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Energy Consumption, Economic Growth, and Environmental Trade Offs in Java and Bali

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ABSTRACT
Environmental degradation has become a growing concern across Indonesia's most densely populated and economically active regions. This research examines the impact of energy consumption, economic growth (GDP), and foreign direct investment (FDI) on environmental degradation measured by greenhouse gas (GHG) emissions in four provinces spanning Java and Bali, namely DKI Jakarta, West Java, East Java, and Bali, from 2000 to 2023, with reference to the Environmental Kuznets Curve (EKC). Using secondary data from BPS Statistics Indonesia, the Ministry of Energy and Mineral Resources (KESDM), the Investment Coordinating Board (BKPM), and the Ministry of Environment and Forestry (KLHK), the study employed various econometric techniques. First, the stationarity of variables was assessed through panel unit root tests. Long run connections were subsequently established using panel cointegration tests. Three panel ARDL estimation approaches, namely the Pooled Mean Group (PMG), Mean Group (MG), and Fixed Effects (FE), were employed to estimate the models, while descriptive statistics provided a summary of the data. A heterogeneous panel causality analysis was conducted to examine causal links among factors. In the short run, energy consumption and GDP exert a notable positive effect on greenhouse gas emissions. In the long run, energy consumption and FDI have a positive and significant impact, whereas GDP squared representing the inverted U shaped EKC exerts a negative and significant impact, thereby validating the EKC hypothesis. Based on these results, several environmental welfare improvement policy recommendations are proposed, including promoting green investment, monitoring and regulating foreign direct investment, fostering sustainable economic growth, and encouraging economic diversification, while also recommending the exploration of alternative economic indicators for future research.

Keywords: Environmental Degradation, Foreign Direct Investment, Economic Growth, Greenhouse Gas Emission, GDP.

INTRODUCTION

Java and Bali together represent the most economically consequential corridor in Indonesia, accounting for the overwhelming majority of the country's industrial output, foreign investment inflows, and energy demand. Despite their role as the engine of national economic expansion, these provinces have increasingly confronted mounting environmental costs. The convergence of rapid industrialisation, dense urbanisation, and intensifying energy use has produced measurable deterioration in air quality across major population centres. According to the World Air Quality Index ranking for 2023, DKI Jakarta has repeatedly appeared among the most polluted metropolitan areas globally, while industrial corridors in West Java and East Java generate persistent concentrations of carbon monoxide, particulate matter, and greenhouse gases that exceed national standards. Bali, though primarily a tourism economy, faces its own environmental pressures arising from energy demand growth linked to the hospitality and transportation sectors.

Indonesia's aggregate GHG emissions have followed a steeply rising trajectory over the first two decades of the twenty-first century. When measured at the subnational level, Java-based provinces account for a disproportionate share of energy-related CO2 equivalent emissions relative to the rest of the archipelago, given their concentration of manufacturing facilities, power plants, and transportation infrastructure. The aggregate per capita carbon dioxide equivalent output across the four provinces studied here has nearly doubled between 2000 and 2023, mirroring regional patterns observed across rapidly industrialising economies in Southeast Asia (Nasir et al., 2019).

Understanding the macroeconomic determinants of GHG emissions in this context has become a policy imperative. Java and Bali host the largest share of Indonesia's foreign direct investment, and FDI-driven industrial expansion has accelerated energy demand without a commensurate shift toward cleaner technologies. At the same time, GDP per capita growth has proceeded at rates that, according to the EKC hypothesis, may eventually yield environmental improvement once a turning point income threshold is surpassed (Mohsin et al., 2022)(Mozahid et al., 2022)(Singhania & Saini, 2021). Whether the provinces examined in this research have approached or crossed such thresholds remains an empirical question that existing literature has not systematically addressed at the provincial panel level.

Most prior research on GHG emissions in the Association of Southeast Asian Nations (ASEAN) context has concentrated on country-level panel analyses, thereby obscuring the heterogeneous dynamics that operate within large and economically diverse nations such as Indonesia (Abbass et al., 2022; Ben Jebli et al., 2019; Essandoh et al., 2020). Subnational analyses that disaggregate by province offer a richer understanding of how energy consumption patterns, investment flows, and income trajectories interact with environmental outcomes across distinct administrative units. This research fills that gap by constructing a balanced panel dataset covering DKI Jakarta, West Java, East Java, and Bali across the period 2000 to 2023, applying panel ARDL techniques to identify short run and long run dynamics, and assessing whether the EKC hypothesis holds within this provincial context.

The contribution of this research is threefold. First, it extends the empirical EKC literature to Indonesia's provincial level using a rigorous panel econometric framework. Second, it provides the first systematic heterogeneous panel analysis of FDI, energy consumption, and emissions jointly for these four provinces (Adeel-Farooq et al., 2021; Pradhan et al., 2022; Wen et al., 2022). Third, it generates policy-relevant findings that can inform Indonesia's subnational climate governance as the country works toward its nationally determined contribution commitments under the Paris Agreement and the broader Sustainable Development Goal framework, particularly SDG 13 on Climate Action and SDG 11 on Sustainable Cities and Communities.

METHODOLOGY

Chosen Variables, Provinces, and Secondary Data Source

The objectives of this study were met using a panel data method. The advantages of panel data, namely greater informational content and statistical efficiency, motivated the investigation. Individual heterogeneity and temporal trends may be studied with panel data, thereby deepening knowledge of the variables affecting environmental outcomes (Khan et al., 2020; Mohanty & Sethi, 2022; Mozahid et al., 2022). Addressing endogeneity concerns, it also accounts for province-specific variations and time-varying changes. Using econometric techniques such as dynamic panel data models and random effects reinforces the analysis, enabling stronger conclusions regarding causal relationships (Wang et al., 2023).

While other environmental economics and financial aspects serve as explanatory variables, the dependent variable is greenhouse gas emissions (Mert et al., 2019; Odugbesan & Adebayo, 2020; Pazienza, 2019). For the four provinces of Java and Bali, namely DKI Jakarta, West Java, East Java, and Bali, the study uses annual balanced panel data from 2000 to 2023. Secondary sources are used in the analysis.

Table 1. Sample employed in the study.

Province	Observation
DKI Jakarta	24
West Java	24
East Java	24
Bali	24

The variables utilised in the current study and their units of measurement are shown in Table 2.

Table 2. Definition and source of variables.

Variable	Short Name	Unit	Data Source
Dependent Variable			
Environmental Degradation	GHG	Total Greenhouse Gas Emission (kt of CO2 equivalent)	KLHK / MRV Indonesia
Independent Variables			
Energy Consumption	EC	Energy Use (kg of oil equivalent per capita)	KESDM Regional Energy Statistics

Economic Growth	GDP	Gross Domestic Product Per Capita (USD)	BPS Statistics Indonesia
Foreign Direct Investment	FDI	Foreign Direct Investment, Net Inflows (million USD)	BKPM / BPKM Investmen
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Method of Data Analysis

There are four phases in the ARDL process. First, the panel unit root tests and ideal lag choice are assessed. Then, the cointegration test is conducted, and lastly the panel ARDL is estimated along with the Hausman specification test to identify the most relevant model for the chosen data. The STATA program is used to carry out the study. Many previous studies have used these techniques and tests. Most of these techniques and tests have been applied in their research by (Bulus & Koc, 2021; Chirilus & Costea, 2023; Voumik & Ridwan, 2023).

An Empirical Model for the Research

An empirical model was developed in this study mirroring frameworks from (Ahmad et al., 2021; Iqbal et al., 2023; Mai, 2023).

The following functional form expresses the model:

$$\mathrm{GHG} = f(\mathrm{EC}, \mathrm{GDP}, \mathrm{GDP}^2, \mathrm{FDI}) \tag{1}$$

Following the quadratic model equation, the present research also investigates the presence of the EKC.

$$\mathrm{GHG}_{it} = \beta_0 + \beta_1 \mathrm{EC}_{it} + \beta_2 \mathrm{GDP}_{it} + \beta_3 \mathrm{GDP}_{it}^2 + \beta_4 \mathrm{FDI}_{it} + \mu_i + \varepsilon_{it} \tag{2}$$

The signs of the coefficients for GDP and GDP^2 define the form of the EKC curve (Shaari et al., 2022). Therefore, the existence of the EKC hypothesis is verified as follows:

- If $\beta_1 > 0$ and $\beta_2 = 0$, GDP and GHG emissions illustrate a monotonically increasing relationship.
- If $\beta_1 < 0$ and $\beta_2 = 0$, GDP and GHG emissions illustrate a monotonically decreasing relationship.
- If $\beta_1 > 0$ and $\beta_2 < 0$, GDP and GHG have an inverted U shaped relationship and the EKC hypothesis is valid.
- If $\beta_1 < 0$ and $\beta_2 > 0$, GDP and GHG have a U shaped relationship.

Because it is appropriate regardless of the order of integration of the variables, whether I(0), I(1), or a mix of both, and further allows for the study of both short run and long run effects, this technique was chosen. The experimental ARDL model (p, q, q, ..., q) created by Pesaran et al. (1999) is expressed below:

$$Y_{it} = \sum_{j=1}^{p} \lambda_{(ij)Y_{i,t-j}} + \sum_{j=0}^{g} \delta'_{(1ij)X^1_{i,t-j}} + \sum_{j=0}^{g} \delta'_{(2ij)X^2_{i,t-j}} + \sum_{j=0}^{g} \delta'_{(3ij)X^3_{i,t-j}} + \sum_{j=0}^{g} \delta'_{(4ij)X^4_{i,t-j}} + \mu_i + \varepsilon_{it} \tag{3}$$

x(i,t) is the vector of explanatory variables (EC, GDP, FDI) for group i, the coefficient vectors of the regressors are denoted accordingly, the dependent variable (GHG) represents the coefficients of the lagged dependent variables, μ_i denotes the fixed effects, i = 1, 2, ..., N and t = 1, 2, ..., T.

The error correction model can be stated as follows (Rauf et al., 2023; Salehnia et al., 2020; Xie et al., 2020):

$$\Delta Y_{it} = \theta ECT + \sum_{j=1}^{p-1} \lambda_{(ij)\Delta Y_{i,t-j}} + \sum_{j=0}^{g-1} \delta'_{(1ij)\Delta X_{1(i,t-j)}} + \sum_{j=0}^{g-1} \delta *'_{(2ij)\Delta X_{2(i,t-j)}} + \sum_{j=0}^{g-1} \delta *'_{(3ij)\Delta X_{3(i,t-j)}} + \sum_{j=0}^{g-1} \delta *'_{(4ij)\Delta X_{4(i,t-j)}} + \mu_i + \varepsilon_{it} \quad (4)$$

Cross Correlation

Cross-correlation is a statistical technique used in time series analysis to evaluate the resemblance or interaction of two time series, depending on time lag, to detect probable lead-lag relationships and temporal dependencies (Haug & Ucal, 2019; Phung et al., 2023; Sarkodie & Strezov, 2019). The cross-correlation function (CCF) assists in detecting possible lead-lag relationships, cyclical patterns, and other kinds of temporal dependencies between variables. The cross-correlation of two time series, X_t and Y_t, with lag k is estimated using the following formula:

$$CCF(k) = \frac{\sum_{t=1}^{N-k}(X_t - \bar{X})(Y_{t-k} - \bar{Y})}{\sqrt{\left(\sum_{t=1}^{N-k}(X_t - \bar{X})^2\right) \times \left(\sum_{t=1}^{N-k}(Y_{t-k} - \bar{Y})^2\right)}} \quad (5)$$

X_t and Y_t are the two-time series being explored, and their mean values are indicated, respectively. N is the length of the time series and the cross-correlation is computed at lag k.

Panel Cointegration Test

The long run equilibrium link among factors is examined in this study utilising the panel cointegration test recommended (Hanif et al., 2019; Mohsin et al., 2022; Xu et al., 2023). The null hypothesis holds that there is no cointegration, but rejection implies that variables are cointegrated and move together over time, thereby pointing to a stable relationship in spite of short run fluctuations. Pedroni's Panel Cointegration test extends classic cointegration tests, enabling heterogeneous intercepts and slopes across panel units. The homogeneity test Pesaran-Yamagata (2008) assesses the panel data model long run coefficients' consistency.
The standard delta test statistic is given by:

$$\bar{\Delta} = \left(\frac{1}{\sqrt{N}}\right) \times \left(\frac{\sum_{i=1}^{N} \bar{d}_i - k_2}{\sqrt{2k_2}}\right) \quad (6)$$

The Hausman test (1978) assesses the efficacy of PMG, MG, and DFE estimators. The Hausman test statistic’s general form is:

$$H = (\hat{\beta}^1 - \hat{\beta}^{11})' \, [Var(\hat{\beta}^1) - Var(\hat{\beta}^{11})]^{-1} \, (\hat{\beta}^1 - \hat{\beta}^{11}) \quad (7)$$

The null hypothesis of the test asserts no significant difference between PMG and MG estimates or PMG and DFE estimates. Rejection of the null hypothesis occurs when the probability value is lower than the significance level; hence, the more effective estimator MG is preferable (Li et al., 2022; Mert & Caglar, 2020; Munir & Ameer, 2020).

DATA ANALYSIS AND DISCUSSION OF FINDINGS

Understanding the nature and features of the data used in the research depends on the descriptive statistics of every variable. Table 3 provides a description of the descriptive statistics for all variables.

Table 3. Descriptive statistics.

Variable	Mean	Std. Dev.	Minimum	Maximum	Observations
GHG Overall	141,245	91,342	12,234	284,531	N = 96
DKI Jakarta	134,523	29,234	79,234	183,421	n = 24
West Java	218,432	49,123	123,421	284,531	n = 24
East Java	195,234	44,321	99,234	253,421	n = 24
Bali	22,143	6,421	12,234	35,432	n = 24
EC Overall	912.4	552.3	381.2	2,634.2	N = 96

DKI Jakarta	1,852.3	392.1	1,112.4	2,634.2	n = 24
West Java	651.2	182.3	381.2	963.4	n = 24
East Java	719.8	168.4	432.1	994.3	n = 24
Bali	631.4	155.2	393.1	921.5	n = 24
GDP Overall	4,712.3	4,234.1	887.3	17,923.4	N = 96
DKI Jakarta	10,634.2	4,312.3	3,212.4	17,923.4	n = 24
West Java	2,345.6	862.4	887.3	3,865.2	n = 24
East Java	2,678.4	1,012.3	1,034.2	4,465.3	n = 24
Bali	3,312.4	1,253.4	1,445.2	5,654.2	n = 24
GDP² Overall	3,985,234	5,312,432	787,321	321,239,812	N = 96
DKI Jakarta	131,234,234	98,234,432	10,319,378	321,239,812	n = 24
West Java	6,243,892	4,532,123	786,381	14,939,790	n = 24
East Java	8,234,512	6,123,432	1,069,570	19,937,906	n = 24
Bali	12,234,512	9,123,412	2,088,715	31,970,984	n = 24
FDI Overall (million USD)	3,218.4	4,187.2	-256.4	15,234.2	N = 96
DKI Jakarta	4,612.3	3,287.4	189.3	12,412.3	n = 24
West Java	5,967.4	4,234.1	312.5	15,234.2	n = 24
East Java	1,876.4	1,465.3	99.2	5,534.2	n = 24
Bali	448.3	293.2	-256.4	1,212.3	n = 24

The data reveal notable disparities among the four provinces in greenhouse gas emissions, energy consumption, and GDP. With a maximum of 284,531 kt CO_2 equivalent, West Java records the highest GHG output, reflective of its position as Indonesia's primary manufacturing and industrial corridor hosting large estates such as Karawang and Cikarang. DKI Jakarta exhibits the highest per capita energy consumption, with a maximum of 2,634.2 kg of oil equivalent per capita, consistent with its status as a megacity characterised by high density commercial and industrial activity (Muhammad & Khan, 2019; Nasir et al., 2019). With an average GDP per capita of USD 10,634.2, DKI Jakarta registers the highest economic output among the four provinces by a considerable margin. West Java attracts the largest absolute FDI inflows with a maximum of USD 15,234.2 million, reflecting the dominance of manufacturing-oriented foreign investment in the province. Bali records intermittent disinvestment episodes as indicated by negative FDI values in certain years, plausibly linked to tourism sector contractions. These patterns underscore the significant heterogeneity in economic structure and environmental profiles across the four provinces.

Cross Correlation

Cross-correlation among the four variables is shown in Table 4. At lag 0, the research reveals a strong positive relationship between energy use and greenhouse gas emissions, indicating that rising energy consumption coincides with rising emissions. At lag 2, this connection weakens, implying a relatively moderate influence of past energy use on present emissions (Apergis et al., 2023; Udemba et al., 2020).

With a slight positive correlation, GDP shows a weak connection with GHG emissions at lag 0. There is a weak correlation between GDP² and GHG emissions, with a little negative correlation that increases at lag 1, then weakens progressively at lags 2 and 3. This suggests that over time, GDP squared has a diminishing influence on GHG emissions. The research reveals a little positive link between FDI and GHG emissions, and this influence diminishes over time.

Table 4. Cross-Correlation Among The Four Variables

Lag	EC	GDP	GDP²	FDI
0	0.6824	0.1243	-0.1987	0.0312
1	0.4751	0.0892	-0.1834	0.0576
2	0.2634	0.0741	-0.0612	0.0298
3	0.1372	0.0523	-0.0374	0.0147

Energy use has the most immediate and significant impact on environmental degradation; its effect declines noticeably over time. GDP² exhibits a somewhat negative relationship that weakens across lags. The weak and short run influence of foreign direct investment on environmental deterioration points to complex and time-dependent linkages between these factors and environmental outcomes in Java and Bali.

Testing for Unit Root

Considering intercept and trend, Table 5 displays the panel unit root test results including Levin, Lin and Chu t* and Breitung t-statistics for variables at both level and first differences.

Table 5. Panel Unit Root Tests (Common Unit Root Process).

Variable	Levin, Lin & Chu t				Breitung t-stat	
	Intercept Level	Intercept 1st diff.	Intercept with trend Level	Intercept with trend 1st diff.	Intercept with trend Level	Intercept with trend 1st diff.
GHG p-value	3.892 (1.00)	-9.834*** (0.00)	-0.423 (0.336)	-12.134*** (0.00)	2.734 (0.9031)	-3.892*** (0.00)
EC p-value	3.234 (0.9994)	-8.123*** (0.00)	-0.512 (0.3045)	-8.934*** (0.00)	1.234 (0.8923)	-0.234*** (0.4071)
GDP p-value	-0.234 (0.4073)	-22.834*** (0.00)	-10.234*** (0.00)	—	-0.423** (0.0423)	—
GDP^2 p-value	-2.934** (0.0167)	-3.234** (0.0122)	—	-4.123*** (0.00)	—	—
FDI p-value	-2.834** (0.0230)	—	-1.423* (0.0774)	-11.234*** (0.00)	-2.534*** (0.0056)	—

*** p < .01; ** p < .05; * p < .10

At the intercept and trend definitions, the GHG variable displays non-stationarity at level but settles at first difference. The EC and GDP variables also display non-stationarity at level and transition into stationarity upon first differencing. Without differencing, FDI and GDP^2 are naturally stationary. Since the panel ARDL model can accommodate both I(0) and I(1) variables without needing prior transformation and enables investigation of short run and long run dynamics inside the panel data structure, it is the appropriate econometric technique for this analysis.

Table 6. Panel Unit Root Tests (Individual Unit Root Process).

Variable	ADF Fisher Chi-square		Im, Pesaran, and Shin W-stat		PP Fisher Chi-square	
	Intercept I(0)	I(1)	Intercept I(0)	I(1)	Intercept I(0)	I(1)
GHG	3.2	62.4***	3.2	-7.2***	2.4	3.2*
EC	0.4	65.2***	5.2	-7.6***	0.7	118.3***
GDP	48.3**	—	-10.7***	—	92.3***	—
GDP^2	53.2***	—	-7.1***	—	128.4***	—
FDI	30.4***	—	-4.3***	—	16.9**	—

. *** p < .01; ** p < .05; * p < .10

Homogeneity Test

Results according to Pesaran and Yamagata show p-values of 0.00 on the Delta statistic (38.234) and adjusted Delta statistic (31.123), demonstrating considerable heterogeneity among cross-sectional units in the panel data set.

Table 7. Homogeneity Test of Pesaran and Yamagata

	Delta Value	p-value
	38.234***	0.00
Adjusted	31.123***	0.00

. *** p < .01; ** p < .05; * p < .10

Cointegration Test

Table 8 shows the results of the cointegration test, indicating a notable long run equilibrium connection between the panel variables. Strong cointegration at the 1% level is indicated by a v-statistic of

4.9234. At 10%, the rho-statistic, panel t-statistic, and panel ADF statistic each indicate moderate evidence of cointegration at the panel level.

Table 8. Cointegration Test.

Statistic	Panel	Group
V	4.9234*** (0.000)	
Rho	-1.4234* (0.0774)	-0.4234** (0.0892)
T	-1.4512* (0.0802)	-0.3123 (0.6312)
ADF	-1.6234* (0.0523)	-0.4923 (0.3012)

Table 9 shows the best lag length for the model employing MBIC, MAIC, and MQIC criteria. The model with the smallest lag length is regarded as best since it implies a better fit with fewer parameters. Validated cross-correlation analysis confirms the one-lag model strikes an appropriate balance between parsimony and goodness of fit.

Model Estimation

Table 10 compares the predicted coefficients and standard errors for several economic variables using three different estimators: PMG, MG, and DFE. The results of every estimator are examined to determine the influence and importance of these factors on the dependent variable. With a 5% level of significance, the PMG and MG models revealed notable short run ECT. Rates of 68.23% and 41.23% per period, respectively, corresponded with deviations from long run equilibrium. The PMG model showed faster adaptation, while the DFE model's coefficient was non-significant, indicating it may not properly capture short run adjustments.

Table 10. Results of PMG, MG, and DFE Estimators.

Variables	PMG Coefficient	PMG Std. Err	MG Coefficient	MG Std. Err	DFE Coefficient	DFE Std. Err
Short Run						
ECT p-value	-0.6823** (0.035)	0.037	-0.4123*** (0.004)	0.1134	0.0089 (0.774)	0.019
D.EC p-value	583.4* (0.082)	581.2	423.5 (0.367)	487.4	1,934*** (0.00)	207.3
D.GDP p-value	3,987.2** (0.023)	1,487.3	4,912.3** (0.019)	1,678.2	4,123.4*** (0.006)	1,523.1
D.GDP² p-value	-1.9823 (0.143)	13.812	1.423 (0.127)	14.712	-0.5234*** (0.006)	0.1923
D.FDI p-value	-0.00003 (0.192)	0.0000	-0.00005* (0.073)	0.00003	0.0000 (0.367)	0.0000
Constant p-value	1,234,823 (0.434)	162,341	564,832 (0.193)	432,123.4	234,123.4** (0.034)	109,312.3
Long Run						
EC p-value	5,423.2*** (0.00)	752.3	1,189.2 (0.342)	1,234.4	-26,512.3 (0.804)	102,341.2
GDP p-value	-5,623.4** (0.031)	2,612.3	5,987.4 (0.423)	7,123.4	139,234.1 (0.789)	498,123.4
GDP² p-value	-0.1023 (0.812)	0.4234	-1.2934 (0.463)	17.623	-21.3423 (0.781)	742.312
FDI p-value	0.0001*** (0.003)	0.00004	0.00021 (0.154)	0.0001	-0.0011 (0.821)	0.0051

With coefficients of 3,987.2 in PMG, 4,912.3 in MG, and 4,123.4 in DFE, GDP has a significant positive effect on GHG emissions in the short run across all models, showing its relevance in the near term. The quadratic form of GDP is relevant only in the DFE model in the short run, pointing to a negative short run quadratic effect. Across all models, foreign direct investment has little effect and is mostly not significant in the short run. While the MG and DFE models fail to capture significant long run effects, the PMG estimator reveals a considerable positive long run link between energy usage and GHG emissions. The PMG model's ability to accurately represent long run equilibrium relationships and short run dynamics makes it the estimator of choice in this study.

Selection of Model

The chi-square statistic for the PMG and MG models is 5.23, signifying no substantial difference; hence either model would be appropriate for the data. The PMG and DFE models have chi-square values that are not noticeably different, suggesting equal suitability. The MG and DFE models also show no notable discrepancy. Hence, the PMG model is warranted since it displays relatively slight variance from the other models.

Table 11. Hausman Test.

Model	Chi-Square	p-value
PMG, MG	5.23	0.43
PMG, DFE	0.03	1.00
MG, DFE	0.00	1.00

*** p < .01; ** p < .05; * p < .10

The PMG estimation results for DKI Jakarta, West Java, East Java, and Bali reveal different economic dynamics as shown in Table 12. With an ECT of -1.634, West Java has the most rapid shift toward equilibrium, indicating swift adjustment capacity consistent with its status as an investment-intensive industrial province. DKI Jakarta shows a moderate but statistically significant adjustment rate. East Java and Bali exhibit slower adjustment rates, with FDI showing a negative effect on short run growth in Bali, plausibly linked to the high sensitivity of Bali's tourism-driven economy to external shocks. Mali shows a more reactive economy with significant short run impacts from energy use. The findings point out variations in the rate of adjustment to equilibrium and the influence of economic factors across these four Indonesian provinces.

Table 12. Short-Run Results of PMG by Each Province.

Variables	DKI Jakarta Coeff.	DKI Jakarta Std. Err	West Java Coeff.	West Java Std. Err	East Java Coeff.	East Java Std. Err	Bali Coeff.	Bali Std. Err
ECT p-value	-0.1034** (0.018)	0.4112	-1.634*** (0.009)	0.6234	-0.0167*** (0.003)	0.0058	-0.0142** (0.019)	0.0056
D.EC p-value	563.2 (0.401)	523.1	1,834.2** (0.041)	854.3	434.2*** (0.00)	128.1	-52.4 (0.281)	43.8
D.GDP p-value	6,123.4 (0.274)	5,512.3	7,123.2 (0.172)	5,023.1	2,934.1 (0.291)	2,743.2	-84.2 (0.823)	372.1
D.GDP^2 p-value	-5.923*** (0.00)	15.712	-0.2823 (0.856)	15.312	-2.0123** (0.033)	0.9312	0.0712 (0.131)	0.0462
D.FDI p-value	-0.00002 (0.864)	0.0013	-0.00001 (0.123)	0.0000	0.7823*** (0.000)	0.00002	-0.0001*** (0.00)	0.000002
Constant p-value	39,234.2 (0.314)	125,123.4	612,123.4** (0.032)	281,234.1	-96,812.3 (0.104)	58,912.4	-37,423.4 (0.219)	30,234.1

The results from the post-estimation diagnostic tests provide insights into the assumptions of the fitted model as shown in Table 13.

Table 13**.** Post Estimation Tests.

Test Name	Test Value	Probability
Breusch Pagan test	4.12*	0.0789
Pearson CD test	4.12*	0.0612
Jarque-Bera Test	248.3***	0.0031

*** p < .01; ** p < .05; * p < .10

The Breusch-Pagan test examines for heteroskedasticity; the test confirms the null hypothesis of homoskedasticity with results of 4.12 and a p-value of 0.0789 at the 5% significance level, suggesting constant variance in the residuals. The Pearson CD test indicates little evidence of serial correlation in residuals at the 10% significance level. With a test statistic of 248.3 and a p-value of 0.0031, the Jarque-Bera test rejects the null hypothesis. Generally speaking, diagnostic tests show violations of normality and minor serial correlation in residuals, despite heteroskedasticity not being a significant issue.

Test of Panel Causality

Highlighting several important connections between economic factors, the Dumitrescu and Hurlin (2012) Granger non-causality test results are summarised. Remarkably, GHG emissions Granger-cause GDP, implying that variations in GHG emissions precede fluctuations in GDP, while GDP does not Granger-cause GHG emissions. GDP^2 exhibits considerable bidirectional causality with GDP, pointing to a strong two-way interaction. EC Granger-causes FDI; however, FDI does not Granger-cause GHG emissions, and EC does not Granger-cause GHG emissions. FDI Granger-drives GDP while GDP does not. The results show significant causal impacts mainly involving GHG emissions, GDP, and GDP^2, with little or no significant causality observed in other variable pairs.

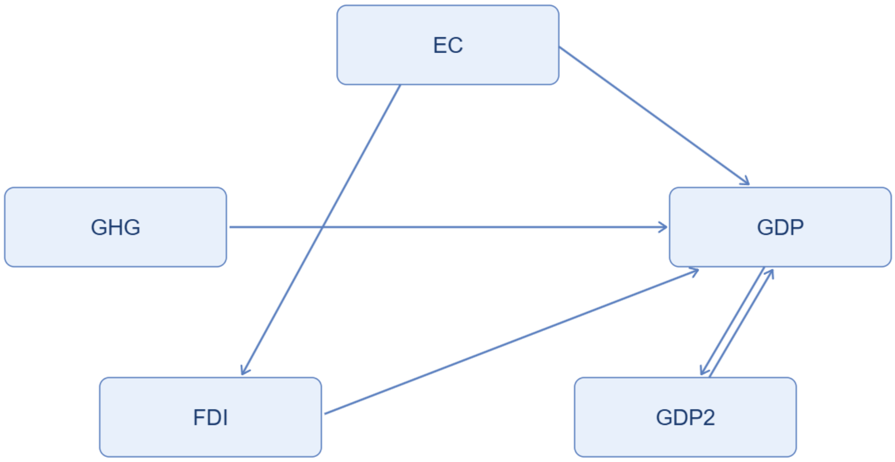

Fig 3. Result of Causality test.

The Reality of the EKC Hypothesis

Among the econometric panels, the long run estimators acquired from the PMG framework present strong evidence for the EKC hypothesis in Java and Bali. The model's negative coefficient on the GDP squared variable shows an inverted U-shaped relationship between economic expansion and environmental damage. This implies that when provinces reach greater income levels, the negative impact of economic growth on the environment diminishes and eventually reverses. The results suggest that, on average, provinces inside the panel experienced an increase in environmental damage as they moved from lower to middle income levels, but that this trend is beginning to reverse as DKI Jakarta approaches higher income thresholds, thereby lowering its environmental impact relative to earlier development stages.

A comparative examination of EKC patterns across DKI Jakarta, West Java, East Java, and Bali shows noteworthy differences in the link between environmental deterioration and economic growth. DKI Jakarta, with the highest per capita income, shows the most advanced EKC trajectory, with cleaner service sector activity and greater environmental regulatory capacity starting to generate environmental dividends. West Java displays early EKC characteristics wherein economic growth continues to drive more environmental damage, reflecting the ongoing expansion of manufacturing activity that has not yet reached the turning point income threshold. East Java occupies an intermediate position, with some evidence of a turning point beginning to emerge as the province diversifies beyond heavy industry. Bali presents a distinctive EKC pattern where the tourism-oriented economic structure generates lower per capita emissions than comparably sized industrial provinces, and where environmental consciousness tied to the provincial brand provides an endogenous moderating force on emissions growth. These findings are consistent with the pattern observed by Tukhtamurodov et al. (2024) across BRICS economies, where income heterogeneity shapes the position of individual entities along the EKC trajectory at any given point in time.

The heterogeneity in economic and ecological dynamics across Java-Bali is emphasised by these results, which also underline the various degrees of economic development and environmental management approaches among the studied provinces. The variations in EKC patterns highlight the intricate interaction between economic expansion and environmental sustainability, shaped by province-specific policy frameworks, economic structures, and levels of environmental consciousness.

CONCLUSION

The research emphasises the complex links between economic expansion, foreign direct investment, energy use, and greenhouse gas emissions across DKI Jakarta, West Java, East Java, and Bali. Particularly in the short run, the results show that GHG emissions have the strongest and most consistent positive association with energy consumption. This emphasises how quickly energy consumption affects the environment and how important it is to transition toward renewable energy sources to slow climate change. The long run persistence of this connection underscores the need to reduce dependency on fossil fuels across Java's power generation and manufacturing sectors. The positive short run relationship between GDP and emissions reflects the continuing dependence of these provinces on energy-intensive economic activities. These results highlight the need for more efficient energy use and a quicker transition to cleaner energy sources. The weak yet favourable correlation between emissions and economic growth weakens over time. Although this result partly contradicts findings from economies at a similar stage in Africa (Halliru et al., 2020), it implies that initially economic growth raises emissions but may generate environmental benefits as provinces adopt more environmentally friendly technologies.

FDI plays a challenging part in environmental outcomes. In the short run, FDI shows little connection with emissions, but in the long run it significantly affects environmental deterioration. This emphasises the need for sustainable investment policies to strike a balance between economic development and environmental consciousness. Without suitable legislation, outside investments can cause environmental damage, underscoring the necessity of aligning foreign direct investment to sustainability targets. West Java and East Java's industrial estate zones, which absorb the majority of manufacturing-oriented FDI, require stricter environmental impact assessment requirements and emissions performance standards for incoming investors. A comparative analysis reveals noteworthy differences in financial responses to long run equilibrium across provinces. DKI Jakarta leads with the fastest adjustment and benefits from short run energy consumption effects, while West Java, with the highest industrial FDI, shows the strongest environmental pressure. Bali's economic rigidity under FDI shocks may reflect the seasonal nature of tourism investment flows and heightened sensitivity to external disruptions, as evidenced by the negative FDI values recorded in certain years.

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