International Journal of Multidisciplinary Research and Growth Evaluation.

Effects of energy use and the extraction of natural resources on the sustainability of the environment in ASEAN nations

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Article Info

ISSN (online): 2582-7138
Volume: 06
Issue: 01
January-February 2025
Received: 11-11-2024
Accepted: 12-12-2024
Page No: 475-488

Abstract

Rapid advancement in economies not only accelerates industrial processes but also amplifies the significance of natural resources. The extensive demand of natural resources to inject the industrial and economic growth, in¬deed corrupt the environment and atmosphere, hence creating an ecological deficit. The study, thus, with the help of ASEAN panel data from 2006 to 2020, evaluates the role of natural resource extraction and energy con¬sumption in environmental sustainability. The outcomes of quantile regression and OLS fixed method are robust and point out the positive relationship of natural resource rent with carbon emissions, hence, indicating that the factor significantly increases environmental pollution. Contrastingly, renewable energy consumption mitigates the emissions, hence, pointing out the negative relationship. This inculcates the importance of renewable re¬sources which are needed at a broader level to improve environmental quality. Under the evidence, the effective implementation of energy conservation policies and procedures on natural resources not only helps economies to maintain their economic growth but also keeps up their environmental performance through a single platform.

DOI: https://doi.org/10.54660/.IJMRGE.2025.6.1.475-488

Keywords: Natural resources extraction and consumption, Economic growth, Industrialization, Environmental sustainability, Carbon emissions

1. Introduction

Drastic changes have been witnessed right from the inception of the world. Amongst all, climate change is one of the major problems as an¬thropogenic activities are impairing the dynamics of an ecosystem. As each year passes, issues relating to environmental preservation and sus¬tainability are now the main concern of countries, hence, gaining more popularity in academia. As climate complexities are accelerating, economies, and scientific communities, all around the globe, are searching for ways to address environmental issues and attain sustain¬ability (Ali *et al*., 2019; Hartani *et al*., 2021; Nathaniel *et al*., 2021c; Quynh *et al*., 2022) [14, 49, 99, 114]. Scholars argue that climate change is a core issue that is mainly caused by global warming. However, no serious efforts were being made to curb the cruel and harsh activities which are the reason for environmental destruction. Resultantly, various programs and conferences have been held in past to abate the horrifying effects of climate change. Paris Agreement 2015, SDG goals, Cancun agreement Kyoto protocol are famous due to greater significance. Sadly,

this giant effort turned into a miserable state as 2016 was the year that was docu¬mented as the Earth's warmest year (IEA, 2019; Phuoc *et al*., 2022) [52, 112]. The reason is the harmful emissions that are trapped in the environment has been added in pile since then, hence making the environment more pol¬luted. GHG emissions are the combination of various gases such as "methane, nitrous oxide, carbon dioxide, cholo fluoro carbons", etc. However, carbon amongst all is one of the deadliest gases as it shares 81% portion of GHG emissions. Above all that, factors such as economic growth, increasing population, excessive exploitation of natural re¬sources, and industrialization are the culprits which are making the sit¬uation more unfavorable due to being essential drivers of CO2 (Dong *et al*. 2019; Tenaw and Beyene, 2021; Dong *et al*. 2019; Ulucak and Khan, 2020) [40, 128, 40, 131, 132].

It is imperative to fulfill human needs and for that several expecta¬tions are associated with countries because of which they are required to advance their EG either by extracting minerals from the planet or in¬volving in the sequential process that quenches the thirst of humanity. However, these activities such as industrialization, NR exploration, EC, etc. exert various environmental issues. The non-stop exploitation in-deed affected the global biosphere as in the early 1700s, the global bios¬phere had 50% uninhabited area having 45% semi-natural state, How¬ever, as of now today, the situation is completely different now. Due to rapid growth, 55% of the terrestrial biosphere comes under human use, leaving 25% for a natural state and 20% for a semi-natural state (Aziz *et al*., 2021; Ojogiwa, 2021) [18, 109]. The statistics reveal that the heat production sector and electricity are responsible for 25% of GHG emissions, whereas natural resource exploration, deforestation, and agriculture are responsible for 24% of emissions (Jermsittiparsert, 2021; Nathaniel *et al*., 2020; Zhao *et al*., 2021) [18, 138].

ASEAN abbreviation for "Association of Southeast Asian Nations" is a group of 10 economies namely "Indonesia, Malaysia, Thailand, Myan¬mar, Singapore, Brunei, Vietnam, Philippines, Laos PDR, and Cambo¬dia". The association has been made in order to promote economic and social progress and cultural development. As per statistics, in the past three decades, the EG rate is about 5.5% (Nathaniel, 2021; Wirsbinna and Grega, 2021; Zhao *et al*., 2022) [100, 134, 139]. As collectively, ASEAN region dis¬plays the growth of 5.2% due to which it is viewed as an important "eco¬nomic bloc" as it is predicted to grow further (Haroon *et al*., 2021; Kamarudin *et al*., 2021; Nasir *et al*., 2019) [48, 57, 97]. Since, the world witness commendable economic expansion in said region, however, the envi¬ronmental consequences cannot be ignored. The region is responsible for the continuous upsurging in environmental destruction. Also, the re¬cent natural disaster incidents push the economies to use non-renewable energy in order to sustain economic growth. According to sources, not until recently, no desired attention was given by the said region. However, Singapore is an exception. Also, the sources claim that it has now become the 3rd largest GHG emitter all over the globe (Ahmed *et al*., 2017; Shibli *et al*., 2021) [10, 124]. As far as natural resources are concerned, the ASEAN region has dwelled in a resource-based economy as these resources not only contribute to livelihood but also help them in economic activities. The natural resources, present in the region, comprises natural gas, copper, petroleum, nickel, timber, tin, iron, etc. 82% of natural rubber is produced by ASEAN countries, Similarly, 70%, 56% and 50% of world coconut, tin, palm oil, and hardwood products are produced in the region. Also, most of the countries are rich in petro¬leum and coal which are not climate-friendly (Ahmed *et al*., 2020; Dan-ish *et al*., 2020; Khattak *et al*., 2021) [9, 48].

As economic growth expedites industrialization, however, it is not possible without exploiting natural resources. Nevertheless, the explo¬ration of natural resources such as agriculture, deforestation, and min¬ing leads to environmental distortion (Liu *et al*., 2022b; Nathaniel and Bekun, 2021) [86, 100, 101, 103]. Although natural resource extraction increases income and benefits the economy, however, it declines biocapacity. However, the adoption of sustainable practices in the production and consump¬tion process could benefit the environment (Lan *et al*., 2022; Yilanci and Pata, 2020) [84, 135]. The reason perpetuates the authors to add renewable energy consumption as a study variable. Also, ASEAN region popula¬tion is on constant rise, meanwhile, economic activities also observe significant growth at exponential rate. The environment in these coun¬tries is getting polluted because of harmful emissions, therefore, natural resources and environment come into jeopardy. The availability of nat¬ural resources as well as living resources, on a long-term basis, is the source of perpetual economic progress (Nathaniel *et al*., 2021d; Qureshi *et al*., 2020; Sadiq *et al*., 2022a; Sadiq *et al*., 2023b) [99, 113, 116, 118]. Considering the delicacy of this problem of today's world, the study bases its research on environmental sustainability.

The study considers ASEAN economies to investigate the phenome¬non due to high emissions, unprecedented growth, natural resource abundance, energy consumption patterns, high population growth, and challenges in maintaining environmental sustainability. Sadly, the re¬gion now faces an ecological deficit due to unsustainable natural re¬source practices and excessive non-REC. Hence, it is imperative to ex¬plore the impact of NRR, EG, REC, IND and PG on carbon emissions in ASEAN economies which is the prime objective of the present study. This way, the study attempts to answer various questions such as fol¬lows:

(a) Do NRR, industrialization, population growth, and economic growth accelerates the percentage of carbon emissions?

(b) Does REC consumption mitigate CO2 emissions?

Having this background, the study contributes in several ways. Firstly, the study puts an effort to scrutinize the nexus among NRR, EG, REC, IND, and PG, carbon emissions in the ASEAN region. The complex framework in this unique setting as per the author's knowledge has not been explored fully. Also, the literary work of outline variables shows a contradicting statement when explored with any of them. Secondly, to extend the knowledge further, the study uses a variety of techniques and methods such as Pooled OLS, quantile regression, etc, hence the shreds of evidence drawn from this study will be inclined towards pol¬icy orientation and help economies to grow without distorting the envi¬ronment.

The rest part of the paper is composed as follows: the second part is an analysis of the relationship of study variables through the lens of past studies. The very next portion is a descriptive detail of the ways ap¬plied to collect the information and the process of utilizing that infor¬mation to extract results. After finding the study outcomes, these are

compared to past studies for support, and the implications of the study are described. The study ends with a conclusion and limitations.

2. Literature review

A sustainable environment is a clean environment having an abun¬dance of natural resources with good quality for both the present and future generations because of the minimum and efficient use of re¬sources to meet the present human needs. A sustainable environment gives assurance of social progress with security to human survival, lead¬ing contented lives and active participation in routine functions (Chien *et al*., 2022c, d; Mustapa *et al*., 2020) [28, 95]. The achievement of environmen¬tal sustainability is influenced by natural resources. The natural re¬source rent increases to stimulate human activities. The activities, which include the use of technologies and energy which enhances the greenhouse gases like CO2 emissions, are a great challenge to environ-mental sustainability (Chien, 2021; Chien *et al*., 2022a, b; Sreenath *et al*., 2021) [32, 31, 125]. Thus, the present study examines the impacts of NRR, GDP growth, PG, and IND on CO2 emissions and environmental sustainabil¬ity.

2.1. Natural resources and carbon emissions

Natural resources rents refer to the difference between the market¬ing prices of the units of any natural resource commodity and the costs of producing the units of that commodity (Ainou *et al*., 2022) [13]. The NRR determine the demand for natural resources as well as the extraction and consumption of natural resources. The increase in natural resource extraction enhances the economic, social, and household activities and the linked operational and supporting processes as well. The increase in these activities and processes enhances CO2 emissions on account of the increasing use of energy and emissions of toxic wastes. In this situa¬tion, the natural resources can't be secured for future use in equal quan¬tity, and so it is impossible to achieve environmental sustainability (Abdul Hamid *et al*., 2020; Alvarado *et al*., 2021; Sadiq *et al*., 2022b; Sadiq *et al*., 2023a) [2, 16, 29, 118].

Existing literature has abundant studies which have explored the as¬sociation of natural resources with carbon emission through different econometric estimations either using panel data or time series data (Ali *et al*., 2022) [15]. However, the documented studies are in contradiction with each other as they were conducted in different regions or time pe¬riods (Bai *et al*., 2022) [19]. For suppose, Balsalobre-Lorente *et al*. (2018) [21] studied the relationship of natural resources along with electricity and EG with carbon emissions in 5 EU economies. The authors used the Panel least squares regression model and reported the pieces of evi¬dence in which it was shown that NR and RE based electricity are help-ful in the reduction of carbon emissions. Similarly, Bekun *et al*. (2019) [25] investigated the linkage of EG, EC, and NRR with carbon emissions in 16 EU regions covering the period from 1996 to 2014. According to the study's results, both constructs increase emissions, hence degrading en¬vironmental quality in the EU context. Baloch *et al*. (2019) [20] also exam¬ined the natural resources and carbon emissions in the BRICS context. The authors added EU and EG as well in the framework. The authors found that natural resources as well as trade vitiate the quality of the environment. Aeknarajindawat (2020) [7] used the autoregressive inte¬grated moving average method to explore the connection of natural re-sources to carbon emission in the Malaysian economy by covering the period from 2008 to 2017. The confined results claim that carbon emis¬sions and natural resources share a positive connection with each other. Furthermore, one of the recent studies conducted by Kwakwa *et al*. (2019) [62] used the "Stochastic Impacts by Regression on Population, Af-fluence, and Technology" framework to explore natural resource extraction with carbon emission in Ghana's economy. The results of the study proclaimed that natural resource extraction increases the % of emissions, thus responsible for environmental destruction. Also, natural resource extraction increases the consumption of energy. Shen *et al*. (2021) [123] also scrutinized the said relationship along with another con¬struct named investment in the Chinese economy. The outcomes of the study revealed that natural resources share a positive association with carbon emissions, where green investment is helpful in the reduction of emissions. The study of Khan *et al*. (2020) [51] used the GMM technique to explore the relationship in BRI economies and documented positive evi¬dence. Whereas, the study of Khan *et al*. (2021) [48] exposed that carbon emissions are increased due to natural resources in case of US economy.

Tufail *et al*. (2021) [129], throw light on the role of NRR in environmental sustainability. The study posits that with the increase in the natural re¬source's rents, the production and extraction of natural resources. The use of these resources as a raw material expands the production activ¬ity, and the use of natural resources as a source of energy creates activ¬ity in transportation and infrastructure. Agboola *et al*. (2021) [8], argue that the entire energy consumption in economic operations, societal functions, and households increases as natural resource rents continue to rise. The usage of any type of energy emits hazardous gases such as CO2 directly, as well as indirectly through the conversion of one form of energy into another and through toxic waste emissions. It is impossi¬ble to attain environmental sustainability in these circumstances. The study conducted by Huang *et al*. (2022) [50] was an investigation of the in¬fluences of natural resource rent, urbanization, and financial develop¬ment on carbon emission and environmental sustainability. The data for natural resource rent, urbanization, financial development, carbon emission, and environmental sustainability were collected from the USA for a period from 1995 to 2015. This study posits that if the nat¬ural resources rents are high, the producers try to extract more natural resources, and more quantity of natural resources are available in the market. Thus, the use of these resources as raw material and fuel in¬creases ultimately cause CO2 emissions into the air and can make it dif¬ficult to grow new natural in the future. So, there is no environmental sustainability.

2.2. Energy consumption, economic growth, and CO2 emissions

The gear in population and economic activities boosts the consump¬tion of fossil fuels which causes high emissions all over the globe. En¬ergy, thereby, is an essential part of a production process as it acceler¬ates economic activities, hence, making advancement in the country's economy (Espíndola and Ribeiro, 2020; Salari *et al*., 2021) [42, 120]. Due to strong linkage, scholars have been taking a keen interest to explore the association of carbon emission with socio-economic indicators by using different modeling approaches. According to Bhattacharya *et al*. (2017) [10], EG and energy

consumption are the main drivers of emissions, however, it varies according to country and region.

The results of Begum *et al*. (2015) [22] and Dinh *et al*. (2022) [37] study re¬jected the EKC hypothesis, hence deduced the long-term and positive association of EC and carbon emission in the Malaysian context in the period of 1970–1980. The study of Ahmed *et al*. (2017) [10] and Javid and Sharif (2016) [34], which were conducted in Pakistan and India respec¬tively, found a directional association between the constructs. How¬ever, when Waheed *et al*. (2018) [133] examined it in the Pakistani context, the relationship was found to be negative as the authors specifically tar¬geted renewable energy consumption. Hence, they concluded that higher consumption of renewable energy leads to the reduction of car¬bon emissions. Furthermore, Dogan & Aslan (2017) [39] claimed according to the evidence that energy consumption and carbon emission share bidirectional causal relation in the context of European countries. How¬ever, in GCC economies, mixed pieces of evidence were found by schol¬ars (Bekhet *et al*., 2017; Duong and Hai Thi Thanh, 2022) [23, 38]. The study of Cai *et al*. (2018) [27] explored the nexus among constructs in G-7 nations. However, the results revealed that no cointegration exists among car¬bon emissions, energy consumption, and economic growth in the case of Canada, France, USA, UK, and Italy, whereas the results were oppo¬site in Germany and Japan. Similarly, the study of Acheampong (2018) [3] proclaims the mixed shreds of evidence in 116 countries, hence, accord¬ing to them, the results varied from region to region. A literary work by Shan *et al*. (2021) [122] analyzes the impacts of economic growth on CO2 emissions and environmental sustainability. The study implies that the increase in economic activities increases the use of energy. When a country is succeeding in getting high GDP growth, there is stimulation in economic activities; so, there are high CO2 emissions, and environ¬mental pollution reduces environmental sustainability. Fu *et al*. (2021) [43], also claim that the need for energy sources to carry out technical tasks and run mechanical or electrical equipment rises in nations with signifi¬cant GDP growth. It is difficult to attain environmental sustainability at this time since CO2 emissions are increasing, the atmosphere is becom-ing unhealthy, the quality of natural resources is declining, and the health of living things is declining (Lin *et al*., 2022, 2022b; Moslehpour *et al*., 2022a; b) [85, 94, 119].

2.3. Industrialization, population growth, and carbon emissions

Through empirical research on environmental sustainability, Sulaiman and Abdul-Rahim (2018) [126] examines PG and CO2 emissions. The information for empirical analysis of PG and its impacts on CO2 emissions was acquired from Nigeria over the set of periods between 1971 and 2010 using the ARDL model. The study proclaims that green¬house gas emissions, especially CO2 emissions, are increasing in the countries where the GDP growth rate increases as it is believed to over¬all human activities. The study of Mohsin *et al*. (2021) [91] enumerates the influences of economic development, energy consumption, and popula¬tion growth on CO2 emissions. This study reveals that the rise in popu¬lation increases emissions from both natural and human sources such as respiration, construction, manufacturing, energy generation, trans¬portation, and other technology used in homes and businesses. Due to its negative effects on the natural climate, and environmental re¬sources, including water and land, green resources, and resources from living creatures, the rising CO2 in the air poses a threat to environmen¬tal sustainability. The literary article of Ullah *et al*. (2020) [130] was an inves¬tigation about the relationship of industrialization to CO2 emissions and environmental sustainability. The authors collected the relevant in¬formation for analyzing the impact of industrialization on CO2 emis¬sions in Pakistan's economy over the time from 1980 to 2018 with the help of the nonlinear ARDL model. The study posits that the increase in industrialization increases the activities based on technologies and fos¬sil fuels. The technologies and fossil fuel consumption enhance pollu¬tion emissions like CO2. This restricts the generation of natural re¬sources and destroys the health of living beings which are hurdles to en¬vironmental sustainability (Tan *et al*., 2021; Moslehpour *et al*., 2022c; Nguyen *et al*., 2021) [127, 119, 103]. Mahmood *et al*. (2020) [88] also examines the impacts of industrialization on CO2 emissions in Saudi Arabia context. The study claims that the use of construction processes, equipment, special¬ized technologies, electric appliances, vehicles, and other infrastructure all rises as industrialization does as well. Industrial processes consume enormous amounts of energy, which results in CO2 emissions, a gas that can harm the ozone layer and trap heat in the planet. This results in a human deficiency in sustaining the environment.

3. Data and materials

The paper evaluates the impact of natural resource rent, natural re¬source depletion, economic growth, industrialization, and population growth on CO2 emissions in ASEAN countries. The study has extracted secondary data from the WDI from 2006 to 2020. The present study used the STIRPAT model of York *et al*. (2003) [103] as the foundation of the proposed framework and according to the STIRPAT framework, popula¬tion, affluence, and technology influence environmental quality. The model specification is given below.

I = PAT.

I represent environmental degradation.

P = Population.

A = Affluence.

T = technology.

It is to be noted that the natural log has been taken of all variables, except the dependent variable. The article has used descriptive statistics and correlation to deter-mine the characteristics of study variables. The study also used the LLC test to asses unit root properties of variables. Moreover, the Harris- Tzavalis test was also employed to evaluate the properties. After con¬firming the integration properties of the variable, Kao integration method is applied to analyze the long-run association of the variable. Once, it was identified that no cointegration existed, pooled OLS method with a technique of fixed effect was considered. To assess in which quantile the variables exert a strong relationship, quantile re¬gression was applied as well.

Besides that, GMM method is applied in the study to investigate the panel data regression. The method is suitable because of various rea¬sons. First, it is super useful for endogenous variables. Secondly, it is useful in such cases as well when there is unobserved heterogeneity. (Ganda, 2019). Due to these reasons, the hypothesis of the study is checked

by GMM technique.

Finally, "panel quantile regression" method is applied to examine the relation of variables. It is needed to check the relationship in differ¬ent quantiles. Since normality of economic sequence is not a require¬ment for OLS, this is why the selected method has an advantage over others. Also, through this method scholars are able to build an under-standing regarding the relationship of constructs beyond the means of data and address the depression of study data.

Lastly, in order to explore carbon determinants, robustness has also been considered (see Table 1).

22. Results

The results display in Table 2 that the mean value of CO2 was 4.307 metric tons per capita, followed by NRR 6.863%, REC 4.812%, GDP 4.917%, while the PG 1275% and IND 36.375%.

Table 3 exposes the results of descriptives according to years. The results uncovered that the ^^2 was lowest in 2007 and highest in 2018. The results also uncovered that the NRR was lowest in 2020, and high¬est in 2006. Moreover, REC was lowest in 2020, and highest in 2006. Furthermore, GDP was -2.421 percent in 2020 and 7.660 percent in 2010. In the case of PG, it was lowest in 2020, while the largest PG was in 2008. Finally, IND was 34.829% in 2016, while the highest value was witnessed in 2006.

Table 1: Variables details.

S#	Variables	Measurement	Sources
01	Environmental Sustainability	CO_2 emissions (metric tons per capita)	WDI
02	Natural Resources Extraction and	Total natural resources	WDI
	renewable energy consumption	rents (% of GDP) Renewable energy per capita (kWh) Renewable energy per capita	WDI
03	Gross Domestic Product	GDP per Capita (annual percentage)	WDI
04	Population Growth	Population growth (annual percentage)	WDI
05	Industrialization	Industry value added (% of GDP)	WDI

Table 2: Descriptives

Variable	Mean	Std. Dev.	Min	Max
co_2	4.307	5.056	0.152	19.500
NNR	6.863	7.096	0.000	35.273
REC	4.812	3.771	-0.308	34.900
GD	4.917	3.684	-9.573	14.526
PG	1.275	0.644	-0.312	5.322
IND	36.375	12.021	18.51	74.113

Table 3: Descriptive statistics by years.

	co_2	NNR	REC	GDP	PG	IND
2006	4.208	10.311	5.084	7.445	1.503	37.959
2007	4.149	9.530	6.282	7.121	1.574	37.212
2008	4.238	9.986	5.111	4.810	1.668	37.400
2009	4.188	7.273	4.717	2.563	1.428	35.905
2010	4.185	7.797	4.230	7.660	1.304	36.087
2011	4.248	9.117	5.222	5.511	1.340	36.626
2012	4.241	7.749	4.425	5.809	1.378	37.098
2013	4.252	6.969	2.916	5.110	1.287	36.372
2014	4.290	6.553	4.517	4.871	1.235	36.281
2015	4.161	5.015	2.185	4.624	1.195	35.391
2016	4.351	4.044	2.875	5.159	1.175	34.829
2017	4.481	4.741	2.946	5.429	1.026	35.653
2018	4.652	5.691	3.106	5.130	1.036	36.688
2019	4.469	4.530	5.551	4.934	1.077	36.516
2020	4.496	3.639	1.776	-2.421	0.905	35.612

The results from Table 4 indicated that the natural resources rent and natural resources depletion, economic growth, industrialization, and population growth have a positive and significant linkage with CO2 emissions in ASEAN countries.

4.1. Unit root test

LLC and Harris-Tzavalis are used for unit roots. It can be seen in Table 5 that carbon emissions, GDP, and renewable energy consump¬tion showed stationarity at a level, however, in the case of NRR, PG, and IND they did not. But in the first difference, all the study variables showed stationarity.

4.2. Cointegration test

The cointegration method was used to investigate the integration between variables. From Table 6, it can be seen that 5 tests were used and all the variables show significance at 0.01 in all of the models. This shows that the unit root is not present in the data.

4.3. Long-run analysis

Table 7 presents a long run-analysis of three constructed models. From the table, we can see that in model 1, GDP and carbon emissions share a positive and significant relationship at 0.1 significance level.

Table 4: Correlations.

Variables	co_2	NRR	REC	GDP	PG	IND
co_2	1					
NRR	.629	1				
REC	.745	-.656	1			
GDP	.485	-.144	-.364	1		
PG	.087	-.060	-.164	-.122	1	
IND	.749	.286	.486	.420	-.096	1
IVs	Model 1		Model 2		Model 3	
	β-value		β-value		β-value	
GDP	0.741*		0.806*		0.268***	
PG	0.208**		0.137*		0.313*	
IND	0.103**		0.201**		0.256**	
REC	-0.245*				-0.165**	
NRR			0.264***		0.341**	

Table 5 Panel Root analysis

Constructs	LLC		Harris- Tzavalis	
	Level	1st difference	Level	1st difference
CO_2	-4.843***	-7.4611***	-6.634***	-26.575***
NRR	-0.565	-2.764***	-1.588**	-25.756***
REC	-4.723***	-0.715*	-1.278*	-22.242***
GDP	-1.977**	4.676*	3.769	-26.779***
PG	0.265	1.832**	0.916***	4.568***
IND	1.452	-1.356**	-4.234**	3.564***

Table 6: Cointegration test.

Tests	Model 1		Model 2		Model 3	
	t-stat	p- value	t-stat	p- value	t-stat	p- value
Modified Dicky	-3.883***	.00	-6.634***	0.00	-3.722***	.00
Fuller						
Dicky- Fuller	-6.241***	.00	-6.578***	0.00	-7.658***	.00
Augmented Dickey-	-4.942***	.00	-5.864***	0.00	-3.704***	.00
Fuller						
Unadjusted	-8.667***	.00	7.859***	0.00	-5.956***	.00
modified Dicky-						
fuller						
Unadjusted Dickey	-4.565***	.00	8.216***	0.00	-8.115***	.00
Fuller						

Table 7: Long-run results.

Constructs	DGMM	FGLS
	Coeff	Coeff
GDP	2.513**	.611***
PG	2.087*	.113*
IND	1.431**	1.654**
REC	-0.650*	-0.519*
NRR	0.303***	0.416***
Constant	–	.765
Observation	150	150
f-stat	19.43	69.01
AR (1) Autocorrelation	.081	No
AR (2)/Panels	.131	Homoscedastic

Table 8: Quantile regression (fixed effect)

IVs	Model 1	Model 2	Model 3
	β-coeff	β-coeff	β-coeff
GDP	1.574**	.013**	.957**
PG	.122**	.123**	.321*
IND	.060**	.124**	.373**
REC	-.893***		-1.274***
NRR		.231**	.134**

Dependent variable: CO_2.

Findings are similar with Rehman *et al*. (2022) [115] and other related stud¬ies. Model 1 also spills that population growth and industrialization are also linked with carbon emission in a positive manner at 5% signifi¬cance level. However, in case of REC, it is negative at 1% significance level. This shows that renewable energy consumption is fruitful in the ASEAN context as with REC, carbon emissions can be reduced.

Model 2, is an extension of model 1 where REC is replaced with nat¬ural resource rent. Model 2 also shows that GDP and carbon emissions are positive and significant at 10%, whereas, population growth and in¬dustrialization are also linked with carbon emissions in a positive man¬ner at 1% and 5% respectively. In case of NRR, a positive and signifi¬cant link can be seen at 10%.

In Model 3, both REC and NRR are introduced simultaneously. In this model, we can see GDP is positively correlated with carbon emis¬sions at 10% significance level. However, in contrast with other models, the magnitude is negligible. Similarly, PG, REC, industrialization and NRR increases carbon emissions due to positive relationship.

4.4 Quantile regression

Quantile regression is used in the study to provide a more robust es¬timation. From Table 8 we can see that GDP increases carbon emission due to positive relation d in Models 1, 2, and 3 at 5%. However, in case of population growth, the positive and significant level in Models 1 and 2 is at 5%, however, in model 3 the relationship is significant at 1%. Similarly, in case of IND, the relationship is significant and positive at 5% in all models. REC and carbon emission are negatively correlated at 10% in Models 1 and 2and natural resource rents are positively corre¬lated at 5% in Models 2and 3.

The results from Table 9 indicated that the NRR, EG, IND, and PG in¬creases CO2 emissions except REC. It is shown that REC is negatively tied to CO2 emissions in the quantiles 1 to 7, while the results also in¬vestigated that the NNR has a significant role on CO2 emissions in the all quantiles except 9. The results also showcase that IND is positively tied to CO2 emissions in all quantiles except 9, while the results also in-vestigated that the GDP has a significant role on CO2 emissions in the quantiles 1–5 and 7, and the results also investigated that the PG has a significant role on CO2 emissions in the quantiles 1 to 5,7 and 9 (see Table 10).

4.5. Robustness test

Robustness was performed to confirm the aforementioned findings. DGMM and FGLS tests were used. As per the results (see Table 9), the DGMM test validates the findings of the study as GDP, IND, PG, and NRR are positive in coefficient of REC is negative. Similarly, FGLS re¬sults are also synced with OLS estimations.

5. Discussions

The results showed that the natural resources rents have a positive link to CO2 emissions. Findings confirm the evidences of Bekun *et al*. (2021) [8], which show that when natural resources demand and rents are getting on increasing, the total use of energy in economic practices, so¬cietal functions, and households increases. The use of any sort of energy releases harmful gases like CO2 emissions directly, converting them into another form of energy (heat or electricity with different voltage power), and through harmful waste emissions. In this situation, envi¬ronmental sustainability can't be achieved. Similarly, Ulucak and Ozcan (2020) [131] reveal that when there is an increase in the natural resources rents, the demand for natural resources is high. With the increased prof¬its from the production of natural resources and in order to meet the de¬mand for natural resources, the interested firms continue to extract a large number of natural resources and apply all possible ways for it. As a result of these initiatives, there are CO2 emissions that disturb the cli¬mate and weather pattern and affect natural resources quality and the health of living beings, which all collectively form an ecosystem. So, this discourages environmental sustainability. The results also agree with Nwani and Adams (2021) [104], which indicate that an increase in the NRR enhances natural resources' production, extraction, and consump¬tion and thus, releases CO2 emissions which is a great hurdle in envi¬ronmental sustainability.

Findings also showed that REC reduces carbon emissions. The find¬ings are inconsistent with Bhattacharya *et al*. (2017) [10], EG and EC are the major source of carbon emissions, however, it varies according to coun¬try and region. Results contradicts with the study of Ahmed *et al*. (2017) [10] and Javid and Sharif (2016) [54], which was conducted in Pakistan and India respectively, and found a directional association between the constructs. However, the findings show consistency with the study of Waheed *et al*. (2018) [133]. The study examined the relationship in Pakistani context and the relationship was found to be negative as the authors specifically targeted renewable energy consumption. Hence, they con¬cluded that higher REC leads to the reduction of carbon emissions.

GDP growth increases CO2 emissions according to study findings. Cai *et al*. (2018) [27] also confirms that the major source of CO2 emissions is the use of energy in large amounts. When a country is making high GDP growth, both at the commercial and community level, the use of energy sources increases for undertaking technical activities and utilizing me¬chanical or electrical appliances. In this situation, when CO2 emissions are rising, the atmosphere is full of suffocation and health, the quality of the natural resources is destroyed, and the living beings do not have good health; so, it is far to achieve environmental sustainability. Adebayo and Beton Kalmaz (2021) [5] also highlights that the achievement of higher GDP growth increases the revenues for the firms from en¬hanced production level and marketing of goods and services. The im-proved financial position allows the firms to expand their business through extension in location, assets, production level, and marketing which enhances the total use of energy, and resultant CO2 emissions de¬stroy environmental sustainability. Mardani *et al*. (2018) [89] also state that the increase in the GDP with the rise in the living standard of people en-courages technology usage that require huge energy. Consequently, the increasing CO2 becomes a threat to environmental sustainability.

Population growth also increases CO2 emissions and show consis¬tency with Namahoro *et al*. (2021) [96], which show that population growth increases both the natural and human sources of CO2 emissions like res¬piration, manufacturing, construction, energy production & consump¬tion, transportation, and different technologies being used in house¬holds and commercial points. The increased CO2 in the air is a threat to environmental sustainability for its adverse impacts on the natural cli¬mate, environmental

resources like water and land, green resources, and living resources. Rehman *et al*. (2022) [115] highlights that in countries where the population is high, the rate of increase in environmental pol¬lution is high because the economic activities are increasing at a fast rate to produce for the basic needs and facilities and therefore, the use of energy sources is high causing CO2 emissions. Dong *et al*. (2018) [40] also show that when the increased population, the use of natural resources like the use of wood and fossil fuels increases in order to fulfill needs like food preparation, accommodation infrastructure, transportation, and earning a livelihood.

The results revealed that industrialization has a positive link to CO2 emissions. These results agree with Ahmad and Zhao (2018) [11], which highlight that an increase in industrialization increases the use of plants, machinery, various specialized technologies, electric appliances, vehicles, and other infrastructure. Huge energy volumes are used in in¬dustrial activities, causing CO2 emissions, a gas that can damage the ozone shield and trap heat in the earth. So, there is a lack of environ¬mental sustainability. These results are supported by Aslam *et al*. (2021) [17], which confirm that human reliance on clean resources de¬creases as a result of industrialization. On the one hand, the depletion of natural resources diminishes the resilience of nature, while greater energy resource consumption and various mechanical processes result in increased GHG emissions. As a result, industrialization is a major source of GHG emissions and does not allow the achievement of envi¬ronmental sustainability. Ghazali and Ali (2019) [46] and Zhang *et al*. (2023) [30] also implies that the invention of various machines or technolo¬gies, as well as their application in residential and commercial activi-Table ties, has increased as industrial production has progressed. In this con¬dition, energy consumption rises, resulting in hazardous gases like CO2 that deplete the ozone layer, raise global temperatures, and restrict the achievement of environmental sustainability.

6. Conclusion, implications, and future directions

The study aimed to examine the influences of NRR, REC, EG, PG, and IND on environmental sustainability in ASEAN economies. The re¬sults showed that an increase in the NRR enhances the production and extraction of natural resources within the country, and the use of nat¬ural resources increase the economic activities and a source of energy enhances the use of technologies transportation, and infrastructure. These activities cause huge CO2 emissions and restrict environmental sustainability. Environmental sustainability can be attained if, on one side, the environmental quality is maintained, and natural resources are in abundance. The depletion of natural resources causes CO2 emissions in large amounts destroying the environment quality and reducing the natural resource quantities, so it creates a hurdle in achieving environ¬mental sustainability. The major cause of CO2 emissions is the manu¬facturing or production activities and supporting operations which in¬clude the use of machinery and energy. So, the increase in GDP growth, which enhances manufacturing and production activities within the country, increases CO2 emissions and destroys the natural environment leading to a lack of environmental sustainability. The results showed that when a country the population growth rate is high, all sorts of hu¬man activities require a specific amount of energy increase. With the in¬crease in such activities, the amount of CO2 emissions into the air also increases. The study also concluded that when the industrial circle is spread to a greater area of land in a country, and more people are en¬gaged in industrial activities, machine use increases, and CO2 emissions go high. The current study has great significance to emerging economies like ASEAN countries as it concerns how to ensure environmental sustain¬ability. For suppose, a balance should be maintained between popula¬tion growth, industrialization, and natural resources in order to restrict carbon emissions. In this modern age, the population is increasing rapidly as well as social and economic activities like lighting, heating, or cooling a building or an area of land, transport facilities, electric ap¬pliances, and various machines, plants, or technologies used in indus¬trial, construction, and other activities. As a result, the use of energy also keeps on increasing, and pollution becomes a hurdle to environ¬mental sustainability and sustainable economic development. Thereby, the present study is a perfect guideline for policymakers on how with some care, they can reduce CO2 emissions and ensure environmental sustainability. The study suggests that if the government, through legis¬lation or economic policies, controls the natural resource rents and nat¬ural resource extraction, it can control the exploitation of these re¬sources, which increases fuel consumption and causes CO2 emissions.

The study guides the regulators in establishing policies regarding envi¬ronmental sustainability by limiting the usage of natural resources. Hence, the government can improve environmental sustainability. Moreover, the study suggests that government and its appointed au¬thorities must form policies to increase GDP growth without causing CO2 emissions, control population growth and reduces environmental as well, and remove negative environmental impacts of industrializa¬tion so that environmental sustainability can be attained.

There are several limitations associated with to present study. The study examines only limited factors like natural resource rents, natural resource depletion, GDP growth, population growth, and industrializa¬tion as indicators of environmental sustainability. The use of a limited number of factors for analyzing environmental sustainability and ignor¬ing the other necessary indicators keeps this study limited. For a com¬prehensive study, the future authors must analyze a maximum number of factors that have to do with environmental sustainability. Moreover, the data to determine the relationship of stated variables was collected from ASEAN countries. The information from a small number of economies can't be appropriate to present results valid to all economies spreading across the world. That is why it would be better to collect the data from multiple economies scattered throughout the world. In this study, only the CO2 emissions have been taken as the measure of envi¬ronmental sustainability. As greenhouse gas emission is the true mea-surement of environmental sustainability, the study scope is limited, and in future studies, it is recommended to use greenhouse gas emis¬sions as the predictor of environmental sustainability.

7. References

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