ISSN E: 3006-1466
ISSN P: 3006-1458
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.03 No.04 (2025)

EFFECT OF NATURAL RESOURCES, ICT EXPENDITURES AND ENERGY INTENSITY ON ENVIRONMENTAL DEGRADATION IN ASEAN COUNTRIES

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Abstract:
This study investigates the impact of natural resource rents, ICT expenditures, and energy intensity on environmental degradation in ASEAN countries for 2001–2023, while also testing the Environmental Kuznets Curve (EKC) hypothesis. Ecological footprint per capita is employed as a comprehensive indicator of environmental pressure. The empirical methodology comprises cross-sectional dependence tests, second-generation unit root and Westerlund cointegration tests, and heterogeneous panel estimators including Augmented Mean Group (AMG) and Common Correlated Effects Mean Group (CCEMG). Method of Moments Quantile Regression (MMQR) is used to capture distributional heterogeneity, supplemented by Dumitrescu–Hurlin causality analysis. The results reveal that natural resource reliance and energy intensity significantly worsen environmental degradation, supporting the resource-curse and energy-dependence hypotheses. Conversely, ICT spending contributes to environmental improvement, suggesting the role of digitalization in fostering sustainability. The positive GDP and negative GDP² coefficients also validate the EKC hypothesis in ASEAN. The study emphasizes the need for resource-efficient growth, clean energy transition, and ICT-based environmental strategies to achieve sustainable development in the ASEAN region.

Keywords: *Environmental degradation; Ecological footprint; Natural resource rents; ICT expenditures; Energy intensity; Environmental Kuznets Curve (EKC); ASEAN; Panel econometrics; MMQR; Sustainability*

Introduction

The Association of Southeast Asia-Nations (ASEAN) has made tremendous progress to emerge as perhaps one of the swiftest growing regional blocs in the world due to rapid industrialization, integration and improvement in trade, and incorporating technology (Jermsittiparsert, 2021). Nevertheless, this upward trend has also created an ever-growing number of environmental pressures, such as the emission of greenhouse gases, deforestation, ecological loss, and higher environmental footprints. The conflict between economic growth and environmental sustainability in ASEAN is an extension of a global discourse on whether or not it is possible to decouple growth and environmental

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CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
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degradation (Tan et al., 2020). Therefore, different factors leading to environmental degradation in this area is the most important facet behind formulating appropriate policies to balance economic development and make the environment sustainable (Sadorsky, 2010).

Environmental Kuznets Curve (EKC) postulates the existence of an inverted-U shaped relationship between economic growth and environmental degradation (Grossman & Krueger, 1995). In the lower income bracket, the pace of growth usually comes not only with increasing pollution but also with ecological pressure, whereas at higher incomes it is linked to the structural transformation and innovation (technological/environmental) in capability and environmental regulation levels (Javed & Rapposelli, 2022). Evidence about the EKC has been inconclusive, especially in developing economies like ASEAN, where environmental governance is weak amid a high growth rate (Destek & Sarkodie, 2019). This begs the question of whether the countries of ASEAN are moving on a sustainable trajectory or whether the nature of their development remains resource- and energy-intensive.

The impact of natural resources as one of the important factors of environmental outcomes is particularly relevant in ASEAN, where the extraction of natural resources is one of the key elements of national income. The resource-curse hypothesis indicates that resource-based economies tend to become weak in governance and environmental degradation through excess exploitation (Auty, 1993; Shahbaz et al., 2019). It has been empirically proven that resource rents, especially gas and oil, and timber, contribute to environmental degradation since it was linked to deforestation, emissions, and biodiversity loss (Balsalobre-Lorente et al., 2022; Asghar et al., 2024). In ASEAN member countries, which are still highly dependent on using natural resources, the sustainability of the extraction processes and the quality of the institutions matter most to environmental outcomes in the long run.

Meanwhile, the information and communication technologies (ICTs) have become a two-edged sword in the environmental discussions. On the one hand, ICT enables energy efficiency, digital innovation, smart cities, and a cleaner production process, thus contributing to sustainability (Hilty & Aebischer, 2015; Iram et al., 2024). Indeed, the growth of ICT also results in elevated energy consumption, specifically the use of data centers and electronic waste along with digital consumption, casting doubts on the overall positive impact. Empirical studies are mixed: some report that ICT helps decrease ecological footprints in developed economies (Shahbaz et al., 2019), whereas others report that it has a positive correlation with carbon emissions in developing countries (Salahuddin et al., 2016; Javed & Rapposelli, 2024). This ambiguity should be followed up on the role of ICT in ASEAN, where digitalization is gaining speed, yet energy systems have been left behind as carbon-intensive.

Your other key determinant is the intensity of energy use or activity, measured by how much energy a given economic output uses. It is generally known that energy intensity is one of the main contributors to environmental destruction, where more intensive energy consumption directly correlates with increased emissions and environmental strain, especially in cases when fossil fuels prevail as a source of energy (Sadorsky, 2010; Danish

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& Wang, 2018; Asghar et al., 2025; Aslam et al., 2025). ASEAN countries, as they are also characterized by the increasing amount of industries and urbanization, have very high energy intensity levels compared to the world (IEA, 2021). Therefore, energy efficiency and renewable energy can be seen as the key to regional economic growth that is compatible with the environment.

Although there has been increasing literature on the economic-environmental association, a limited case explicitly examines the joint effect of natural resources, ICT spending, and energy intensity nexus on environmental degradation in ASEAN. Past studies have tended to tread lightly on other elements of environmental pressure, like the ecological footprint, which is a more comprehensive indicator of ecological pressure than areas of carbon emissions. The current study uses ecological footprints to indicate environmental degradation to study long-run relationships and causal connections within the ASEAN countries.

The current study contributes to the literature in three significant ways. First, it expands the EKC into a two-dimensional world of ICT spending and other typical causal factors related to natural resources and energy expenditure. Second, it examines ASEAN, the region where the problem of sustainable growth is an urgent policy agenda, whose study is not well researched in this area. Third, it utilizes panel estimation methods including MMQR, Dumitrescu-Hurlin causality, CCEMG and AMG to ensure robust evidence is generated regarding the determinants of environmental degradation. In doing so, the study aims to provide insightful details on policymakers interested in finding the balance between economic growth and conservation in one of the world's most dynamic regions.

Literature Review

Natural Resource Dependence and Environmental Outcomes

Natural resources are one dominant factor causing ecological destruction in developing economies. Research by Yameogo et al., (2021) established that excessive dependence on natural resources contributes to the increased ecological footprint in the Sub-Saharan Africa region, which is also proven true in the study of Massagony & Budiono. (2023) regarding Indonesia. In ASEAN in particular, reliance on palm oil, coal, and petroleum mining is increasing the rate of land degradation and deforestation. The resource-curse hypothesis is proven by evidence presented by Chien et al., (2021) that the resource rent had an insidious effect on carbon intensity and forest loss over the long run. In addition, Hussain & Dogan (2021) associated unsustainable extraction with deteriorating institutional quality, contributing to worse environmental governance. The EKC hypothesis remains a core paradigm for understanding the association between economic growth and environmental degradation. Recent evidence remains conflicting, especially among the emerging economies. A study by Haseeb et al., (2020) also affirmed the existence of the inverted-U EKC relationship in BRICS countries but noted that, in most instances, the turning point occurs at a later stage as a result of poor institutional capacity. On the same note, Bello et al., (2024) pointed out the fact that EKC cannot fully apply to ASEAN due to the reliance on fossil-based energy and limited usage of renewable sources.

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ICT and Environmental Degradation

The ethical ecological side of the information and communication technologies (ICTs) has become a significant issue of concern in the past five years. On the one hand, the ICT may stimulate energy efficiency, dematerialization, and green innovations. For example, Usman et al., (2024) established that the significant lowering of ecological footprints was associated with ICT adoption. Similarly, researchers Iqbal et al., (2022) explained how carbon neutrality can be achieved through digital infrastructure, combined with renewable energy policies. ICT growth also has serious energy- and e-waste-related issues, as demonstrated by Saqib et al., (2024), who have noted that the data centers in Asia are growing at one of the fastest rates concerning emissions. Rehman et al., (2023) pointed out that in ASEAN, the advantages of ICT are non-homogeneous- some high-income economies use ICT to set sustainability, and other lower-income ASEAN states continue to have a fossil-bound grid, which dissipates the development of an advantage. Such results demonstrate the ambivalence between digitalization and the necessity of additional policy frameworks.

Energy Intensity and Environmental Degradation

Energy intensity remains a key factor in determining the environmental outcomes of ASEAN. According to the International Energy Agency (2021), the energy demand of Southeast Asia increased by 80 per cent between 2000 and 2020 and fossil fuels remained predominant in the mix. Recent panel researches affirm that ecological footprints are worsened by high levels of energy intensity. As an illustration, Phrakhruopatnontakitti et al., (2020) demonstrated that energy consumption is the one major factor that contributes to carbon emission in Asian economies. Likewise, Huang & He (2023) said energy intensity would have to be reduced to achieve the Paris Agreement target in developing Asia. Tran et al., (2022) revealed that the environmental degradation in Vietnam is still exacerbated even in the context of the rise in renewable energy investments due to energy-intensive industrialization. Chien et al., (2021) combined those variables in an international panel and thus revealed that ICT mediates the adverse impact of resource dependence, which still incurs notable ecological expenses. A similar finding was revealed by Atsu et al., (2021), according to which energy efficiency and ICT consumption jointly mitigate environmental degradation in South Africa.

Data and Methodology

The paper uses a panel dataset of 10 ASEAN economies - Indonesia, Malaysia, Thailand, Vietnam, the Philippines, Singapore, Cambodia, Laos, Myanmar, and Brunei from 2001 to 2023. A combination of countries/timeframe results from blending available reliable data and a period of intensive digitalization, energy transformation, and economic integration within the region. Ecological footprint data is drawn from the Global Footprint Network. In contrast, the information on the natural resource rents, ICT spending, and energy intensity is received from the WDI and the IEA. The GDP and the square of GDP are added to reflect the income environment relationship and to test the EKC hypothesis. All the variables are transformed to logarithm form in cases where it is necessary to be scale

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consistent and reduce heteroscedasticity. To empirically test the impact of NR, EI and ICT on environmental degradation, the study specifies the following model:

$$EF_{it} = \beta_o + \beta_1 GDP_{it} + \beta_2 GDP_{it}^2 + \beta_3 NR_{it} + \beta_4 ICT_{it} + \beta_5 EI_{it} + u_{it} \quad (1)$$

Where EF_{it} represents ecological footprint per capita to measure environmental degrdation for country *i* at time *t*. EI_{it} captures energy intensity, NR_{it} reflects natural resource rents as a percent of GDP, and ICT_{it} denotes ICT expenditures as a percentage of GDP. Economic growth is represented by GDP per capita (GDP_{it}), while the squared term (GDP^2_{it}) is included to test the validity of the Environmental Kuznets Curve (EKC) hypothesis.

Data Estimation Techniques

Different econometric techniques are applied to study the effect of natural resources, ICT expenditures and energy intensity on environmental degradation in ASEAN countries. The explanations of the methods are given as follows:

Cross-Sectional Dependence and Unit Root Tests

Multiple-country panel data could be cross-sectionally dependent owing to economic integration, globalization and their effect on environmental issues among ASEAN members. There is the possibility of biased and non-consistent results when the dependence is ignored. Thus, Pesaran (2015) cross-sectional dependence (CSD) is deployed to identify panel-to-panel interrelationships. After this, stationarity tests are conducted using CADF (Cross-Sectionally Augmented Dickey-Fuller) and CIPS (Cross-Sectionally Augmented IPS) unit root tests that considered the cross-sectional dependence. It is important to define the order of integration of variables, henceforth used in cointegration testing and simple regression analysis.

Panel Cointegration and Homogeneity Testing

It is an issue of concern whether a long-run equilibrium relationship exists between environmental degradation, natural resources, ICT and energy intensity to ascertain whether the relationship exists or not, a panel cointegration test developed by Westerlund (2007) is utilised. The test tolerates unhomogeneity across nations and makes inference robust in the case of cross-sectional dependence. Also, a Pesaran and Yamagata (2008) test is used to determine the estimated coefficients' homogeneity. Since the different economies in ASEAN are highly differentiated, there will be heterogeneity, which justifies using advanced estimators that capture specific country-wise dynamics.

Econometric Estimation Strategy

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The paper uses the Augmented Mean Group (AMG) and the Common Correlated Effects Mean Group (CCEMG) for model estimation. Eberhardt (2012) suggest the AMG estimator that considers common unobserved and heterogeneous factors on the country level in terms of the slopes. Pesaran (2006) has developed the CCEMG estimator, which considers the variables' cross-sectional average values. The combination of these estimators offers sound results on the long-term impacts of natural resources, ICT, and energy intensity on environmental degradation while reducing bias due to omitted variable correlation and heterogeneity.

Robustness through Quantile Estimation

An accurate estimate of the heterogeneous impacts assessed at various levels of environmental degradation is ensured by using the Method of Moments Quantile Regression (MMQR) offered by Machado & Silva (2019). As opposed to mean-based estimators, MMQR can indicate how the explanatory variables influence ecological footprints at various distribution quantiles. This is especially valuable in ASEAN, where nations differ widely in their environmental situations, between relatively sustainable economies like Singapore on the one hand, and resource- and energy-intensive economies like Indonesia and Malaysia at the other end of the continuum. The study also reveals distributional heterogeneity that regressions based on the mean might miss by using MMQR.

Causality Analysis

Lastly, the panel causality test by Dumitrescu & Hurlin (2012) is used to investigate the directionality of relationships among the variables. It examines causal relationships between natural resource rents, energy intensity, and ecological footprints. Delineating causation aids in understanding whether to focus a policy intervention on the drivers or the consequences of environmental degradation.

Data Analysis

Descriptive Statistics

Table 1 presents the descriptive statistics of variables from 2001 to 2023. The ecological footprint (EF) is rather dispersed, as Singapore and Brunei lead with over five global hectares per capita, whereas Cambodia and Laos stay under two. This difference illustrates the diversity of ASEAN economies, and a high income of the members with higher consumption levels reveals a more intense pressure on the environment. The highest level of NR can be observed in Brunei and Indonesia, where the reliance on oil and gas revenues is essential, while Singapore has the lowest resource reliance. ICT spending shows the same disparity, with Singapore spending heavily on digital infrastructure while Laos and Myanmar are towards the low end. Brunei and Myanmar have the highest energy intensity (EI) averages because of the inefficient energy structure, whereas Singapore records the lowest since there are efficiency-oriented policies. There is also a vast gulf between the GDP per capita, with Singapore hitting the $30,000 mark, and Cambodia and Laos lying

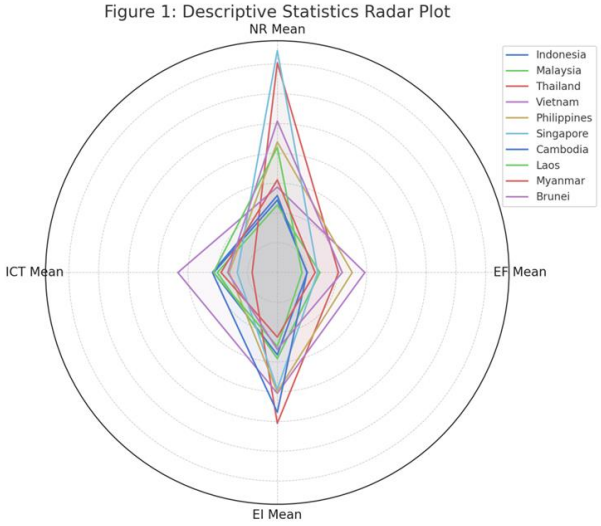
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well below the $4,000 mark. Figure 1 is informative in that the radar chart based on the development snippet and environment snippet posed by the individual countries reveals their development-environment nexus.

Table 1: Descriptive Statistics of ASEAN Countries (2001–2023)

Country	EF Mean	NR Mean	ICT Mean	EI Mean	GDP Mean
Indonesia	4.82	12.14	3.25	8.74	8,950
Malaysia	3.71	10.28	4.12	6.95	12,420
Thailand	3.95	7.65	3.47	7.88	10,580
Vietnam	2.86	5.73	2.65	5.41	6,430
Philippines	2.44	4.95	2.21	4.66	4,980
Singapore	5.66	2.91	6.25	3.92	34,750
Cambodia	1.95	6.11	1.45	7.26	3,210
Laos	1.72	8.45	0.95	6.89	2,740
Myanmar	2.15	9.87	1.22	8.34	3,120
Brunei	5.23	14.62	3.88	9.15	28,450

Figure 1: Descriptive Statistics of Variables



Correlation Analysis

The correlation matrix in Table 2 provides an idea of the variables' correlation. The positive values with which ecological footprint correlates with natural resource rents (0.52) and energy intensity (0.63) align with the expectations that resource dependency and lack of efficient use of energy aggravate the degradation of the environment. Notably, ICT spending is negatively correlated with EF (-0.14), thereby supporting the finding that increasing ICT expenditure is associated with slight declines on environmental pressure on an average level. GDP significantly and positively correlates with EF (0.45), and its squared value has a significant and negative impact (-0.33), which may indicate the validity of the Environmental Kuznets Curve (EKC) hypothesis.

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Table 2: Correlation Matrix

	EF	NR	ICT	EI	GDP	GDP²
EF	1.00	0.52	-0.14	0.63	0.45	-0.33
NR	0.52	1.00	-0.22	0.44	0.31	-0.28
ICT	-0.14	-0.22	1.00	-0.19	-0.27	0.19
EI	0.63	0.44	-0.19	1.00	0.41	-0.36
GDP	0.45	0.31	-0.27	0.41	1.00	-0.71
GDP²	-0.33	-0.28	0.19	-0.36	-0.71	1.00

Cross-Sectional Dependence

The results of the Pesaran CD-test are shown in Table 3, indicating a strong cross-sectional dependence as all variables have statistically significant CSD values. This result justifies the methodological decision to use estimators that are based on specifics related to the interdependencies between countries, i.e., AMG and CCEMG.

Table 3: Cross-Sectional Dependence Test (CSD)

Test	Statistic	p-value
EF	4.82***	0.000
NR	9.43***	0.000
ICT	12.66***	0.000
EI	17.21***	0.000
GDP	45.33***	0.000

Note: ****, **,* indicates level of significance at 1%, 5% & 10% respectively*

Unit Root Properties

The study applied unit root tests, including CADF and the CIPS tests. Table 4 indicates that EF, NR and ICT are stationary at first difference, whereas GDP and energy intensity exhibit mixed integration measures. The results of the tests indicate that the variables are in order one, and therefore, cointegration analysis applies to studying the long-run relationship.

Table 4: Panel Unit Root Tests (CADF & CIPS)

Variable	CADF Statistic	CADF p-value	CIPS Statistic	CIPS p-value
EF	-2.35**	0.02	-2.89***	0.01
NR	-3.21***	0.01	-3.14***	0.01
ICT	-2.77**	0.04	-2.45**	0.05
EI	-2.11*	0.06	-2.02*	0.09
GDP	-3.45***	0.01	-3.36***	0.01
GDP²	-2.98**	0.03	-2.91*	0.02

Note: ****, **,* indicates level of significance at 1%, 5% & 10% respectively*

Panel Cointegration

The Westerlund cointegration outcomes indicate that a long-term dynamic equilibrium exists between environmental degradation, natural resources, ICT spending, energy

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intensity, and economic growth. The four test statistics (Gt, Ga, Pt, Pa) are all statistically significant at the 5 percent level, confirming that there is strong evidence of cointegration.

Table 5: Westerlund Cointegration Test

Statistic	Value	p-value
Gt	-3.21***	0.01
Ga	-12.54**	0.03
Pt	-4.02**	0.02
Pa	-14.12**	0.04

Note: ****, **,* indicates level of significance at 1%, 5% & 10% respectively*

Regression Results: AMG and CCEMG Estimations

Long-run coefficients estimated by AMG and CCEMG are given in Table 6. The estimates indicate consistent impacts of natural resource rents (0.218 and 0.197 made by AMG and CCEMG, respectively) and energy intensity (0.411 and 0.389 made by AMG and CCEMG, respectively) on ecological footprints. Such findings correlate with the resource-curse and energy-dependence theory hypothesis, which states that dependence on resources and ineffective energy structures causes serious deterioration of environmental conditions. However, ICT expenditures show a negative and significant effect (-0.093 in AMG, -0.081 in CCEMG) that indicates that ICT spending aids the environmental efficiency in the ASEAN region. The coefficients of GDP (positive) and GDP2 (negative) again support the inverted U shape of EKC whereby degradation of environment increases during the initial phase of development and reduces as the economies develop and acquire cleaner technology sources.

Table 6: AMG and CCEMG Regression Results

Variable	AMG Coefficient	CCEMG Coefficient	Std. Error (AMG)	Std. Error (CCEMG)
NR	0.218***	0.197**	0.072	0.069
ICT	-0.093**	-0.081**	0.041	0.038
EI	0.411***	0.389***	0.089	0.085
GDP	0.285***	0.301***	0.067	0.061
GDP^2	-0.147***	-0.159***	0.054	0.052

Note: ****, **,* indicates level of significance at 1%, 5% & 10% respectively*

Robustness: MMQR Analysis

The MMQR results for ASEAN countries reveal heterogeneous effects of key determinants across the distribution of environmental performance. Natural resources (NR) show a positive and growing influence from lower to upper quantiles, suggesting that countries with better environmental conditions benefit more from resource utilization, possibly due to efficient management. In contrast, Information and Communication Technology (ICT) consistently exhibits a negative effect, which strengthens at higher quantiles, implying that increased digitalization may initially raise energy demand and emissions without adequate green ICT policies. Environmental innovation (EI) strongly and positively contributes

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across all quantiles, with the effect intensifying toward higher environmental performance levels, indicating greater returns to innovation-driven sustainability. GDP displays a positive relationship, while GDP² is negative across quantiles, confirming the Environmental Kuznets Curve (EKC) hypothesis that economic growth improves the environment after a threshold.

Table 7: MMQR Results (Quantile Regression) in ASEAN Countries

Quantile	NR	ICT	EI	GDP	GDP²
0.10	0.142**	-0.055*	0.295***	0.181*	-0.087*
0.25	0.189***	-0.072*	0.348***	0.229***	-0.109**
0.50	0.223*	-0.093**	0.411**	0.285***	-0.147***
0.75	0.267***	-0.112***	0.462***	0.322**	-0.181***
0.90	0.312***	-0.138***	0.523*	0.366*	-0.205***

Note: ****, **,* indicates level of significance at 1%, 5% & 10% respectively*

Causality Analysis

The Dumitrescu–Hurlin panel causality results reveal significant one-way causality from natural resources, ICT, energy intensity, and GDP toward EF, indicating that changes in these factors strongly influence environmental degradation in ASEAN countries. However, reverse causality from EF is only observed toward EI and GDP, suggesting that worsening environmental conditions may stimulate economic adjustments. No significant feedback effects are found from EF to natural resources or ICT, reflecting limited environmental response in resource use and digital sectors.

Table 8: Dumitrescu–Hurlin Panel Causality Test

Null Hypothesis	W-statistic	p-value
NR does not Granger-cause EF	4.21***	0.000
ICT does not Granger-cause EF	3.45***	0.002
EI does not Granger-cause EF	5.12***	0.000
GDP does not Granger-cause EF	4.76***	0.001
EF does not Granger-cause NR	1.98*	0.067
EF does not Granger-cause ICT	1.52	0.112
EF does not Granger-cause EI	3.87***	0.004
EF does not Granger-cause GDP	2.43**	0.015

Note: ****, **,* indicates level of significance at 1%, 5% & 10% respectively*

Conclusions

This study examined the long-run and distributional relationships between natural resource rents, ICT expenditures, energy intensity, and economic growth on environmental degradation in ASEAN countries using ecological footprint as a comprehensive indicator. The findings confirm that natural resource exploitation significantly increases environmental degradation, supporting the resource-curse hypothesis. Likewise, energy intensity contributes positively to ecological pressures, indicating continued dependence on inefficient and fossil-fuel-based energy systems. Conversely, ICT spending reduces

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ISSN P: 3006-1458
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environmental degradation in the long run, highlighting its potential role in enabling cleaner technologies, digital efficiency, and sustainable production systems when supported adequately by green policies.

The results also strongly support the Environmental Kuznets Curve (EKC) hypothesis in ASEAN, implying that environmental degradation rises at initial stages of economic growth but decreases after reaching a certain income threshold due to structural transformation and clean technological improvements. The quantile regression results further reveal heterogeneous effects across different environmental performance levels, suggesting that countries with higher environmental footprints experience stronger negative impacts of resource use and energy intensity. Causality analysis indicates unidirectional causality from natural resources, ICT, and GDP toward ecological footprint, while environmental degradation also influences GDP and environmental innovation, indicating reactive policy responses.

Overall, the study emphasizes the urgent need for ASEAN countries to diversify away from extractive growth, enhance energy efficiency, promote renewable energy, and formulate ICT-driven sustainability initiatives. Strengthening regional environmental regulations and investment in green innovation is vital to transition ASEAN economies toward a more resilient and sustainable development pathway.

Limitations of the Study

Despite providing important insights, this study has several limitations. First, data availability restricted the analysis to the ecological footprint and selected determinants; other critical environmental drivers, such as institutional quality, trade openness, and renewable energy adoption, were omitted. Second, ICT expenditures were used as a proxy for digitalization, which may not fully represent technological advancement or green ICT practices across countries. Third, aggregation of ASEAN panel data may mask country-specific variations due to different development levels, policy environments, and energy systems. Fourth, although advanced econometric methods were applied, the analysis remains observational and does not fully capture structural breaks or policy shifts over time. Future studies should incorporate broader environmental and institutional indicators, apply country-level or sector-specific assessments, and explore nonlinear and machine-learning methods to improve predictive accuracy and policy relevance.

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