., Euchi, J., Hasaballah, A.H., Al-Tit, A. (2019), Determinants of environmental sustainability: Evidence from Saudi Arabia. Science of the Total Environment, 657, 1592-1601

Opoku, E. E. O., Dogah, K. E., & Aluko, O. A. (2022). The contribution of human development towards environmental sustainability. *Energy Economics*, *106*. https://doi.org/10.1016/j.eneco.2021.105782

Parr, A. (2016). *Capital, Environmental Degradation, and Economic Externalization* (T. Gabrielson, C. Hall, J. M. Meyer, & D. Schlosberg, Eds.; Vol. 1). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199685271.013.6

Prasetyanto, P. K., & Sari, F. (2021). Environmental Kuznets Curve: Economic Growth With Environmental Degradation In Indonesia. *International Journal of Energy Economics and Policy*, *11*(5), 622–628. https://doi.org/10.32479/ijeep.11609

Prawesti, Y. A. (2021). *Pengaruh Pertumbuhan Ekonomi, Kemiskinan, dan IPM terhadap Kualitas Lingkungan Hidup di Pulau Jawa Tahun 2009-2018*.

Ramadhantie, S. S., Ramadhan, M. J., & Hasibuan, M. A. (2021). Pengaruh Indeks Pembangunan Manusia Terhadap Indeks Kualitas Lingkungan Hidup Di Indonesia Menggunakan Regresi Data Panel. *EKOLOGIA*, *21*(1), 35–43. https://doi.org/10.33751/ekologia.v21i1.2111

Roodman, D. (2006). How to do Xtabond2: An Introduction to Difference and System GMM in Stata. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.982943

Roodman, D. (2009). How to do Xtabond2: An Introduction to Difference and System GMM in Stata. The Stata Journal, 9(1), 86-136. https://doi.org/10.1177/1536867X0900900106

Sapkota, P., & Bastola, U. (2017). Foreign direct investment, income, and environmental pollution in developing countries: Panel data analysis of Latin America. *Energy Economics*, *64*, 206–212. https://doi.org/10.1016/j.eneco.2017.04.001

Sen, A. (1987). *The Standard of Living* (G. Hawthorne, Ed.). Cambridge University Press. http://www.amazon.com/Standard-Living-Tanner-Lectures-Values/dp/0521368405/ref=sr_1_1?s=books&ie=UTF8&qid=1310680161&sr=1-1

Sen A. (1999). Development as freedom. *Oxford University Press*.

Sugiawan, Y., & Managi, S. (2016). The environmental Kuznets curve in Indonesia: Exploring the potential of renewable energy. *Energy Policy*, *98*, 187–198. https://doi.org/10.1016/J.ENPOL.2016.08.029

Tenaw, D., & Beyene, A. D. (2021). Environmental sustainability and economic development in sub-Saharan Africa: A modified EKC hypothesis. *Renewable and Sustainable Energy Reviews*, *143*, 110897. https://doi.org/10.1016/j.rser.2021.110897

van den Bergh, J. C. J. M., & Botzen, W. J. W. (2018). Global impact of a climate treaty if the Human Development Index replaces GDP as a welfare proxy. *Climate Policy*, *18*(1), 76–85. https://doi.org/10.1080/14693062.2016.1227954

van der Kroon, B., Brouwer, R., & van Beukering, P. J. H. (2013). The energy ladder: Theoretical myth or empirical truth? Results from a meta-analysis. *Renewable and Sustainable Energy Reviews*, *20*, 504–513. https://doi.org/10.1016/j.rser.2012.11.045

Williamson, C. (2017). Emission, Education, and Politics: An Empirical Study of the Carbon Dioxide and Methane Environmental Kuznets Curve. *The Park Place Economist*, *25*.

Wintoki, M. B., Linck, J. S., & Netter, J. M. (2012). Endogeneity and the dynamics of internal corporate governance. *Journal of Financial*

Economics, *105*(3), 581–606. https://doi.org/10.1016/j.jfineco.2012.03.005

Wolf, M. J., Emerson, J. W., Esty, D. C., de Sherbinin, A., & Wendling, Z. A. (2022). *2022 Environmental Performance Index*.

Wooldridge, J. M. (2012). *Introductory Econometrics: A Modern Approach*. Cengage Learning.

Yao, Y., Ivanovski, K., Inekwe, J., & Smyth, R. (2020). Human capital and CO2 emissions in the long run. *Energy Economics*, *91*, 104907. https://doi.org/10.1016/j.eneco.2020.104907

Zafar, M.W., Zaidi, S.A.H., Khan, N.R., Mirza, F.M., Hou, F., Kirmani, S.A.A., 2019. The impact of natural resources, human capital, and foreign direct investment on the ecological footprint: the case of the United States. Res. Policy 63, 101428

Zen, I. S., Noor, Z. Z., & Yusuf, R. O. (2014). The profiles of household solid waste recyclers and non-recyclers in Kuala Lumpur, Malaysia. *Habitat International, 42*, 83–89. https://doi.org/10.1016/j.habitatint.2013.10.010