

The Perspective of Carbon Emission: Evident from Asymmetric of Health Expenditure, Economic Growth and Energy Consumption in India

Anusha Karakki Omkeshappa^{1*}, Chukiatt Chaiboonsri², Anuphak Saosaovaphak³

¹University, Chiang Mai University, Thailand

^{2,3}Faculty of Economics, Chiang Mai university, Thailand

Abstract

Carbon emission is one of the important variables that influence human health and the environment. Similarly, economic growth is influencing the health expenditure of the people. Literacy rate is an important variable that enhances economic growth and diminishes health expenditure. Recent studies on health expenditure, GDP, and CO₂ have been conducted with symmetric results that apply to a combined country representation. There is a lack of literature available on assessing Gross Domestic Product (GDP), Energy consumption on CO₂. In addition, empirical studies relating to asymmetric relationships are scarce in the Indian Context. The purpose of the study is to measure the asymmetric relationship between Health Expenditure (HE), Carbon Di-oxide (CO₂), economic growth (EC), and energy consumption in India. This study collects the data from world bank database. Annual data is used in the study. The period analysed covers the years 2000 and 2022. The data relating to Health Expenditure (HE), Carbon Di-oxide (CO₂), Energy Consumption (EC), literacy rate, and economic growth variables obtains from World development Bank. The results derived from the variables give insights to the public health officials and policy makers to develop a strategy that can control carbon emissions in the country.

Keywords: Gross Domestic Product (GDP), Energy Consumption (EC), Literacy Rate, Carbon Emission (CO₂), Health Expenditure (HE), NARDL and India.

I. INTRODUCTION

India is one of the developing countries in the world. The economic growth size of the country is huge in the world. Recently, there has been a tremendous change in global population, which influences the social and geographical effects on the overall environment (Ahmed et al., 2023) of the country. One of the important factors that influences the environment is economic growth. The economic growth is used to measure the welfare of citizens of a particular country. There is a fluctuation in the economic growth rate of India between 2000 and 2022. There is a quite fluctuation in the growth rate between 2004 and 2007, and then a slight decrement is noted in 2008, then a volatility in the growth rate from 2009 to 2019, and a negative growth is

*Corresponding Author Email: iankojayk333@gmail.com

Published: 29 April 2026

DOI: <https://doi.org/10.70558/IJSSR.2026.v3.i2.301036>

Copyright © 2026 The Author(s). This work is licensed under a Creative Commons Attribution 4.0 International License (CC BY 4.0).

recorded in 2020, and there is an increment in 2021, and volatility is observed in the next consecutive years, which is illustrated in the Figure 1. The overall growth rate of India is 6.26.

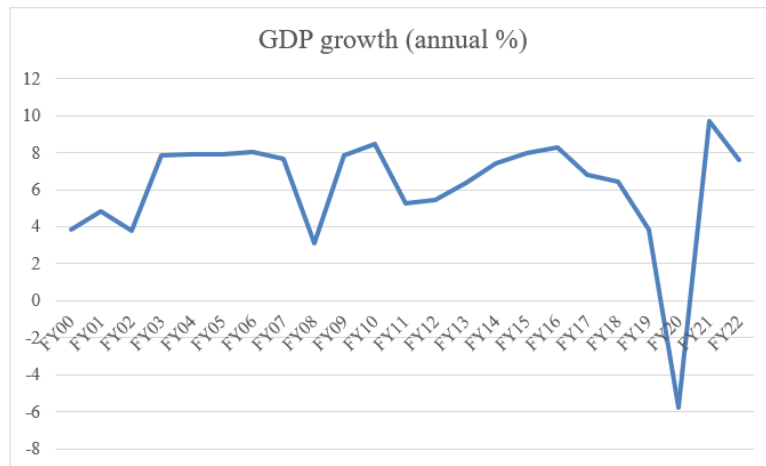


Figure 1. Gross Domestic Product of India

International Energy Agency stated that the consumption of oil, natural gas, and coal increases the energy consumption (EC) across the world. The contribution of oil is 40.8%, natural gas is 10%, and coal is 16.2% (Ahmed et al., 2023). India is the second largest emitter of CO₂ in the world (Ahmed et al., 2023; Neog & Kumar Yadava, 2020). The country generates 66% of its electricity using global EC, petroleum, and coal (Ahmed et al., 2023). The consumption of energy and its spending raise energy demand (Neog & Kumar Yadava, 2020) in the country. The higher consumption is due to an increment in population growth, changes in lifestyle, development in the manufacturing sector and higher economic competitiveness (Qayyum et al., 2021), urbanization (Minh et al., 2023), and globalization (Abbasi et al., 2020). Figure 2 illustrates the EC from 2000 to 2022. There has been a gradual increment in EC in the country for about seventeen years. A slight decrement in EC is recorded in 2020, and then the demand for consumption increases in the next years. Overall, the consumption of energy increased from 488 mtoe in 2004 to 1012 Mtoe. As a result, energy is an important component, and the overall consumption increases day by day.

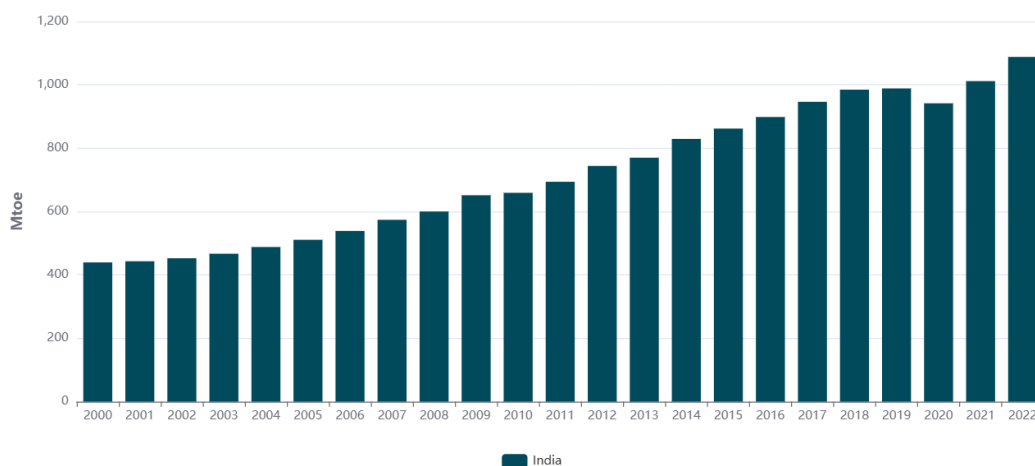


Figure 2. Energy consumption of India

The higher EC increases CO₂ levels in the country (Salari et al., 2021). This increases global warming issues, energy crisis, and climatic changes in the nation (Ofori-Sasa et al., 2023). The term CO₂ emission refers to the higher release of CO₂ during the combustion of gas, liquid, solid and gaseous fuels. Nowadays, the emissions are increases day by day and an average emission is 2763.338mt. This is due to increased dependence on fossil fuels, massive emissions of smokes and energy sources. Figure 3 illustrates the carbon emission of India from 2000 to 2022, and the overall emission is 29.04. The increment is gradually high from 2004 to 2019, and there is a slight decrement in 2020 and a steep one recorded in the next year.

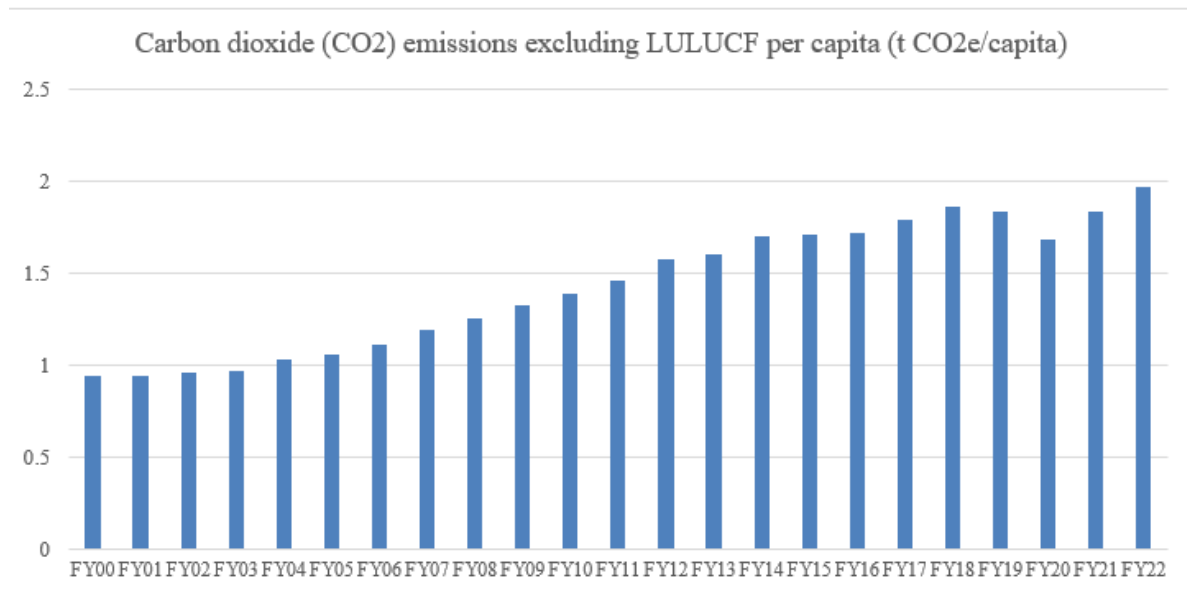


Figure 3. Carbon di oxide emission

The increasing emissions are damaging human health, the environment (Apergis et al., 2018; Ahmat et al., 2025; Apergis & Payne, 2009; Hamid & Wibowo, 2023) and economy of the country (Atuahene et al., 2020; Lakshmanasamy, 2025; Sreenu, 2022).

Health is another key determinant of the calibre of human capital (Islam, 2024). A good health of an individual increases productivity and accelerate GDP of the nation (Abdullah et al., 2016; Atuahene et al., 2020). Nowadays, health is given top priority, as it is greatly influenced by environmental aspects (Abdullah et al., 2016), and it is varied in terms of severity and complexity. Environmental degradation is caused by CO₂ (Ahmed et al., 2023; Khan et al., 2024) which leads to numerous respiratory illnesses, increases heat- related illnesses, and tropical diseases (Socol et al., 2023) for the people. This increases economic expenditure of both people and government (Ahmed et al., 2023). Thus, healthy living is becoming increasingly difficult as environmental quality deteriorates greatly (Abdullah et al., 2016). Developing countries like India are in urgent need of economic development, which emits more and costs around 5% of GDP (Khan et al., 2024) and poses threats for humans in the country. The health expenditure is the most important expense highly associated with carbon dioxide emissions (Kirea et al., 2020). Figure 4 illustrates the current health expenditure of Indians between 2000 and 2022. According to the Figure 4, there is a steep increment in health expenditure from 24.92 in 2004 to 75.54 in 2021. The increment in expenditure is due to

increment in national income, environmental pollution, and high energy intensity (Khan et al., 2024). Consequently, there is a need to investigate how the quality of life of human beings and their health are influenced by carbon emissions.

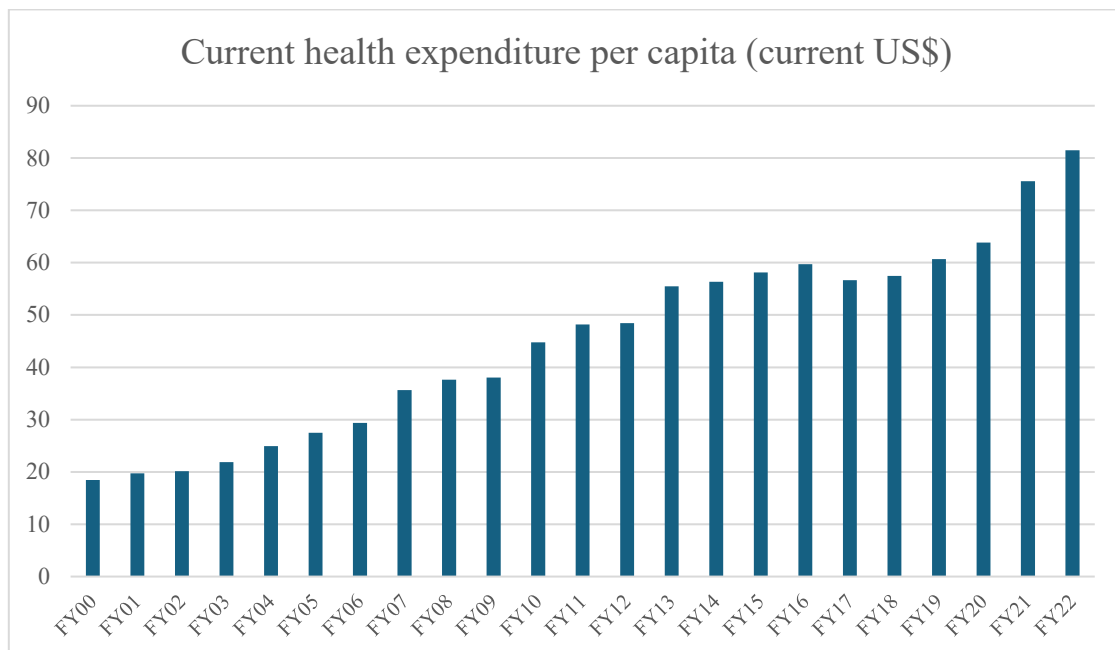


Figure 4. Health expenditure of India

Literacy rate can be described as the proportion of individuals aged 15 years and above who can read and write a short statement about their daily lives. This is widely acknowledged as a measure of the development of human capital. The higher the literacy levels, the higher the public health resulting enhanced economic development. On contrary, a low literacy level hinders both economic and social progress (Ikeokwu et al., 2025) of the country. Thus, literacy is essential in reducing poverty and enhancing sustainable development in the country. The main research question of the study is to examine whether there is an asymmetry linkage between HE, CO₂, GDP, and EC over the period 2000-2022.

II. PURPOSE OF THE STUDY

1. To examine the Asymmetric influence of EC, Literacy Rate, Economic Growth on CO₂ Emission in India.
2. To Estimate the Short and Long-term impact of CO₂ Emission on HE in India.

III. SCOPE AND RELEVANCE

The scope of the study is to measure the asymmetric relationship between HE, CO₂, economic growth, and EC in India. The data between 2000 and 2022 from the World Bank database is used. This study covered a period of 22 years. The period of decision is by the availability of data in World Bank indicators. There must be sufficient data to estimate the effects in the variables. The results derived from the variables give insights to the public health officials and policy makers to develop a strategy that can control carbon emissions in the country. The results will be useful for the government to develop policies and strategies not only to reduce

emissions, enhance energy consumption, diminish HE, and improve economic growth of the country.

IV. LITERATURE REVIEW

Apergis et al. (2018) examine the association between health expenditure and CO₂ for 42 African countries between 1995 and 2011. According to their findings, there is a long run two-way causality between HE and CO₂.

Hamid & Wibowo (2023) empirically assess the extent to which the condition of CO₂ influences the HE sectors for ASEAN regions, spanning twenty years. The results showed that the CO₂ relationship with HE is significant. This represents that the public health is highly influenced by CO₂ emissions, resulting in higher HE and degrading the environment.

Wang et al. (2020) measures the linkage between HE and CO₂ in China. The results showed that two-way causality exists between HE and CO₂. On the other hand, one way causality exists between environment and particularly with Chinese economy.

Begum et al. (2020) measure the dynamic correlation between CO₂ and GDP in Malaysia, spanning 26 years, using the DOLS. The outcome confirmed that positive and significant effects were found between GDP and CO₂. This represents that the greater the expansion of GDP, the greater the CO₂ emission in the country.

Begum et al. (2020) measures the dynamic impacts between CO₂ and economic growth in Malaysia, spanning 26 years, using the dynamic ordinary least squares method. The findings of the study confirmed that positive and significant effects were found between economic growth and CO₂. This represents that the higher the expansion of GDP, the higher the CO₂ in the country.

Islam (2024) investigated how HE, CO₂, associate with GDP for SAARC member countries. The outcome show that two-way causality was found between carbon emission and GDP and the same was observed between HE and GDP. Furthermore, one way causality was found only in carbon emissions. The results derived from the studies have proved that GDP contributed to CO₂, which was found from the cross-correlation, DOLS, and GMM approaches.

Ahmat et al. (2025) examine the effects between EC, CO₂, and GDP in Malaysia between 1986 and 2021. The findings showed that the effect of EC, GDP, and CO₂ was positive influence in short run and long run.

Gardiner & Hajek (2020) used data from 1990 to 2015 for EU countries to confirm the causal and cointegration link between GDP, EC, and CO₂. This study classified EU nations into two types: Old EU nations and New EU nations. The outcome of cointegration confirm that there is a long-run relationship between CO₂, GDP, and EC. Also, short-run two-way causality is predominant for the variables. However, there are one-way causalities between GDP, EC and CO₂ in EU countries.

Mukhtarov et al. (2023) adopt the dynamic OLS method to measure the linkage between EC, GDP, and CO₂ for Azerbaijan between 1993 and 2019. The empirical evidence supports that there was a negative effect between EC and CO₂, whereas GDP positive effect on CO₂.

Xin et al. (2023) found that literacy rate negatively associated with CO₂ in China. Although Turkey has followed the IT-based education model in enhancing the quality of human capital and reduce its environmental degradation, Eyuboglu & Uzar (2021) reported findings that higher education negatively influences carbon emission. (IKEOKWU et al., 2025) revealed that literacy rate exhibits a long-run negative and insignificant effect on emission while showing short-run positive and significant results. This indicates mixed results for Nigeria.

The recent literature on health expenditure, GDP, and CO₂ has been conducted with different methodologies, and the periods of the study are also different between studies. These studies have offered the symmetric results that apply to a combined country representation. Most importantly, (Hussain Ansari & Islam Ansari, 2022) mentions that symmetric linkage is observed between GDP, carbon emission, and energy consumption on health expenditure. On contrary, a small number of studies have assessed the asymmetric link between variables such as (remittance, financial development (Neog & Kumar Yadava, 2020), crude oil, FDI (Sreenu, 2022), geopolitical risks, EC, GDP (Zhao et al., n.d.), income, population growth (Ahmed et al., 2023), and health expenditure (Khan et al., 2024) and carbon emissions. The studies have used different combination of variables like remittances, infant mortality to address the relationship between CO₂ emissions and Health expenditure in particular with India. In addition, these studies have utilized methods like ARDL and cointegration test to check the validity of EKC in India. This study adopts NARDL as a method of estimation technique to support the validity of EKC hypothesis. This helps to explore the linkage between variables in the short and long run. To the best of our knowledge, no studies have looked at this subject in these countries.

V. CONCEPTUAL FRAMEWORK OF THE STUDY

The endogenous variable of the study is CO₂ emissions. The exogenous variable of the study includes HE, literacy rate, economic growth, and energy consumption.

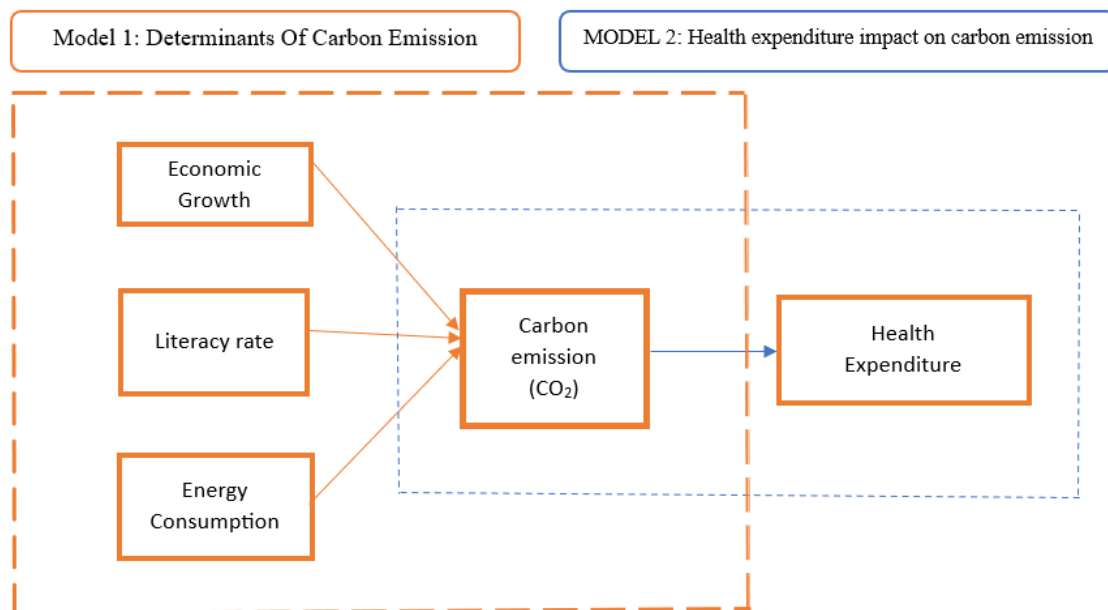


Figure 5. Conceptual framework

VI. METHODOLOGY AND DATA

The current study adopts an empirical research design. Eighteen years of annual data on CO₂, EC, GDP, literacy, and educational attainment was collected from the World Bank's development indicators. Data selection is based on the proposed econometric technique. EKC describes a U-shaped inverse linkage between GDP and CO₂, with the latter increasing as the economy grows to a certain point, and then falling again as the Indian country uses its increased wealth. The asymmetric theory has been used to measure the linkage between the variables. Thus, the study utilizes nonlinear ARDL to estimate asymmetric effects of variables in the long run and short run.

VI. I. DATA COLLECTION

This study collects the data from world bank database. Annual data is used in the study. The period analyzed covers the years 2000 and 2022. The data relating to HE, CO₂, EC, literacy rate, and economic growth variables obtains from World development Bank. GDP serves as a proxy for economic growth, CO₂ emissions serve as a proxy for environmental factors, and health resources represent health expenditures. Carbon emissions measures in metric tons, while EC measures in billion kilowatt-hours, HE in USD, and GDP per capita in constant USD in 2015. Literacy rate is measured by the percentage of people who age 15 years and above. Table 3.2 lists the description of variables, measurements, and its sources of data. This study covers the entire Indian nation and is determined based on the characteristics of nations, such as geographical, economic, and socio-cultural diversity and natural resources. In this study, the entire India is considered to understand the research more precisely.

Variables	Abbreviations	Measurements	Description	Sources of data
Health expenditure	HE	USD	This is the total health expenditure per capita	WDI
Economic growth	GDP	USD	GDP is the total of all producer output plus taxes and less any applicable subsidies. GDP is computed in current USD (constant 2015) without taking product depreciation into account.	WDI
Energy consumption	RE	billion kilowatt-hours	Energy consumption is energy extracted from one kilogram of crude oil	WDI
Carbon emissions	CO ₂	Metric tons	The emissions are calculated by dividing the national total carbon emission from production and consumption processes by the respective nation population	WDI
Literacy rate	LTR	In percentage	The literacy rate of adults (%) is the percentage of people aged 15 years and above.	WDI

Figure 6. Description of variable

VI. II. ECONOMETRIC MODELS

Unit root test: The unit root test checks the order in which the variables are integrated. The Dickey-Fuller Test with GLS Detrending was a straightforward adaptation of the ADF test that involves detrending the data to remove explanatory variables before performing the regression test. Ng and Perron (2001) use the GLS detrended data to create the four-test statistics yd . The test statistics are the ERS Point Optimal test statistic (MPT), the Sargan-Bhargava test statistic (MSB), and modified versions of the Phillips-Perron MZa and MZt statistics.

$$\text{Model 1- } CO_2 = \beta_0 + \beta_1GDP + \beta_2LR + \beta_3EC + \epsilon_t$$

$$\text{Model 2: } CO_2 = \beta_0 + \beta_1HE + \epsilon_t$$

ARDL Co-integration Approach: This study uses the ARDL bound test co-integration method. Pesaran and Shin (1999) developed this, and Pesaran et al. further developed it. (2001), in order to look into the long-term linkage with variables. This technique is popular among economists and econometricians because it enables the cointegration modelling even in situations where all variables stationary in levels [I (0)], after the first difference [I (1)], or a combination of the two.

$$\Delta \ln CO_t = \alpha + \sum_{i=1}^p \lambda_{1i} \Delta \ln CO_{2(t-i)} + \sum_{i=0}^q \lambda_{2i} \Delta \ln EC_{(t-i)} + \sum_{i=0}^r \lambda_{3i} \Delta \ln EG_{(t-i)} + \sum_{i=0}^s \lambda_{4i} \Delta \ln LR_{(t-i)} + \phi_1 \ln CO_{2(t-1)} + \phi_2 \ln EC_{t-1} + \phi_3 \ln EG_{t-1} + \phi_4 \ln LR_{t-1} + \epsilon_t \quad (1)$$

Where the parameters $\lambda_{mi} = 1, 2,$ and so on, which indicates the short-term linkage, whereas ϕ_i represent the long-term linkage. This method is used to calculate the previous equation and to examine the long-term linkage between the regress and regressors by limiting the parameters of the long-run variables to zero. Therefore, testing the alternative hypothesis of co-integration against the null hypothesis (no co-integration), which shows that $H_0 = \phi_1 = \phi_2 = \phi_3 = \phi_4 = 0$. The F-test was used to evaluate the hypothesis. Next, the calculated F-statistics is contrasted with the Pesaran et al. (2001) asymptotic critical value bounds to determine whether a long-term relationship (co-integration) exists.

$$\ln CO_{2t} = \phi_0 + \phi_1 \ln EC_t + \phi_2 \ln EG_t + \phi_3 \ln LR_t + \epsilon_t \quad (2)$$

$$\ln HE_t = \beta_0 + \beta_1 \ln CO_{2t} + \mu_t \quad (3)$$

The final stage of the bound test is to estimate the short run elasticities. This is done by using the error correction framework shown in equation (4)

$$\Delta \ln CO_{2t} = \delta_1 + \xi_{ect} ECT_{t-1} + \sum_{i=1}^p \lambda_{1i} \Delta \ln CO_{2(t-i)} + \sum_{i=0}^q \lambda_{2i} \Delta \ln EC_{(t-i)} + \sum_{i=0}^r \lambda_{3i} \Delta \ln EG_{(t-i)} + \sum_{i=0}^s \lambda_{4i} \Delta \ln LR_{(t-i)} + \eta_t \quad (4)$$

$$\Delta \ln HE_t = \beta_0 + \sum_{i=1}^p \varphi_i \Delta \ln_{(t-i)} + \sum_{i=0}^q \theta_i \Delta \ln CO_{2(t-i)} + \omega ECT_{t-1} + \eta_t \quad (5)$$

where ξ_{ect} is the error correction term and ξ_{ect} is the coefficient that indicates how much the model adjusts to its long-run equilibrium. In other words, ξ_{ect} is the rate at which the deviation from the long-run equilibrium at time $t=1$ is corrected at time t .

Nonlinear Autoregressive Distributed Lag Model: Shin et al. (2014) introduces NARDI, as an asymmetrical extension of the frequently used ARDL model developed by Pesaran and Shin (1990) and Pesaran et al. (2001) to identify long-term and short-term asymmetric among the variables. This is why we also use this modelling approach. First, the asymmetric long-run CO₂ emission equation is defined (Shin et al., 2014):

$$\ln CO_{2t} = \alpha + \phi_1 \ln Y_t^+ + \phi_1 \ln Y_t^- + v_t \tag{6}$$

$$\ln HE_t = \alpha_0 + \phi_1 \ln CO_{2t}^+ + \phi_1 \ln CO_{2t}^- + v_t \tag{7}$$

Where,

- Y^+ and Y^- represent the positive and negative changes in Y_t . They are defined as

$$Y_t^+ = \sum_{i=0}^t \Delta Y_i^+ + \sum \max(\Delta Y_i, 0) \tag{8}$$

$$Y_t^- = \sum_{i=0}^t \Delta Y_i^- + \sum \min(\Delta Y_i, 0) \tag{9}$$

Where $Y = EC, EG, LR$

Therefore, the long-term relationship as shown in equation 1 reflects the asymmetric pass-through of long-term health expenditure, energy consumption, and GDP to CO₂ emissions.

$$\Delta \ln CO_{2t} = \alpha + \sum_{i=1}^p \lambda_i \Delta \ln CO_{2(t-i)} + \sum_{i=0}^{q1} \theta_{1i}^+ \Delta EC_{t-1}^+ + \sum_{i=0}^{q2} \theta_{1i}^- \Delta EC_{t-1}^- + \sum_{i=0}^{q3} \theta_{2i}^+ \Delta EG_{t-1}^+ + \sum_{i=0}^{q4} \theta_{2i}^- \Delta EG_{t-1}^- + \sum_{i=0}^{q5} \theta_{2i}^+ \Delta LR_{t-1}^+ + \sum_{i=0}^{q6} \theta_{2i}^- \Delta LR_{t-1}^- + \xi ECT_{t-1} + \mu_t \tag{10}$$

$$\ln HE_t = \delta_0 + \sum_{i=1}^p \delta_{1i} \Delta \ln HE_{(t-i)} + \sum_{i=0}^{q1} \theta_{1i}^+ \Delta CO_{2(t-i)}^+ + \sum_{i=0}^{q2} \theta_{1i}^- \Delta CO_{2(t-i)}^- + \psi_1 HE_{(t-1)} + \psi_2 \ln CO_{2(t-1)}^+ + \psi_3 \ln CO_{2(t-1)}^- + \varepsilon_t \tag{11}$$

where p and q are lag orders and all variables are as described above.

$\gamma_1 = \frac{\phi_1}{\phi_0}$, $\gamma_2 = \frac{\phi_2}{\phi_0}$, are the long-term effects of increasing and decreasing GDP, energy consumption, and health spending on CO₂ emissions, respectively.

$\sum_{i=0}^{q1} \theta_{2i}^+ \Delta Y_{t-1}^+$ evaluates the short-run effects of GDP growth, health expenditure, and energy consumption on CO₂ emissions.

$\sum_{i=0}^{q2} \theta_{2i}^- \Delta Y_{t-1}^-$ Measures the short-term impact of EC, HIE, and GDP declines on CO₂ emissions. Furthermore, the short-term effect of GDP declines, HE, energy consumption on

CO₂ emission is also reported, along with the long-term linkage are not symmetric. According to Katrakilidis and Trachanas (2012), the final NARDL model specifications are obtained by using a general to specify approach to mitigate the minimal errors. In addition, we used the Pesaran et al. (2001) and Shin et al. (2014) boundary testing method to test for co-integration between variables using estimated NARDL. The Null hypothesis in Wald F test is involved in this, $\phi_1 = \phi_2 = \phi_3 = \phi_4 = 0$. According to Kurtović et al. (2022). dynamic multipliers are computed to evaluate the cumulative effects of HE, EC, GDP, and carbon emissions over time.

$$m_h^+ = \sum_{j=0}^h \theta_j^+ \tag{12}$$

$$m_h^- = \sum_{j=0}^h \theta_j^- \tag{13}$$

VII. RESULTS

VII.I. DESCRIPTIVE STATISTICS

Table 1. Descriptive statistics

Particulars	CO ₂	EC	GDP	HE	LR
Mean	1.431312	36.83043	6.118778	45.22746	30.77269
Median	1.463374	36.10000	7.410228	48.18242	0.000000
Maximum	1.969296	47.10000	9.689592	81.50889	76.32000
Minimum	0.939790	0.000000	-5.777725	18.47883	0.000000
Std. Dev.	0.351336	9.547986	3.154864	18.39301	36.04920
Skewness	-0.114377	-2.428727	-2.421027	0.097443	0.291233
Kurtosis	1.517910	10.77469	9.830957	2.019775	1.119437
Jarque-Bera	2.155213	80.53898	67.18632	0.957205	3.714292
Probability	0.340409	0.000000	0.000000	0.619649	0.156118
Sum	32.92017	847.1000	140.7319	1040.232	707.7719
Sum Sq. Dev.	2.715617	2005.609	218.9697	7442.658	28589.99
Observations	23	23	23	23	23

Table 1 shows the descriptive statistics and offers information for the variables used in the analysis with the number of observations, mean, standard deviation, minimum values, maximum values, skewness, and kurtosis for the sample period 2000 and 2022. The mean represents the average values of the variables, whereas the standard deviation indicates how much the generated data deviates from the mean value. The mean value of CO₂ is 1.43, with a maximum value of 1.96 and a minimum value of 0.93. Energy consumption has an average value of 36.83 and peaks at 47.10 in 2000 and 2022. In the period considered, GDP has an average value of 6.11 with a standard deviation of 3.15. GDP values peak at 9.68 and have a minimum value of -5.77. This indicates that there has been a lot of fluctuation in the economic performance of India. The mean value of HE is 45.22, with a minimum value of 18.47 and a

maximum value of 81.50. This does speak to the changes in health care expenditure of the country during the period and shows differences in government spending on health services by India. The mean value of LR is 30.77 with a standard deviation of 36.04 and peaks at 76.32, indicating a significant variation in the variable. This represents that there were noticeable changes in its level in the study period. The skewness values of variables (CO₂, EC, and GDP) were negative, and the rest of the variables (HE and LR) were positive. The skewness for CO₂ is moderate, which is closer to zero, while EC and GDP have high negative skewness, and it indicates that these variables are not following a normal distribution. In terms of kurtosis, CO₂, HE, and LR were in line with the acceptable range, while EC and GDP indicated a leptokurtic distribution, meaning that the data have a high peak compared to the normal distribution. A normality test is used to find out if the data is normally distributed. This can be assessed with the Jarque-Bera test. The variables such as EC and GDP have p-values less than 0.05, indicating that these are not normally distributed. On the other hand, the variables CO₂, HE, and LR have p-values of 0, and the values are greater than 0.05, indicating that the variables are normally distributed. As a result, the data series is suitable for further investigations.

VII. II. CORRELATION

Table 2. Correlation

Particulars	LR	HE	GDP	EC	CO ₂
LR	1.00	0.44	-0.22	-0.37	0.40
HE	0.44	1.00	-0.01	-0.81	0.97
GDP	-0.22	-0.01	1.00	-0.10	0.00
EC	-0.37	-0.81	-0.10	1.00	-0.77
CO ₂	0.40	0.97	0.00	-0.77	1.00

Table 2 shows the correlation matrix suggests that the correlation was assessed for CO₂ and the other variables of the study. The results show that HE and LR have a significant and positive effect on CO₂. Also, EC has a negative association (-0.77) with CO₂. This indicates that ECs are likely to drive CO₂ in opposite directions. Although GDP does influence CO₂ negatively and multicollinearity is almost certainly common. Though conclusions are not derived based on correlations, these results confirm the EKC hypothesis that high economic growth is associated with environmental performance and reduced emissions.

VII. III. UNIT ROOT TEST

This study employed ADF and PP tests to assess the stationarity or non-stationarity in the variables.

Table 3. ADF

Particulars	At level			First difference		
	No constant	Intercept	Trend & intercept	No constant	Intercept	Trend & intercept
CO ₂	3.22 (0.99)	-2.62 (0.10)	-2.15 (0.48)	-0.53 (0.46)	-3.86 * (0.0088)	-1.25 (0.868)
EC	-2.36 (0.02)	0.63 (0.98)	-2.25 (0.43)	-0.79 (0.35)	-2.66 (0.09)	-1.34 (0.84)
GDP	-0.48 (0.49)	-4.4 (0.002)	-4.38 (0.01)	-4.83 (0.000)	-4.65 (0.0016)	-4.74 (0.0062)
HE	4.38 (0.99)	-0.04 (0.94)	-4.89 (0.050)	-0.58 (0.44)	-2.99 (0.05)	-2.67 (0.25)
LR	-1.61 (0.09)	-2.66 (0.09)	-3.05 (0.13)	-6.18 (0.00)	-6.02 (0.00)	-6.01 (0.00)

Table 3 shows the results obtained from the ADF test. This indicates that all the variables are stationary at levels with the evidence of a p-value that is less than the 5% level of significance, while CO₂ is stationary at the first difference, which indicates that the variables are stationary, resulting in no evidence of a unit root. This implies that bound test procedures can be used, as none of the variables are I(2). As a result, this satisfies the criteria for the ARDL and NARDL models, which can be executed in an efficient way.

Table 4. PP test

Particulars	At level			First difference		
	No constant	Intercept	Trend & intercept	No constant	Intercept	Trend & intercept
CO ₂	3.51 (0.99)	-0.002 (0.94)	-2.27 (0.43)	-2.75 (0.00)	-4.24 (0.037)	-4.06 (0.02)
EC	-1.26 (0.18)	0.34 (0.97)	-1.36 (0.84)	-1.79 (0.06)	0.21 (0.96)	-2.58 (0.29)
GDP	-1.05 (0.25)	-4.4 (0.0024)	-4.65 (0.064)	-13.24 (0.00)	-11.74 (0.00)	-11.20 (0.00)
HE	4.16 (0.99)	0.87 (0.99)	-1.85 (0.64)	-2.09 (0.03)	-3.69 (0.01)	-3.80 (0.03)
LR	-1.54 (0.11)	-2.71 (0.08)	-3.05 (0.13)	-6.09 (0.00)	-5.95 (0.001)	-6.01 (0.000)

The PP test results indicate that GDP is the only variable found to be stationary at level, while CO₂, EC, HE, and LR are found to be stationary in the first difference. These results indicate a mixture of I(0) and I(1), which met the criteria of the ARDL and NARDL approaches.

VII. IV. ARDL RESULTS

VII. IV. I. MODEL 1

Table 5. Bound testing approach – Model 1

Particulars	F-statistics	1%		5%		10%	
		I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
Asymptotic	6.51	3.65	4.66	2.79	3.67	2.37	3.2
Actual sample		4.61	5.96	3.27	4.30	2.67	3.58

Immediately confirmed that there is no integration of order 2 from the unit root test; implemented the bound test approach to determine whether there is a long-run cointegration between the variables. Table 4.7 shows the bound test F-value for model 1 is 6.51, which is higher than critical values and is significant. This rejects the null hypothesis stating that GDP, energy consumption, literacy rate, and CO₂ do have a long-run relationship.

Table 6. Long run for model 1

Variable	Coefficient	Std. Error	t-Statistic	Prob.
EC	-0.057674	0.003029	-19.04017	0.0000
GDP	0.030719	0.015557	1.974666	0.0797
LR	-0.000443	0.000559	-0.792794	0.4483
C	3.525572	0.162995	21.62997	0.0000

Table 6 shows that EC have a negative and statistically significant effect on CO₂ with the p-value of 0.000 which is lesser than 5% level of significance. This implies that a percentage increment in CO₂ will decrease EC by -0.05. GDP have a statistically insignificant and positive influence on CO₂ in long run. The coefficient of literacy rate is -0.000443, the negative sign represents a negative relationship with CO₂ and is insignificant.

Table 7. Short run for model 1

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(EC)	-0.012712	0.001840	-6.908046	0.0001
D(EC(-1))	0.050806	0.013044	3.894924	0.0036
D(GDP)	0.007683	0.001841	4.174261	0.0024
D(GDP(-1))	-0.016220	0.003290	-4.929542	0.0008
D(GDP (-2))	-0.006117	0.003524	-1.735760	0.1166
D(LR)	0.000124	0.000193	0.643080	0.5362
CointEq(-1) *	-0.652736	0.095156	-6.859671	0.0001
R-squared	0.872162	Mean dependent var		0.050584
Adjusted R-squared	0.813160	S.D. dependent var		0.065988
S.E. of regression	0.028523	Akaike info criterion		-4.006979
Sum squared resid	0.010576	Schwarz criterion		-3.658473
Log likelihood	47.06979	Hannan-Quinn criter		-3.938947
Durbin-Watson stat	2.386589			

Table 7 shows that the term "error correction" is negative and statistically significant. This indicates that 65.27% convergence towards long-run equilibrium. Energy consumption has a negative and statistically significant with CO₂ in the short run. It is evident that the p-value is higher than 0.05. GDP is also seen to have an effect on CO₂ in the short run due to having a p-value less than 0.05. LR has no statistically significant CO₂ in the short run. This is evident through the attainment of a p-value greater than the 5% level of significance. Thus, it is clear that GDP has a positive effect on CO₂, whereas EC has a negative and significant effect on CO₂. The adjusted R-square of Model 1 is 0.813, representing that 81.3% of the dependent variable (CO₂) is explained by the independent variables (literacy rate, GDP, and energy consumption). The value helps to confirm the specification of the model. The Durbin-Watson test of the model was 2.38, which is within the threshold limit (1.5-2.5), and thus, there is no problem of autocorrelation.

VII. IV. II. MODEL 2

Table 8. Bound testing approach – Model 2

Particulars	F-statistics	1%		5%		10%	
		I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
Asymptotic		4.94	5.58	3.62	4.16	3.02	3.51
Actual sample =35	6.53	5.76	6.48	3.95	4.53	3.22	3.75
Actual sample=30		6.02	6.76	4.09	4.66	3.30	3.79

Table 8 shows the bound test F-value for model 2 is 6.53 which is larger than critical values and is significant. Ther results indicate that there is a long run relationship between HE and CO₂ is confirmed.

Table 9. Long run for model 2

Variable	Coefficient	Std. Error	t-Statistic	Prob.
HE	0.020566	0.000715	28.78190	0.0000
C	0.587416	0.034262	17.14479	0.0000

Table 9 shows that HE is significantly and positively influence CO₂, representing that a percentage increment in HE, increases CO₂ by 0.02.

Table 10. Short run for model 2

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(CO2(-1))	0.238695	0.149966	1.591654	0.1323
D(HE)	0.000589	0.002868	0.205543	0.8399
D(HE(-1))	-0.013550	0.005484	-2.470673	0.0260
CointEq(-1)*	-0.933018	0.198000	-4.712210	0.0003
R-squared	0.615951	Mean dependent var		0.049024
Adjusted R-squared	0.548178	S.D. dependent var		0.064713
S.E. of regression	0.043499	Akaike info criterion		-3.262537
Sum squared resid	0.032166	Schwarz criterion		-3.063581
Log likelihood	38.25664	Hannan-Quinn criter.		-3.219359
Durbin-Watson stat	2.494817			

Table 10 shows that ECM is negative and significant, implying that the variables adapt to their long-run equilibrium in the event of disequilibrium. The speed of adjustment from short-run to long-run equilibrium moves at 93.3%. This implies that 93.3% of the distortions brought about by the shocks of the year before might be restored in this year. Additionally, the past values of CO₂ determine the present values, as the lag of the dependent variable is significant. The adjusted R-square of Model 2 is 0.548, representing that 54.8% of the dependent variable (CO₂) is explained by the independent variables (health care expenditure). The value helps to confirm the specification of the model. The Durbin-Watson test of the model was 2.49, which is within the threshold limit (1.5-2.5), and thus, there is no problem of autocorrelation.

VII. V. NARDL RESULTS

VII. V. I. MODEL 1

Table 11. Wald test for Model 1

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(CO2(-1))	0.238695	0.149966	1.591654	0.1323
D(HE)	0.000589	0.002868	0.205543	0.8399
D(HE(-1))	-0.013550	0.005484	-2.470673	0.0260
CointEq(-1)*	-0.933018	0.198000	-4.712210	0.0003
R-squared	0.615951	Mean dependent var		0.049024
Adjusted R-squared	0.548178	S.D. dependent var		0.064713
S.E. of regression	0.043499	Akaike info criterion		-3.262537
Sum squared resid	0.032166	Schwarz criterion		-3.063581
Log likelihood	38.25664	Hannan-Quinn criter.		-3.219359
Durbin-Watson stat	2.494817			

According to the Table 11, the Wald test for GDP-EC (($F = 2.68$; $P - value = 0.18$) which indicates that there is no evidence of long run asymmetry relationship between the variables. Similarly, the Wald test for GDP-LR ($F=3.39$; $p=0.13$) represents that no long run asymmetry interactions between GDP and LR. On the other hand, the Wald test for EC-LR indicates that there is a long run asymmetry interaction between energy consumption and literacy rate ($F=4.0652$; $p=0.05$). As a result, EC and LR is the only pair have a long run asymmetric relationship between the variables.

Table 12. Bound test for Model 1

Particulars	F-statistics	1%		5%		10%	
		I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
Asymptotic GDP_EC	4.53	3.41	4.68	2.62	3.79	2.26	3.35
Asymptotic GDP_LR	5.23	4.29	5.61	3.23	4.35	2.72	3.77
Asymptotic EC_LR	2.88	3.41	4.68	2.62	3.79	2.26	3.35

Table 12 shows that the cointegration bounds test for asymmetric models for three pairs of variables. Firstly, GDP-EC shows that the F-value is 4.53 which is lower than upper bound level. This implies that there is no evidence of long run asymmetry interactions between GDP and EC. Secondly, GDP-LR shows that the F-value is 5.23 which is lower than upper bound level. This implies that there is no evidence of long run asymmetry interactions between GDP and LR. Thirdly, EC-LR shows that the F-value is 2.88 which is lower than upper bound level. This represents that there is no evidence of long run asymmetry interactions between EC and LR. Thus, this shows that there is no evidence of long run and co-integration between GDP, EC, LR and CO₂.

Table 13. Asymmetric long run parameters- Model 1

GDP_EC		GDP_LR		EC_LR	
Variable	Coefficient	Variable	Coefficient	Variable	Coefficient
	-2.248725		-0.372241		-0.022840
EC_POS	(0.9466)	EC	(0.91)	EC_POS	(0.5086)
	2.270981		1.313484		-0.027700
EC_NEG	(0.9470)	GDP_POS	(0.92)	EC_NEG	(0.0208)
	-5.645575		1.392778		0.007746
GDP_POS	(0.9453)	GDP_NEG	(0.92)	GDP	(0.5963)
	-8.884101		0.002208		0.001213
GDP_NEG	(0.9455)	LR_POS	(0.89)	LR_POS	(0.0672)
	-0.173411		0.025373		-0.001700
LR	(0.9452)	LR_NEG	(0.92)	LR_NEG	(0.0232)

Table 13 shows the results of NARDL model for the asymmetric association for three pairs of variables. In the results table, the independent variable of economic growth designated by

GDP_POS and GDP_NEG whereas energy consumption designated by EC_POS, EC_NEG and literacy rate designated as LR_POS, LR_NEG in the long run. Table shows the long run parameters for every variable individually. The asymmetric long run coefficient of EC_NEG has a significant relationship with CO₂. Negative parameter of EC implies that 1% decrement leads to -0.02 decrement in CO₂. This shows that EC negatively influences CO₂ in India. Similarly, LR is negative (-0.01) with a p-value of 0.02 which is lesser than 5% level of significant. This means that an LR negatively influences CO₂ in India. This indicates that decrease in LR diminishes the CO₂ in the long term. For example, 1% decrement in LR leads to 0 -0.001 decrease CO₂. In contrast, EC have statistical insignificant on both positive and negative shocks on CO₂. Similarly, GDP have a statistical insignificant on both positive and negative shocks on CO₂. LR have a statistical insignificant on both positive and negative shocks on CO₂. Overall, EC, GDP and LR is not a relevant asymmetric indicator for two pairs of parameters (GDP-EC & GDP-LR). Overall long run asymmetric interactions were found only in LR and EC negative shocks on CO₂ on EC-LR pair of variables.

Table 14. Short run cointegration tests - Model 1

GDP_EC		GDP_LR		EC_LR	
Variable	Coefficient	Variable	Coefficient	Variable	Coefficient
C	-0.322525 (0.0030)	C	0.764914 (0.0005)	C	0.574514 (0.0005)
D(CO ₂ (-1))	0.404131 (0.1073)	<u>D(CO₂(-1))</u>	0.252479 (0.1723)	D(EC_POS)	-0.067333 (0.0022)
D(EC_NEG)	-0.002401 (0.3166)	D(EC)	0.000812 (0.6554)	D(EC_NEG)	-0.008115 (0.0004)
D(EC_NEG (-1))	0.080873 (0.0074)	<u>D(EC(-1))</u>	0.045693 (0.0051)	<u>D(EC_NEG(-1))</u>	0.043078 (0.0048)
D(GDP_POS)	0.059828 (0.0028)	D(GDP_POS)	0.029278 (0.0053)	D(GDP)	0.002040 (0.3252)
D(GDP_POS (-1))	0.012698 (0.0543)	<u>D(GDP_POS(-1))</u>	0.007651 (0.0895)	<u>D(GDP(-1))</u>	-0.008276 (0.0114)
D(GDP_NEG)	0.018251 (0.0022)	D(GDP_NEG)	0.009378 (0.0155)	D(LR_NEG)	-0.000265 (0.3251)
D(GDP_NEG (-1))	-0.066578 (0.0020)	<u>D(GDP_NEG (-1))</u>	-0.063421 (0.0007)	<u>CointEq(-1)*</u>	-0.718593 (0.0010)
D(LR)	0.000488 (0.0511)	D(LR_NEG)	-0.000402 (0.1463)		
<u>D(LR(-1))</u>	-0.001767 (0.0025)	<u>D(LR_NEG(-1))</u>	-0.002113 (0.0011)		
<u>CointEq(-1)*</u>	0.014126 (0.0014)	<u>CointEq(-1)*</u>	-0.051673 (0.0007)		
R-squared	0.951030	0.969424		0.935498	
Adjusted R-squared	0.896618	0.935450		0.897871	
F-statistic	17.47845	28.53474		24.86287	
Prob(F-statistic)	0.000103	0.000013		0.000003	
Durbin-Watson stat	2.946852	3.244918		2.838896	

Table 14 shows the short run estimated coefficient of NARDL for three pairs of variables in Model 1. The empirical results for GDP-EC pair shows that GDP is positive and statistically significant in the short run. This indicates that 1% increment in CO₂ increases GDP by 0.05. Also, GDP and LR negative have a negative and significant effect in the short run. This reveals that 1% drop in GDP leads to 0.066 decrease CO₂ in short run. Similarly, 1% drop in CO₂ leads to LR decrease of 0.0017 in short run.

The results of GDP-LR pair shows that the GDP_Neg is positive and significant in the short run. This represents that 1% increment in GDP lead to 0.009 increment in CO₂. The lagged negative change in GDP is negative and significant at 5% level of significance. Similarly, the lagged negative change in LR is negative and significant. This represents that 1% drop in LR leads to 0.02 decrement of CO₂ in short run.

The results of EC-LR pair shows that EC_pos is negative and significant in the short run. This represents that 1% increment in EC lead to 0.006 decrement in CO₂. The lagged negative change in EC is negative and significant at 5% level of significance. Similarly, the lagged negative change in GDP is negative and significant. The ECT of -0.718 reverts to equilibrium which is negative and significant.

VII. V. II. MODEL 2

Table 15. Wald test for Model 2

Test Statistic	Value	df	Probability
F-statistic	7.892381	(3, 15)	0.0022
Chi-square	23.67714	3	0.0000
Null Hypothesis: C (3) =C (4) =C (5) =0			
Null Hypothesis Summary:			
Normalized Restriction (= 0)		Value	Std. Err.
<u>C(3)</u>		0.000589	0.003525
C (4)		0.005050	0.005320
C (5)		0.013550	0.005985
Restrictions are linear in coefficients.			

Table 15 shows the results of Wald test. F-test and chi-square test values were 7.89 and 23.67 respectively with a p-values of 0.00 which is lesser than 5% level of significance. This test confirms that the existence of cointegration in long run effect of CO₂ on HE.

Table 16. Bound test for Model 2

Particulars	F-statistics	1%		5%		10%	
		I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
Asymptotic	9.48	5.15	6.36	3.79	4.85	3.17	4.14
Actual sample		6.18	7.87	4.26	5.47	3.43	4.47

Table 16 shows that the cointegration bounds test for asymmetric models shows that the F-value is 9.48 which is higher than upper bound level at 1%, 5% and 10% significance levels. Thus, this shows that there is evidence of long run and co-integration between HE and CO₂.

Table 17. Long run cointegration tests for Model 2

Variable	Coefficient	Std. Error	t-Statistic	Prob.
HE_POS	0.020753	0.001857	11.17386	0.0000
HE_NEG	0.070591	0.026230	2.691246	0.0176
C	0.933013	0.047909	19.47484	0.0000

Table 17 shows the results of NARDL model for the asymmetric association between HE and CO₂. In the results table, the independent variable of Health care expenditure long run coefficient designated by HE_POS and HE_NEG. The results indicate that negative and positive shocks in CO₂ bring about a statistically significant change in HE in the long run. A positive shock in HE has a positive and significant effect on HE. This implies that 1% increment in CO₂ increases HE by 0.020 while a negative shock in HE implies that 1% drop in CO₂ increases 0.070 in HE.

Table 18. Short run cointegration tests - Model 1

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(HE_NEG)	-0.013291	0.013109	-1.013893	0.3278
<u>D(HE_NEG (-1))</u>	-0.054869	0.013727	-3.997016	0.0013
<u>CointEq(-1)*</u>	-0.502267	0.064219	-7.821097	0.0000
R-squared	0.673770	Mean dependent var		0.050584
Adjusted R-squared	0.635390	S.D. dependent var		0.065988
S.E. of regression	0.039845	Akaike info criterion		-3.470141
Sum squared resid	0.026990	Schwarz criterion		-3.320781
Log likelihood	37.70141	Hannan-Quinn criter.		-3.440984
F-statistic	3.083253	Durbin-Watson stat		2.494817
Prob(F-statistic)	0.002805			

* p-value incompatible with t-Bounds distribution.

Table 18 shows the short run estimated coefficient of NARDL for Model 2. The empirical results shows that estimated coefficient negative and statistically insignificant. In the short run, HE had a positive and insignificant relationship with CO₂ but D(HE (-1)) is negative and significantly positive. The effect of CO₂ in the short run indicates that 1% increment in CO₂ decreases HE by -0.013. A long run causal relationship can be deduced because the error correction terms of -0.50 returns to equilibrium and significant. This implies that in the event of a disequilibrium, CO₂ adjust to its long run equilibrium with a speed of adjustment of 50%.

VII. VI. DIAGNOSTIC AND STABILITY TESTS

VII. VI. I. ARDL MODEL 1

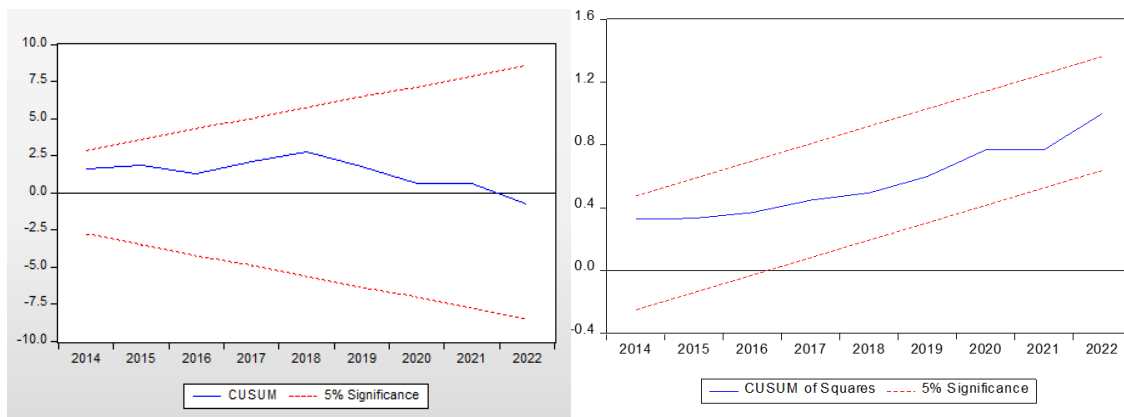


Figure 7. CUSUM test and CUSM test of square

The results of CUSUM test and CUSM test of square reveals that the model is stable and the plots are inside 95% confidence band graphs indicating that model is stable. This represents hat model is stable and no structural break is observed during the study period. On that basis, NARDL was estimated for Model1.

VII. VI. II. ARDL MODEL 2

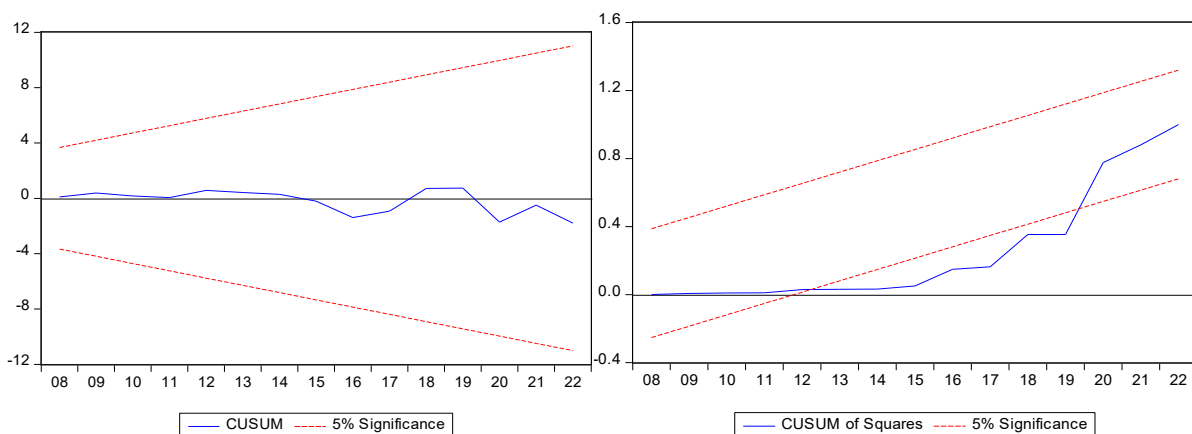


Figure 8. CUSUM test and CUSM test of square

The results of CUSUM test reveals that the model is stable. CUSUM square test indicates that the relationship between HE and CO₂ can be non-linear. On that basis, NARDL was estimated.

VII. VI. III. NARDL MODEL 1

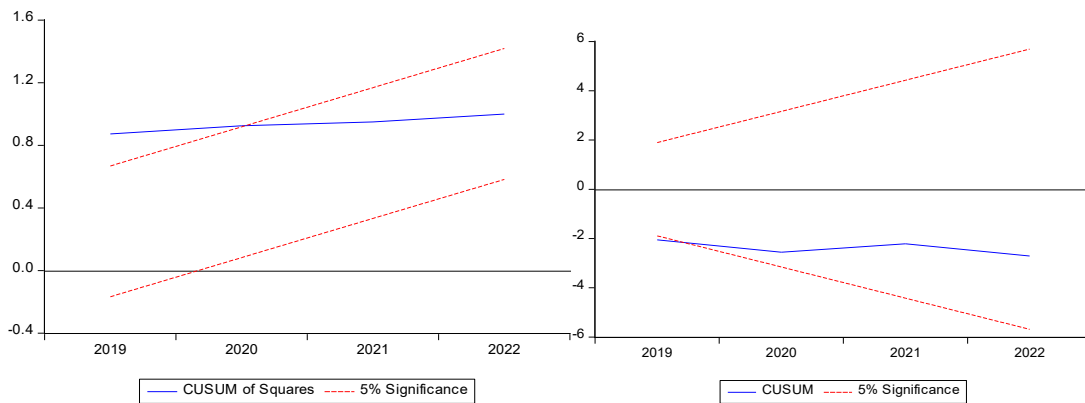


Figure 9. GDP_EC

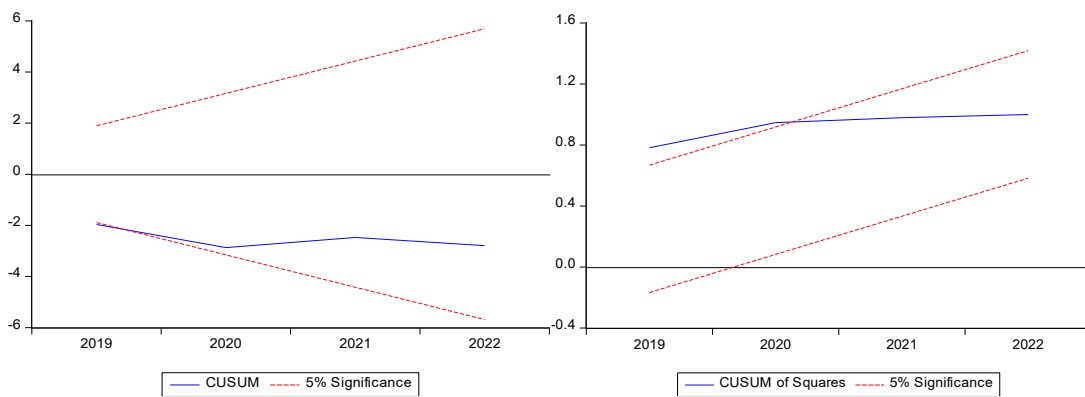


Figure 10. GDP_LR

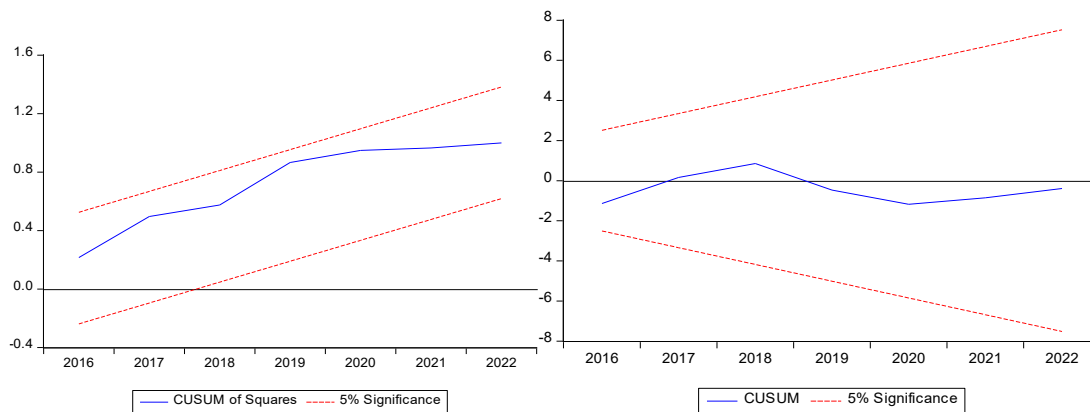


Figure 11. EC_LR

The CUSUM and CUSUMSQ tests are updated relatively with respect to breakpoints. These figures prove that the stability in the parameters of the model with CUSUM and CUSUMSQ tests. The model is stable as the blue line falling inside the critical bounds at 5% level of significance. This demonstrates that the coefficients are stable and dependable and confirms there is a long run relationship between EC, LR and CO₂.

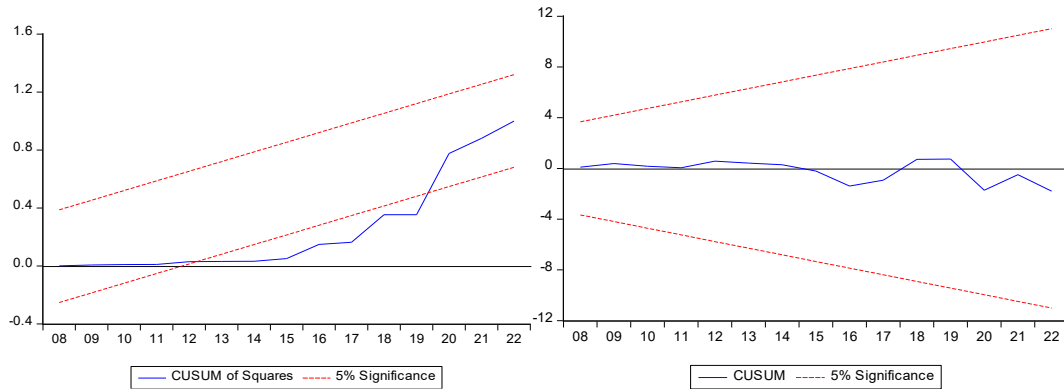


Figure 12. CUSUM and CUSUMSQ tests of NARDL model

Figure 12 shows the plot of stability test results using CUSUM and CUSUMSQ tests of NARDL model to assess the interactions between HE and CO₂. These figures prove that the stability in the parameters of the model with CUSUM and CUSUMSQ tests. Figure 12 shows that the model is stable as the blue line falling inside the critical bounds at 5% level of significance. This demonstrates that the coefficients are stable and dependable and confirms there is a long run relationship between CO₂ and HE. As a result, the model has performed well supported by normally distribution, no autocorrelation and heteroscedasticity.

VIII. CONCLUSION

The main purpose of the study is to examine the asymmetric influence of EC, literacy rate, and economic growth on CO₂ emissions in India using the annual data from 2000 to 2020. The study applied linear ARDL and non-linear ARDL models to assess the symmetric and asymmetric interactions of CO₂ emissions in the country. This helps to find out the long-run and short-run interactions between the variables. Particular attention is given to the Environmental Kuznets Curve, environmental degradation, and human capital theory. With the support from the theory, the results offer a complete picture to understand the interactions between GDP, HE, EC, LR, and CO₂.

This study has utilized ADF and PP to ascertain the integral properties of variables. The ADF and PP tests have identified mix order integration levels I (0) and I (1). After confirming that there are no integrated variables I(1), the lag length criterion can be used to find out the optimal lag. After determining the optimal lag, the symmetry and asymmetry of data can be estimated with ARDL and nonlinear ARDL models to check the long-run and short-run cointegration in the model.

A linear ARDL model is applied to determine the short-term and long-term cointegration in the model. The ARDL bound test showed that there are short-term and long-term effects of EC and GDP on CO₂ in India. The findings demonstrate that EC is negative and significantly enhances CO₂ in the long term, but the previous period of EC further decreases CO₂ in the short term. This indicates that there is an inverse effect between EC and CO₂, meaning the higher the consumption leads to changes in CO₂ in the long run. Also, the empirical results indicate that an increment in GDP contributes to an increase in CO₂ in the short run. This represents GDP as the primary source to increase energy consumption in the country. As a result, GDP rises

may increase the production, which further increases per capita income and labour demand, resulting in high EC. There is a lack of symmetry interactions found between GDP and CO₂ in the long run. The ECM is negative and significant, which represents that the rate of adjustment to long-run equilibrium is 65.27%. Overall, the linear ARDL model suggests a positive effect of GDP on CO₂ in the long run, whereas a negative and significant effect of EC validates CO₂. The model reliability is confirmed with CUSUM and CUSUMSQ.

The asymmetric effect of EC, GDP, LR, HE, and CO₂ is examined. The results showed that LR with negative shocks shows a negative and significant relation with CO₂. Similarly, negative shocks in EC show a negative and significant relation in the long run. On the other hand, the short-run results of asymmetric variables of GDP-EC show that the positive and negative shocks of GDP have a significant effect on CO₂. In addition, the lagged negative shocks of GDP (-1) indicate that the effect of the previous period is negative and significant on CO₂. The outcome indicates that an increase in GDP increases CO₂, which confirms the EKC hypothesis in India for the short run. In addition, the lagged variable of LR (-1) indicates the effect was identified between LR and CO₂. Also, the short-run results of asymmetric variables of GDP—LR indicate that negative shocks and negative lags of GDP have a significant effect on CO₂. Similarly, the lagged variable of LR (-1) indicates that LR has an effect on CO₂. Finally, the short-run results of EC-LR show that the positive shocks of EC have a negative and significant effect on CO₂. The lagged variable of negative shocks of EC (-1) has a positive and significant effect on CO₂, whereas the lagged variable of GDP (-1) has a negative and significant effect on CO₂.

The results from the analysis point out that GDP has a symmetric relationship with CO₂ in the long term. On the other hand, asymmetric interactions between EC and CO₂ are short- and long-term, whereas GDP and CO₂ are found in the short term. Also, the asymmetric effect of the lagged variable of GDP and LR (-1) is observed to be significant negative and significant, whereas the effect of negative shocks of EC (-1) is found to be positive and significant. Statistical significance of long-term coefficients suggests that positive and negative shocks of HE have distinct effects on CO₂. The positive shocks in HE is more persistent than negative ones. Although the signs are positive, the coefficients of the positive shocks are statistically significant, whereas the negative shocks are insignificant in the long run. The stability test of CUSUM and CUSUMQ proves that the estimated parameters are stable for the study period.

This study examined the symmetric or asymmetric interactions between the variables for India. This leaves room to carry out further research for other developing or underdeveloped countries. The present study utilizes CO₂ as a proxy for environmental degradation. On the other hand, future study may consider other pollution indicators to expand the work. Similarly, utilizing other proxies for literacy rate may offer an effective insight about the association between LR and CO₂. Also, future work needs to be done to address the issues of normality and autocorrelation issues found after executing NARDL from the variables (GDP, EC, LR, and CO₂)

VIII. I. RECOMMENDATIONS

Harmful gases are being released in the Indian atmosphere, which increases CO₂ emissions in

the country. The government of India has to make stringent regulations to reduce the emission in the country. The dominance of health expenditure increases positively due to CO₂ emissions in India. This implies that the lack of stringent measures in the country increases CO₂ emissions, which in turn influences the people's health. Thus, the government has to formulate health expenditure policies that safeguard the health of individuals and enhance the production of healthy capital in the country.

Literacy rates in India negatively associate with CO₂ emissions. This implies that the policymakers have to take proactive measures to manage upcoming effects effectively. They have to redefine literacy programs in India. Integration of literacy with environmental practices can have a huge effect on individuals and make them more associated with the environment. Also, inclusion of environmental literacy in the curriculum will play a key role in minimizing negative effects with CO₂ emissions.

Indian policymakers should understand the symmetric relationship between GDP and CO₂ emissions and plan appropriate strategies that enhance long-term economic development and guarantee a safer environment. The ECK hypothesis suggests that the government should frame policies to reduce the effect of CO₂ emissions. Policymakers should create an energy policy that ensures both a healthy environment and sustainable economic growth. Finding out the economic sectors that rely less on energy and making sure that they don't receive additional resources. They have to find out unproductive industries that use an excessive amount of resources and offer them advice on how to increase productivity. Companies should be motivated to adopt energy-saving technologies to increase their energy efficiency. All these measures will increase productivity and close the gap between demand and supply for energy.

ACKNOWLEDGEMENTS

This research work was partially supported by Chiang Mai University.

REFERENCES

- Neog, Y., & Yadava, A. K. (2020). Nexus among CO₂ emissions, remittances, and financial development: a NARDL approach for India. *Environmental Science and Pollution Research*, 27(35), 44470-44481.
- Abbasi, M. A., Parveen, S., Khan, S., & Kamal, M. A. (2020). Urbanization and energy consumption effects on carbon dioxide emissions: evidence from Asian-8 countries using panel data analysis. *Environmental Science and Pollution Research*, 27(15), 18029-18043.
- Minh, T. B., Ngoc, T. N., & Van, H. B. (2023). Relationship between carbon emissions, economic growth, renewable energy consumption, foreign direct investment, and urban population in Vietnam. *Heliyon*, 9(6).
- Qayyum, M., Ali, M., Nizamani, M. M., Li, S., Yu, Y., & Jahanger, A. (2021). Nexus between financial development, renewable energy consumption, technological innovations and CO₂ emissions: the case of India. *Energies*, 14(15), 4505.
- Ofori-Sasu, D., Abor, J. Y., Agyekum Donkor, G. N., & Otchere, I. (2023). Renewable energy

- consumption and carbon emissions in developing countries: the role of capital markets. *International Journal of Sustainable Energy*, 42(1), 1407– 1429.
- Salari, M., Javid, R. J., & Noghanibehambari, H. (2021). The nexus between CO₂ emissions, energy consumption, and economic growth in the U.S. *Economic Analysis and Policy*, 69, 182–194.
- Abdullah, H., Azam, M., & Zakariya, S. K. (2016). The impact of environmental quality on public health expenditure in Malaysia. *Asia Pacific Journal of Advanced Business and Social Studies (APJABSS)*, 2(2), 365-379.
- Ahmat, N., Christopher, S., Saputra, J., Sukemi, M. N., & Nawawi, M. N. (2025). The impact of energy consumption, economic growth, and non-renewable energy on carbon dioxide emission in Malaysia. *International Journal of Energy Economics and Policy*, 15(1), 143-152.
- Ahmed, M., Huan, W., Ali, N., Shafi, A., Ehsan, M., Abdelrahman, K., ... & Fnais, M. S. (2023). The effect of energy consumption, income, and population growth on CO₂ emissions: evidence from NARDL and machine learning models. *Sustainability*, 15(15), 11956.
- Apergis, N., & Payne, J. E. (2009). CO₂ emissions, energy usage, and output in Central America. *Energy policy*, 37(8), 3282-3286.
- Apergis, N., Jebli, M. B., & Youssef, S. B. (2018). Does renewable energy consumption and health expenditures decrease carbon dioxide emissions? Evidence for sub-Saharan Africa countries. *Renewable energy*, 127, 1011-1016.
- Atuahene, S. A., Yusheng, K., & Bentum-Micah, G. (2020). Health expenditure, CO₂ emissions, and economic growth: China vs. India.
- Abdullah, H., Azam, M., & Zakariya, S. K. (2016). The impact of environmental quality on public health expenditure in Malaysia. *Asia Pacific Journal of Advanced Business and Social Studies (APJABSS)*, 2(2), 365-379.
- Hamid, E. S., & Wibowo, B. S. (2023). The impact of CO₂ emission on health expenditure: Lesson learned from ASEAN five countries. *IOP Conference Series: Earth and Environmental Science*, 1180(1).
- Khan, A., Khan, M. A., & Asif, M. (2024). Assessing the impact of carbon emission, health expenditure, IMR and GDP on life expectancy in India: using Cointegration approach. *J Environ Energy Econ*, 3, 54-62.
- Lakshmanasamy, T. Carbon Emissions and Public Health in India: VECM Estimation of the Causal Relationship between Air Pollution and Public Health Expenditure.
- Sreenu, N. (2022). Impact of FDI, crude oil price and economic growth on CO₂ emission in India:-symmetric and asymmetric analysis through ARDL and non-linear ARDL approach. *Environmental Science and Pollution Research*, 29(28), 42452-42465.

- Socol, A., Iuga, H., Socol, D., & Iuga, I. C. (2023). Does climate change drive up government healthcare costs in the European Union?. *Frontiers in Environmental Science*, *11*, 1286099.
- Begum, R. A., Raihan, A., & Said, M. N. M. (2020). Dynamic impacts of economic growth and forested area on carbon dioxide emissions in Malaysia. *Sustainability*, *12*(22), 9375.
- Islam, L. M. R. (2024). LINKAGES AMONG CARBON DIOXIDE (CO₂) EMISSION, HEALTH SPENDING AND ECONOMIC GROWTH: A STUDY SAARC MEMBER COUNTRIES. *Zbornik radova Ekonomskog fakulteta u Istočnom Sarajevu*, (28), 23-38.
- Wang, X. (2024). Correlation analysis of energy consumption, carbon emissions and economic growth. *Energy Informatics*, *7*(1).