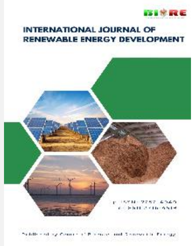
Contents list available at CBIORE journal website

International Journal of Renewable Energy Development

Journal homepage: https://ijred.cbiore.id



Research Article

Do the various sources of energy consumption affect the environmental degradation in India?

Abdul Hayy Haziq Bin Mohamad[a,b,c] and Rossazana Ab-Rahim[a*]

[a] *Faculty of Economics and Business, Universiti Malaysia Sarawak, Malaysia*

[b] *School of Business and Management, University of Technology Sarawak, Malaysia*

[c] *Centre on Technological Readiness and Innovation in Business Technopreneurship, Malaysia*

Abstract. India possesses ample opportunities for economic growth, resulting in a surge in electricity demand. As per the Environmental Performance Index (EPI), India's rank on environmental health and ecosystem viability stands at a lowly 168th out of 180 countries. Historically, India relied on fossil fuels for electricity generation, leading to substantial environmental degradation that have harmed the environment. In recent times, India has diversified its electricity generation sources, incorporating not only fossil fuels but also nuclear power and renewable resources. However, despite these changes, India still struggles with high CO_2 emissions which indicates the level of environmental degradation. Hence, this study aims to investigate the sources of energy consumption in India: fossil fuels, renewable energy, and nuclear energy. By utilising the ARDL and NARDL methodologies, this study enriches the empirical studies by examining energy consumption trends in India from 1985 to 2021. The findings of this study shed light on whether the adoption of renewable energy and nuclear energy significantly aids in reducing carbon emissions in India, thereby facilitating the attainment of the Sustainable Development Goal (SDG), Therefore, it is of the utmost necessity for India to emphasize the formation of clean energy in their energy policy to achieve the SDG7 by the year 2030. This study found a positive correlation between GDP per capita and CO_2 emissions, highlighting the urgent need to reduce India's dependency on fossil fuels. The ARDL analysis further confirms that fossil fuel-generated energy contributes to CO_2 emissions, whereas nuclear-generated energy reduces them.

Keywords: Electricity, Energy, CO_2 Emissions, Sustainable Development Goal, India.

Received: 6th June 2023; Revised: 26th Nov 2023; Accepted: 17th Dec 2023; Available online: 3rd Jan 2024

1. Introduction

Due to its vast population, India has a significant electricity consumption annually. India's demand for power has sharply increased in recent years as a result of the country's economic growth and rising urbanization. But India has a lot of problems trying to meet its need for electricity. The nation's electricity industry is characterized by a high level of inefficiency, subpar infrastructure, and excessive reliance on fossil fuels such as coal (Wang & Song 2019). As a result, India frequently has inconsistent electricity supplies, including frequent power outages and blackouts (Rehman & Hussain 2017). According to report by India energy outlook 2021, India is the nation that will have the greatest growth in energy consumption in 2024 due to its rapidly growing economy, population, urbanization, and industrialization (IEA 2023).

Consequently, it becomes imperative for a nation of this magnitude to shift its energy production from fossil fuels to renewable and clean sources (Qayyum *et al.* 2022, Ortega-Ruiz *et al.* 2022). Several countries still depend on fossil fuels as their main electricity source due to their ability to offer more reliable power (Chen *et al.* 2022, Martins *et al.* 2018). Nonetheless, it is not justifiable to compromise the value of the environment for the sake of electricity generation (Covert *et al.* 2016).

Ahmed *et al.* (2022) and Sasmaz *et al.* (2020) suggest fossil fuel is the significant contributors to the emissions of CO2 and greenhouse gases, thereby playing a major role in the occurrence of severe climate change. Martins *et al.* (2019) offer evidence of substantial climate change, including global warming and the subsequent rise in temperatures worldwide. This phenomenon has led to the melting of arctic glaciers and the resulting increase in sea levels (Stokes *et al.* 2022, Yarzábal *et al.* 2021). Other past studies such as Gussmann & Hinkel (2021), Shah *et al.* (2020), and Piecuch (2020) recommend countries such as the Maldives and Pakistan, as well as coastal areas of the United States (Florida and Louisiana), are already experiencing coastal erosion due to rising sea levels.

The escalation of fossil fuel prices is often triggered by geopolitical conflicts in oil-exporting nations, which can include warfare. According to Estrada *et al.* (2020), conflicts in Middle Eastern countries disrupt the oil supply, leading to a significant increase in prices. A similar situation arose during the recent Russia-Ukraine conflict, due to the fact that Russia is one of the primary exporters of oil and natural gas in the world (Adekoya *et al.* 2022). Furthermore, the sanctions on Russia have also impacted global oil supply, resulting in price hikes (Mbah & Wasum 2022). As the results, the fluctuations of electricity tariff during political crises in oil-exporting nations exacerbates the

* Corresponding author
Email: arrossazana@unimas.my (R. Ab-Rahim)

https://doi.org/10.61435/ijred.2024.55836
ISSN: 2252-4940/© 2024.The Author(s). Published by CBIORE

issue of energy security and encourages other countries to transition towards renewable energy sources such as hydroelectric facilities and solar power generation (Żuk & Żuk 2022, San-Akca *et al.* 2020).

The rise in CO_2 emissions resulting from the combustion of fossil fuels presents significant concerns, including the potential damage to the ozone layer in the atmosphere (Baldwin & Lenton 2020). On this note, the air pollution associated with high CO_2 emissions poses health risks, especially for individuals with pre-existing respiratory conditions (Guo *et al.* 2019). The power generation relying on fossil fuels carries numerous detrimental consequences, potentially leading to irreversible damage. Hence, it is crucial to fully support the adoption of clean energy sources; apart from mitigating the issue of climate change, it also fosters sustainable economic growth (Gibba & Khan 2023).

India is undoubtedly poised to have a substantial annual electricity demand due to her status as the world's most populous country which could imply the potential for further growth, (Das *et al.* 2022). The rising levels of carbon dioxide emissions that are caused by the burning of fossil fuels to generate energy are giving people all over the world greater cause for concern (Ali et al., 2022). While this presents an unavoidable challenge, the implementation of clean energy infrastructure offers hope and serves as a solution to mitigate India's CO_2 emissions (Ozgur *et al.* 2022). In line with the objective of Sustainable Development Goal 7 (SDG7), it is imperative for India to address this issue.

The SDG7 seeks to assure universal access to affordable, reliable, sustainable, and modern energy with the following goals:

i. By the year 2030, make sure that universal has access to energy that is both affordable and reliable.
ii. By 2030, the proportion of renewable energy used worldwide.
iii. By 2030, there should be an increasing in energy efficiency and should occur at a rate double the current world average.
iv. By 2030, international cooperation among all nations in the research and development of technology relating to renewable and environmentally friendly forms of energy.

Figure 1 provides a comparison of electricity consumption (TWh) from three different energy sources in India. Since 2017, electricity consumption from fossil fuels has exceeded 1000 TWh, which is four times higher than that from renewable sources and thirty times greater than nuclear energy. This comparison between fossil fuels and renewables is crucial in assessing India's progress towards meeting the SDG 2030 targets. Nuclear energy is categorized separately from renewable energy due to its non-renewable nature, despite deriving from uranium sources. Nuclear energy offers advantages such as zero carbon dioxide emissions and minimal environmental contamination. However, its classification as clean energy is a subject of debate due to the potential risks of high radioactive effects in the event of a nuclear reactor accident, as exemplified by the Chornobyl catastrophe in Russia in 1986 (Berger 2010, Ludovici *et al.* 2020).

Figure 2 demonstrates that India's population is growing at a consistent rate each year, moving from 1,354 million people in 2017 to 1,396 million people in 2020 and starting to reach 1,407 million people in 2021. Compare to the electricity from fossil based, there is increasing pattern from 2017 to 2018 with 6.46%. there is slide downward pattern in between 2019 to 2020 with 5.92%.

This is due to the lockdown and mobility restrictions that have been imposed all over the world, which have a knock-on effect of affecting numerous companies that are tied to the consumption of power (Kanitkar 2020). In most cases, this results in a lower demand for electricity during that given year. However, in 2021, several countries started opening their national borders owing to economic pressures (Brodeur *et al.* 2021, Vyas 2020), which led to an increase in the need for energy. In fact, India demonstrates an increase of 11.25% in high fossil-based power in 2021, which is in line with the increase in the Indian population.

The negative effects on the environment are one of the key issues that arise from India's over reliance on fossil fuels. The combustion of fossil fuels results in the emissions of greenhouse gases, which are a contributing factor in both climate change and global warming. The effects of climate change are already being felt in India, specifically in the form of rising temperatures, an increase in the frequency of heatwaves, and irregular rainfall patterns, all of which are having a negative impact on agricultural and water supplies (Mohammad & Goswami 2019).

It's evident that India relies heavily on fossil fuels to generate electricity, which raises concerns about achieving SDG 7 goals by 2030. India has the potential to make a major reduction in its carbon footprint and to contribute to global efforts to address climate change if it makes the switch to renewable energy sources.

Past studies have tended to focus on the nexus between the energy consumption and economic growth; nevertheless, this study departs from the practice of past studies by examining and comparing the environmental effects of nuclear power, fossil fuels, and renewable forms of energy in India. Employing Autoregressive Distributed Lag(ARDL) and Nonlinear Autoregressive Distributed Lag(NARDL) models, this study examines the consumption of all energy sources in India over the period 1985 to 2021. The findings of this study shed light

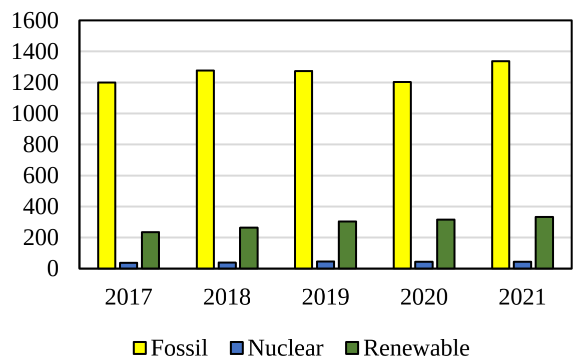


Fig. 1 Indian Electricity Consumption (TWh) (2017 – 2021).

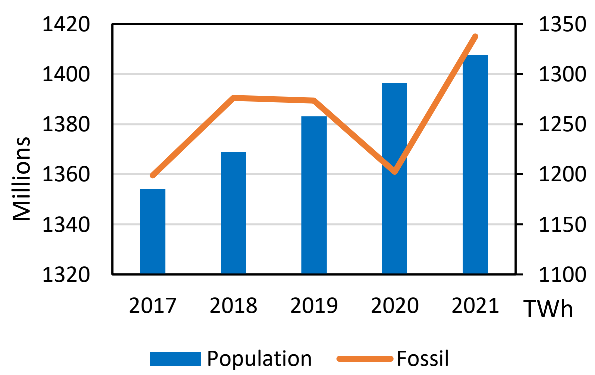


Fig. 2 India population compare to fossil energy.

whether the consumption of renewable and nuclear energy significantly reduces carbon emissions in India, contributing to the achievement of Sustainable Development Goal 7 (SDG7).

2. Literature Review

The past empirical studies focus to examine the relationship between CO2 emissions consumption with many other variables and reflect the issues with energy crisis. In India, coal and oil serve as the primary sources of energy. Various studies consider these fossil fuels to be crucial components when discussing their effects on the environment. Kartal (2022) conducted a study that involved five countries, including India, from 1965 to 2019. Many others studies also conclude the same, as the utilizing sources of non-renewable energy may result in an increase in CO2 emissions (Lin & Xu 2020, Zhang *et al.* 2020; Uzair *et al.* 2022; Mohamad *et al.* 2023). Therefore, reducing CO2 emissions is an important goal to work toward because its substance is one of the major contributors to climate change (Bauer *et al.* 2016, Adedoyin *et al.* 2020, Ehsanullah *et al.* 2021).

Moreover, the transformation toward renewable energy consumption has a stronger influence on economic growth than non-renewable energy consumption in most of the European countries case studies (Ntanos *et al.* 2018) and green policy has given more confident for the investor to invest in these countries (Ben Mbarek *et al.* 2018; Guo *et al.* 2021). Adekoya *et al.,* (2022) also claim that the African countries gains benefit from the utilise of the renewable energy.

The above-mentioned studies utilised multivariate adaptive regression to analyse the countries' use of fossil fuel, nuclear energy, and renewable sources in relation to environmental degradation. The results showed that fossil fuels have a negative impact on the environment. Furthermore, Ali *et al.* (2022) and Hossain *et al.* (2023) discovered that the fossil fuels utilised to generate electricity significantly contribute to the degradation of the environment. Sharif *et al.* (2020), also found that India among top 10 polluted countries in the world, and with the renewable energy can reduce the CO2 emissions in India.

Numerous studies employ the ARDL methodology to investigate the correlation between CO_2 emissions and diverse independent variables. Some researchers in the field of energy security posit that nuclear power can serve as a substitute for fossil fuels. Sadekin *et al.* (2019) assert that nuclear energy is a dependable and secure energy source that fosters economic growth. In their research, Ozgur *et al.* (2022) explore the impact of nuclear energy on CO_2 emissions by integrating Kuznets' theory into a sustainable evidence interpretation. Their analysis of data spanning from 1970 to 2016 indicates that nuclear energy is a more sustainable option in India than fossil fuels.

Several studies such as Danish *et al.* (2021), Lau *et al.* (2019), and Hassan *et al.* (2020), suggest that India can reduce its CO_2 emissions by adopting nuclear energy. Moreover, not only does nuclear energy have a positive impact on the environment, but it also significantly contributes to India's economic growth, as recommended by Bandyopadhyay & Rej (2021). In fact, the utilization of nuclear energy resources has transformed India's economic activity (Wolde-Rudael 2010, Ghosh & Kanjilal 2020).

Das *et al.* (2022) employ the dynamic ARDL method to examine the trend of renewable energy consumption in India over the past two decades, highlighting a gradual increase. Subsequently, Das *et al.* (2023) assesses the feasibility of India adopting a carbon-neutral agenda by 2070. The authors suggest that a 1% increase in renewable energy consumption leads to a corresponding decrease of 0.8% in CO2 emissions. Similarly, Sreenu (2022) examines the effects of foreign direct investment (FDI), economic growth, and crude oil prices on CO2 emissions in India between the years 1990 and 2020, utilizing both ARDL and NARDL research approaches.

The NARDL approach was employed to assess the significant impact of crude oil consumption, particularly when experiencing positive shocks, on CO_2 emissions. Study by Mujtaba & Jena (2021) to examine the impact of economic development, energy use, FDI inflows, and oil toward the CO2 emissions between 1986 and 2014 using the NARDL method. The examination of the asymmetric relationship between energy consumption and CO2 emissions has received others researchers' attention. Shahbaz *et al.* (2021) employed the NARDL model on data spanning from 1980 to 2019 and found that positive changes in energy consumption led to increased CO_2 emissions, while negative changes in energy consumption result in decreased CO_2 emissions in India. Recognizing the significance of renewable energy in attracting investors, Caglar (2020) underscores its role in stimulating investment in the country.

Therefore, there have been a great number of previous studies that have focused on the CO2 emissions in India; however, the purpose of this study is to address the gap in knowledge regarding the impact on the environment caused by different energy consumption in India between the years 1985 and 2021.

3. Methodology

This study aims to determine the nexus between CO2 emissions and GDP per capita, FDI, and energy consumption from three different sources (fossil, nuclear, and renewable); the general specification and estimation of the models as below:

$$CO_2e_t = f(GDP_t, FDI_t, FOSSIL_t, NUCL_t, RES_t) \quad (1)$$

Equation (1) can also be rewritten as follows:

$$CO_2e_t = \beta_0 + \beta_1 GDP_t + \beta_2 FDI_t + \beta_3 FOSSIL_t + \beta_4 NUCL_t + \beta_5 RES_t + \varepsilon_t \quad (2)$$

The variables in Equation (2) are:

CO_2e_t : Carbon dioxide emissions per capita (Mt)
GDP_t : Gross Domestic Product per capita
FDI_t : Foreign Direct Investment (Net inflow)
$FOSSIL_t$: Energy consumption from fossil resources (TWh)
$NUCL_t$: Energy consumption from nuclear resources (TWh)
RES_t : Energy consumption from renewable resources (TWh)

Data spanning from 1985 to 2021 sourced from various databases was analysed in this study. To gauge the sustainability impact, CO_2 emissions per capita data from Our World in Data (OWiD) was used as a proxy. CO_2 emissions have been identified as the biggest contributor to climate change (Adedoyin *et al.* 2020, Sadatshojaie & Rahimpour 2020), and several studies have found it to be a crucial variable in sustainable issues (Abbasi *et al.* 2021, Yurtkuran 2021, Sreenu 2022). The GDP per capita data from World Development Indicators (WDI) was used as an independent variable, which is an important measure of economic activity (Magazzino *et al.* 2021).

FDI can have a complex impact on CO2 emissions, as it can lead to both positive and negative effects on the environment, which is an important variable to able this study to use NARDL method (Mujtaba & Jena 2021). The various types of energy that use fossil, nuclear and renewable sources are the classified as the control variables to analyse the impact toward CO2 emissions. There is a risk of having a heteroscedasticity when analysis time series data with various variable. To avoid it, all the variables in Equation (2) are transformed in the logarithmic form.

To examine the impact of different sources of energy consumption on CO_2 emissions in India, the ARDL model, also known as the bounds testing cointegration technique developed by Pesaran *et al.* (2001), was employed. This methodology has been widely utilised in past studies to estimate the relationship between CO_2 emissions and various sources for electricity generation, as demonstrated by Anwar *et al.* (2021), Yurtkuran (2021), Sikder *et al.* (2022), and Kartal *et al.* (2023). According to Hassler & Wolters (2006), the ARDL model provides an efficient framework for evaluating and estimating long-run connections based on actual time series data, and it does so in a number of different ways. Another method closely related to ARDL is the Johansen (1991) approach.

The cointegration test approach based on Johansen (1991) necessitates that all the variables be integrated in the same order, i.e. I(1) then the cointegration can be analysed. However, if some of the variables were integrated in between I(0) and I(1), then the correlation were not able to be identified. Thus, many researchers used the ARDL model as the method offers more flexibility. Pesaran *et al.* (2001) suggest that the major advantage of ARDL is its flexibility in analysing variables of different orders of integration and able to interpret the relationship between the selected variables. The ARDL model was used in this study to measure the short-run ECM (Equation 4) and the long-run model (Equation 5). The Equation (3) shows the ARDL model as follow:

$$dlnCO_2e_t = \beta_0 + \beta_1 dlnGDP_{t-1} + \beta_2 dlnFDI_{t-1} + \beta_3 dlnFOSSIL_{t-1} + \beta_4 dlnNUCL_{t-1} + \beta_5 dlnRES_{t-1} + \varepsilon_t \quad (3)$$

Short run ECM:

$$dlnCO_2e_t = \beta_0 + \beta_1 dlnGDP_{t-1} + \beta_2 dlnFDI_{t-1} + \beta_3 dlnFOSSIL_t + \beta_4 dlnNUCL_t + \beta_5 dlnRES_{t-1} + ECM_{t-1} \quad (4)$$

ECM_{t-1} : Error correction factor

Long-run model is derived from Equation (4) by assuming that the difference variables are zero, and normalizing the equation, the following model is obtained:

$$lnCO_2e_t = \beta_0 + \beta_1 lnGDP_{t-1} + \beta_2 lnFDI_{t-1} + \beta_3 lnFOSSIL_{t-1} + \beta_4 lnNUCL_{t-1} + \beta_5 lnRES_{t-1} + \varepsilon_t \quad (5)$$

In order to evaluate the asymmetric effect of fossil, nuclear and renewable energy consumption on sustainability environment, this study employs the NARDL approach introduced by Shin *et al.* (2014). The advantage of using the NARDL is able to compare the positive and negative value impact on the CO2 emissions.

$$lnFOSSIL_t = lnFOSSIL_0 + \Delta FOSSIL^+{}_t + \Delta FOSSIL^-{}_t \quad (6)$$

$$lnNUCL_t = lnNUCL_0 + \Delta NUCL^+{}_t + \Delta NUCL^-{}_t \quad (7)$$

$$ln\mathrm{RES}_t = ln\mathrm{RES}_0 + \Delta\mathrm{RES}^+{}_t + \Delta\mathrm{RES}^-{}_t \quad (8)$$

Where *lnFOSSIL,, lnNUCL,* and *lnRES* represent the random initial value and $lnFOSSIL^+{}_t + lnFOSSIL^-{}_t + lnNUCL^+{}_t + lnNUCL^-{}_t + lnRES^+{}_t + lnRES^-{}_t$ denote partial sum processes which accumulate positive and negative changes, respectively, and are defined as:

$$lnFOSSIL^{\pm}{}_t = \sum_{x=1}^{t} \Delta ln\, FOSSIL^+{}_x = \sum_{x=1}^{t} max\,(\Delta lnFOSSIL^+{}_x, 0), \sum_{x=1}^{t} \Delta ln\, FOSSIL^-{}_x = \sum_{x=1}^{t} min\,(\Delta lnFOSSIL^-{}_x, 0) + \varepsilon_t \quad (9)$$

$$lnNUCL^{\pm}{}_t = \sum_{x=1}^{t} \Delta ln\, NUCL^+{}_x = \sum_{x=1}^{t} max\,(\Delta lnNUCL^+{}_x, 0), \sum_{x=1}^{t} \Delta ln\, NUCL^-{}_x = \sum_{x=1}^{t} min\,(\Delta lnNUCL^-{}_x, 0) + \varepsilon_t \quad (10)$$

$$lnRES^{\pm}{}_t = \sum_{x=1}^{t} \Delta ln\, RES^+{}_x = \sum_{x=1}^{t} max\,(\Delta lnRES^+{}_x, 0), \sum_{x=1}^{t} \Delta ln\, RES^-{}_x = \sum_{x=1}^{t} min\,(\Delta lnRES^-{}_x, 0) + \varepsilon_t \quad (11)$$

To verify the positive and negative shocks of the variables, we employ Equations (9) to (11), and the asymmetric method is described below.

$$lnCO_2e_t = \beta_0 + \beta_1 lnGDP_{t-1} + \beta_2 lnFDI_{t-1} + \beta_3 lnFOSSIL^+{}_{t-1} + \beta_4 lnFOSSIL^-{}_{t-1} + \beta_5 lnNUCL^+{}_{t-1} + \beta_6 lnNUCL^-{}_{t-1} + \beta_7 lnRES^+{}_{t-1} + \beta_8 lnRES^+{}_{t-1} + \varepsilon_t \quad (12)$$

4. Results and Discussion

The study includes 37 observations with annual data spanning from 1985 to 2021. Table 1 presents the statistical description of the variables used in the econometric model. The central tendency measurements of all variables indicate a statistically normal distribution. This conclusion is based on the small difference between the mean and median values, which do not exceed a 10% gap (Yitzhaki 2003). The skewness statistic, tested on all variables, reveals values ranging between 1 and -1, indicating a relatively symmetrical distribution (Bai & Ng 2005, Orcan 2020).

Table 1 demonstrates a strong correlation between the variables, where any increment in one variable corresponds to an increment in the other. The results in the table emphasize that the highest correlation is between CO_2 emissions and energy consumption from fossil sources, followed by GDP per capita and energy consumption from nuclear energy. Even though the correlation between CO_2 emissions and energy consumption from renewable resources and FDI is the lowest, it nevertheless bears a very strong correlation, as all variables' values exceed 0.7 (Kozak 2009, Ratner 2009). Figure 3 supports

Table 1
Statistical description and matrix correlation.

	LCO2	LGDP	LFDI	LFOSSIL	LNUCL	LRES
Mean	0.035	1.874	-0.522	6.224	2.707	4.708
Med.	-0.055	1.840	-0.121	6.301	2.870	4.455
Max.	0.655	2.044	1.287	7.199	3.810	5.806
Min.	-0.673	1.740	-3.604	4.868	1.392	3.891
Std. Dev	0.405	0.107	1.417	0.678	0.781	0.563
Skew.	0.046	0.243	-0.910	-0.311	-0.160	0.441
Jarque-bera	1.831	1.434	2.507	2.050	1.678	1.979
	(0.346)	(0.126)	(0.065)	(0.370)	(0.240)	(0.246)
Obs.	37	37	37	37	37	37
LCO2	1.000					
LGDP	0.968	1.000				
LFDI	0.850	0.796	1.000			
LFOSSIL	0.988	0.939	0.896	1.000		
LNUCL	0.968	0.965	0.762	0.937	1.000	
LRES	0.956	0.931	0.845	0.958	0.904	1.000

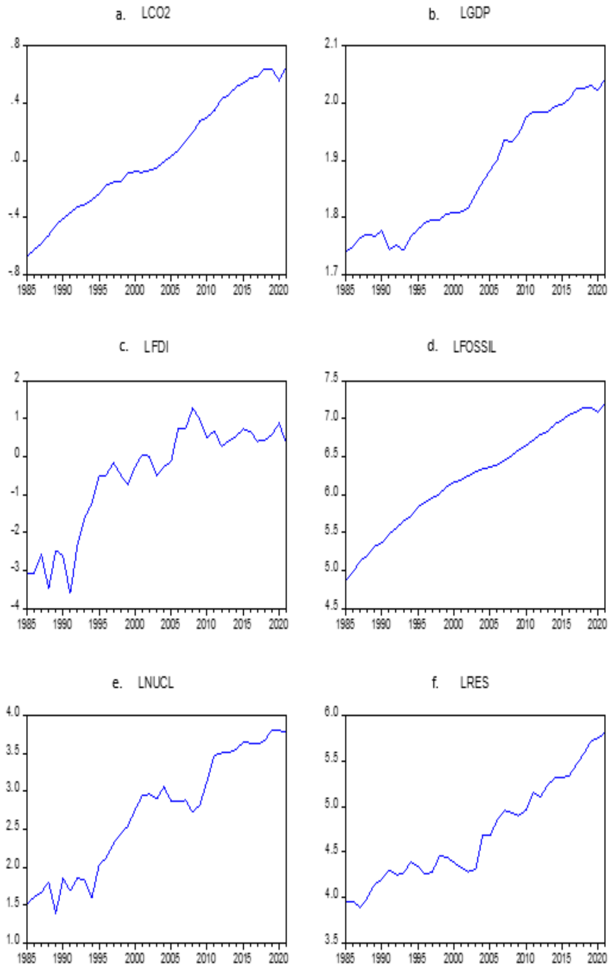


Fig. 3 Variables trend analysis.

Table 2
Unit Root Test

Test	ADF		PP	
Variable	level	First dif.	level	First dif.
LCO2	-3.267 *	-1.385	-2.036	-5.648 ***
LGDP	-1.822	-5.587 ***	-1.836	-5.628 ***
LFDI	-1.842	-6.976 ***	-1.668	-6.988 ***
LFOSSIL	-2.454	-5.075 ***	-2.487	-5.078 ***
LNUCL	-3.503	-7.811 **	-2.891	-7.811 ***
LRES	-1.909 *	-6.028 ***	-1.938	-6.137 ***

Note: (*) Significant at 10%; (**) Significant at 5%; (***) Significant at 1%

these findings, showing an increasing trend for all six variables with minimal fluctuations.

The labels in Figure 3 shows a. LCO2; log Carbon dioxide emissions per capita, b. LGDP; log Gross Domestic Product per capita, c. LFDI; log Foreign Direct Investment, d. LFOSSIL; log Energy consumption from fossil resources, e. LNUCL; log Energy consumption from fossil resources and f. LRES; log Energy consumption from renewable resources. The CO2 emissions (LCO2) and energy from fossil (LFOSSIL) patterns for India was reported having consistently increase from 1985 until 2018. It was discovered that India highly dependent on fossil fuels, which caused the nation to emit large amounts of CO2 annually (Udemba *et al.* 2021; Uzair *et al.* 2022). Following that, India had a decline in 2019 and the early 2020. However, the CO2 emissions and energy from fossil once more rise at the end of 2021. It was found that this is cause by the environment impact of COVID-19.

According to Gupta *et al.* (2021), the crisis of COVID-19 has made the people in India to stay at home to prevent the spreading of this virus. Thus, relatively reducing the CO2 emissions been released from transportation such as cars and buses (Pal *et al.* 2022). Other finding that related with the economy are the track of the Gross Domestic Product per capita (LGDP) in early 2019 and Foreign Direct Investment (LFDI) within 2019 until 2021; as the COVID-19 caused the economy to contract. The lockdown in India has positive impact on the reducing of CO2 emissions (Pradhan & Ghosh 2021), however it damaging the economy caused the decline of the GDP and FDI (Goswami *et al.* 2021; Jena *et al.* 2021; Joshi *et al.* 2020;). According to Kanitkar (2020), the India economy has negatively impact from the most of countries empowered the lockdown.

The nuclear energy (LNUCL) and energy from renewable resources (LRES) represent the clean energy as these 2 resources has minimum impact on damaging the environment (Rehm 2023; Jaiswal *et al.* 2022). Both of these resources are found strongly increasing trend especially for nuclear energy after year 1995 in Figure 3. This is positive impact from the deal between India and United States, in the "US-India Joint Statement on Civil Nuclear Cooperation", which has enhanced the greater collaboration in civil nuclear technology between these countries (Fuhrmann, 2009; Grover, 2017)..

In order to conduct the ARDL test, it is imperative to ensure that all variables are stationary at level and/or first level in unit root tests (Pesaran *et al.* 2001). As shown in Table 2, all variables

Table 3
ARDL Bound Test

F- Value	Level of Significant (%)	Lower bound	Upper bound
11.65	10	2.08	3.00 ***
	5	2.39	3.38 ***
(K = 5)	2.5	2.7	3.73 ***
	1	3.06	4.15 ***

Note: (*) Significant at 10%; (**) Significant at 5%; (***) Significant at 1%

Table 4
Selected ECM ARDL Short-run and Long-run

ARDL (SR)	ECM with selected short-run model	ARDL (LR)	Long-run co-integration model
Model	(1, 2, 2, 2, 1, 0)	Variable	Coefficient
Variable	Coefficient	LGDP	1.0401 ***
D(LGDP(-1))	-0.955 ***	LFDI	-0.0115
D(LFDI(-1))	0.00826 *	LFOS	0.545 ***
D(LFOSSIL(-1))	0.442 ***	LNUCL	-0.0743***
D(LNUCL)	-0.0324 ***	LRE	0.056
CointEq(− 1)*	-0.796 ***	C	-5.421 ***

Note: (*) Significant at 10%; (**) Significant at 5%; (***) Significant at 1%

are statistically stationary at first difference when using the Phillips-Perron (PP) test. While using the Augmented Dickey-Fuller (ADF) test, it is evident that most variables are stationary at first difference, except for CO_2 emissions and energy consumption from renewable resources which are solely stationary at levels. This confirms the presence of cointegration among the variables, thus making it appropriate to use the ARDL approach.

In order to determine whether or not the model is appropriate for long-run co-integration analysis, the ARDL bound test contributes to an extremely important role. Indicating the existence of a long-run relationship in the model is the fact that the estimated F-value must be greater than the upper bound threshold (Coakley & Fuertes 1997, Maddala & Wu 1999, Rehman *et al.* 2021). The computed value of F is 11.65, and this value is more than both the lower and the upper bound values that were determined for this study (as shown in Table 3). This substantiates the hypothesis that there is, in the long run, a co-integration between the CO_2 emissions and the electrical resources.

Table 4 clearly displays two distinct ARDL approaches utilizing the most suitable model (1, 2, 2, 2, 1, 0) for both short and long-term ECM. The study's findings unequivocally demonstrate that all variables are highly significant at 1% in relation to CO2 emission. Moreover, FDI is the sole variable demonstrating significance at 10% and with a positive value. This outcome aligns with other studies such as He *et al.* (2020) whereby the impact of FDI on CO2 emissions in India was significant and positive. Nevertheless, the GDP per capita is significant but negative value (-0.9546).

The nuclear energy also resulting negative value with -0.0324 with the significant of 1%. Thus, there is a negative cointegration between the income of India and the energy consumption from nuclear energy toward the CO2 emissions. There a study mentioned that nuclear energy is a future energy (Sadekin *et al.* 2019). This is because nuclear energy was a low CO2 emission (Lenzen 2008, Bisconti 2018, Pata & Samour 2022), there also other studies getting the same results for nuclear energy was less damage to the environment (Danish *et al.* 2021, Kartal *et al.* 2023). In the short term, the ECT demonstrates that there is a disequilibrium; nevertheless, it is getting adjusted at the speed of 79% per year towards the equilibrium point in the long run. Meaning, it will take 1 year for short run model get to the equilibrium level.

After analyzing the ECM short run model and comparing it to the long run model, it appears that there are two variables that are not significant. Specifically, FDI with negative value and renewable resources for energy consumption were found to be non-significant. This suggests that there is no relationship between FDI and CO_2 emissions long run estimate for ARDL. This finding is consistent with the work of Voumik & Ridwan (2023) who identified the relationship of FDI towards the environment in Argentina.

On the other hand, in the long run ARDL model, GDP and fossil fuel were found to be significant with the same positive value of 1.0401 and 0.5446, respectively. This indicates that there is a correlation between India's income and energy consumption from fossil fuels, which is strongly affecting CO_2 emissions. It means that the burning of fossil fuels for generating energy consumption and the increasing GDP in India may result in producing more CO_2 emissions. According to Jayanthakumaran *et al.* (2012) and Pachiyappan *et al.* (2021), India's competitiveness in the economy has negatively impacted the environment.

The Fully Modified OLS (FMOLS) and Dynamic OLS (DOLS) in Table 5, are the alternative methods to the long-run model. These tests are used to check the robustness of the ARDL long run in Table 4. In the ARDL long run is getting 4 variable significant, and only energy consumption from renewable resources and FDI is not significant. The study can consider the ARDL long run is robust as the significant variables such as GDP, energy consumption from fossil and constant are also found significant in FMOLS and DOLS with positive value. The energy consumption from nuclear energy is also significant because all these robustness tests are getting negative value. Therefore, this clarifies the ARDL long run is considered robust.

The results of the residual diagnostic test in Table 6 show all the findings are normal. There is no heteroskedasticity and serial correlations problem is detected using the Breusch-Godfrey Serial Correlation LM, Breusch-Pagan-Godfrey and ARCH test. The Jarque-Bera test also finds that the data is normally distributed.

Table 5
Robustness Test (FMOLS and DOLS)

Variable	FMOLS	DOLS
LGDP	1.110 ***	0.951 ***
LFDI	-0.0323 **	-0.0115
LFOSSIL	0.551 ***	0.557 ***
LRES	0.0485	0.0519
LNUCL	-0.0806 **	-0.0676 *
C	-5.505 ***	-5.338 ***

Note: (*) Significant at 10%; (**) Significant at 5%; (***) Significant at 1%

Table 6
Residual Diagnostic Test

Diagnostic test	F-value	Finding
Breusch-Godfrey Serial Correlation LM	0.2499	No serial correlations problem
Normality test (Jarque-Bera)	2.5572	Normal distributed
Heteroskedasticity test Breusch-Pagan-Godfrey test	0.7195	No Heteroskedasticity problem
ARCH test	0.2060	No Heteroskedasticity problem

Table 7
Nonlinear ARDL Results

Variable	Coefficient	St. Error	t-ratio
LCO2(-1)	0.287 *	0.139	2.0611
LGDP(-2)	0.953 ***	0.227	4.203
LFDI	0.0071	0.0052	1.378
LFOSSIL_POS(-2)	-0.534 ***	0.125	-4.264
LFOSSIL_NEG(-1)	-0.495	0.468	-1.0579
LNUCL_POS(-2)	-0.0410	0.0270	-1.516
LNUCL_NEG(-2)	0.104 **	0.0343	3.0408
LRES_POS(-2)	-0.0960 **	0.0359	-2.673
LRES_NEG(-2)	0.424 **	0.140	3.0368
C	-2.266 ***	0.480	-4.723

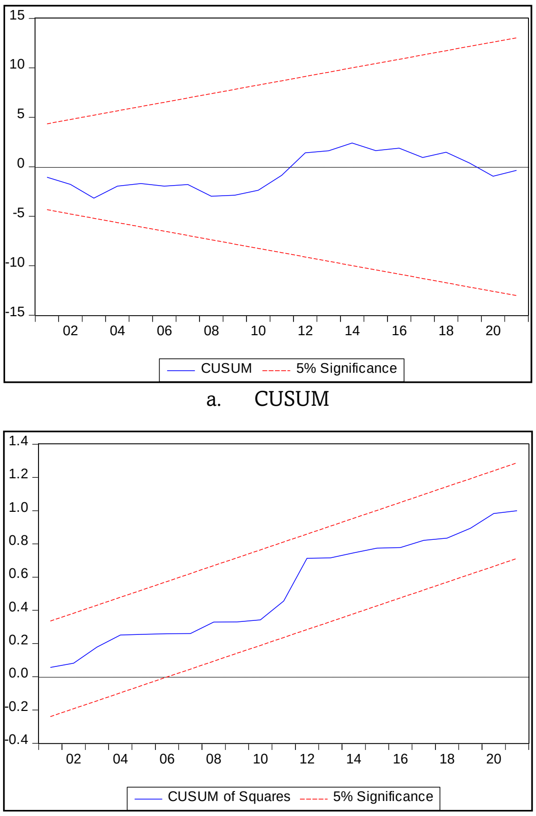
Note: (*) Significant at 10%; (**) Significant at 5%; (***) Significant at 1%

As shown in Table 7 of the NARDL analysis, both CO_2 and GDP values exhibit significant positive trends. The objective of this study is to determine whether India is adequately equipped to accomplish the SDG7 target of creating sustainable energy by 2030. In the past, India has mainly relied on coal for electricity generation (Kopas *et al.* 2020, Wang & Song 2021), but has now begun to incorporate renewable resources and nuclear energy (Kumar & Majid 2020, Roy & Schaffartzik 2021, Bandyopadhyay & Rej 2021). Therefore, this study examines the effect of different sources of energy consumption on CO_2 emissions. By utilizing the NARDL model, the findings indicate the impact on the environment with either a positive or negative sign, providing a more comprehensive perspective on the issue.

According to Mujtaba and Jena's (2021) study, energy consumption in India exhibits a significant positive trend. However, the previous NARDL analysis did not specifically focus on the sources of energy consumption. This study aims to assess whether India is on track to achieve the SDG7 target of sustainable energy by 2030 by analyzing the impact of different types of energy consumption on CO_2 emissions. The NARDL model was used to separate energy consumption into three types: fossil, nuclear, and renewable. The findings show that renewable resources have a significant impact on both positive and negative signs at 5%. A positive sign of -0.096 indicates that when electricity is generated from renewable resources, consumption increases, and CO_2 emissions may decrease. Conversely, when consumption from renewable resources decreases, CO_2 emissions may increase. The negative sign for nuclear energy also yielded the same result.

On the other hand, there is an unexpected result for the electricity generated from fossil sources. The positive sign is significant, which means there is a cointegration towards CO_2 emissions. However, the value is -0.5340, indicating that even when consumption of electricity from fossil sources increases, CO_2 emissions may decrease. This result contradicts with several studies such as Jackson *et al.* (2019), Sharma & Kautish (2020), Ali *et al.* (2022), Wang *et al.* (2022) which found that the use of fossil fuels may increase CO_2 emissions. However, there are also studies supporting the unusual result, as many studies found that clean coal technology can reduce the amount of carbon released into the atmosphere (Jiang *et al.* 2020, Xie 2021, Jie *et al.* 2021). According to Joy & Qureshi (2023), it is possible for India to lower the amount of carbon emissions produced by coal-fired power plants by utilizing one of the approaches available, such as new technology less carbon coal.

Generally, the models employed in this study are stable, and all variables can be identified using the CUSUM and CUSUMQ tests to evaluate parameter stability (Pesaran *et al.* 2001). Moreover, the stability of the model is reinforced by the fact that both a. CUSUM and b. CUSUM of Square fall within the red line, as depicted in Figure 4.



a. CUSUM

b. CUSUM of Squares

Fig. 4. NARDL CUSUM Test and CUSUM Square Test.

5. Conclusion

India has the world's second-largest population, after China, with more than 1.4 billion people. As a result of the extremely high population, there is a significant need for energy, which is an essential resource for the expansion and growth of the economy. Therefore, it is of the utmost necessity for India to emphasize the formation of clean energy in their energy policy to achieve the SDG7 by the year 2030. This study found a positive correlation between GDP per capita and CO_2 emissions, highlighting the urgent need to reduce India's dependency on fossil fuels. The ARDL analysis further confirms that fossil fuel-generated energy contributes to CO_2 emissions, whereas nuclear-generated energy reduces them.

As India is getting more populated each year and the world is moving toward the sustainable energy, therefore, the India government must implement a renewable energy policy to lower the amount of CO_2 it emits annually. Green policies will benefit society and the economy as well. One significant advantage is the reduction of pollution and air pollutants derived from fossil fuels. This will benefit the community's overall health by lowering problems such as respiratory diseases and health issues related to environmental pollution. Moreover, the economic benefits are the increased energy security, and job growth in the renewable energy sector. As the decentralised renewable energy solutions can also close the energy gap between urban and rural areas by empowering rural populations.

The switch to renewable energy is benefiting the environment as well as perhaps drawing in foreign capital to invest in India. Long-term solutions are necessary to address and control the issue of carbonization, and this study underscores the significance of renewable and nuclear energy as alternative energy sources. India must act fast to ensure long-term environmental sustainability and stability, and nuclear energy holds significant potential as a sustainable energy source for future generations.

The fact that there are still more regions in India that need to be thoroughly investigated in the pursuit of more renewable energy sources is one of the limitations of this study. As a result, it is strongly suggested that future studies take into consideration more in-depth measurements of renewable energy sources such as solar, hydro, and wind in India.

Author Contributions: AHHM: Conceptualization, methodology, formal analysis, writing—original draft, RAR; Conceptualization, supervision, resources, final draft

Funding: This research is funded by Universiti Malaysia Sarawak.

Conflicts of Interest: The authors declare no conflict of interest.

References

Abbasi, K. R., Adedoyin, F. F., Abbas, J., & Hussain, K. (2021). The impact of energy depletion and renewable energy on CO2 emissions in Thailand: fresh evidence from the novel dynamic ARDL simulation. *Renewable Energy*, *180*, 1439-1450, https://doi.org/10.1016/j.renene.2021.08.078

Adedoyin, F., Ozturk, I., Abubakar, I., Kumeka, T., Folarin, O., & Bekun, F. V. (2020). Structural breaks in CO2 emissions: are they caused by climate change protests or other factors?. *Journal of environmental management*, *266*,110628, https://doi.org/10.1016/j.jenvman.2020.110628

Adekoya, O. B., Ajayi, G. E., Suhrab, M., & Oliyide, J. A. (2022). How critical are resource rents, agriculture, growth, and renewable energy to environmental degradation in the resource-rich African countries? The role of institutional quality. Energy Policy, 164, 112888, https://doi.org/10.1016/j.enpol.2022.112888

Adekoya, O. B., Oliyide, J. A., Yaya, O. S., & Al-Faryan, M. A. S. (2022). Does oil connect differently with prominent assets during war? Analysis of intra-day data during the Russia-Ukraine saga. *Resources Policy*, *77*,102728, https://doi.org/10.1016/j.resourpol.2022.102728

Ahmed, M., Shuai, C., & Ahmed, M. (2022). Influencing factors of carbon emissions and their trends in China and India: a machine learning method. *Environmental Science and Pollution Research*, *29*(32), 48424-48437, https://doi.org/10.1007/s11356-022-18711-3

Ali, M.U., Gong, Z., Ali, M. U., Asmi, F., & Muhammad, R. (2022). CO2 emission, economic development, fossil fuel consumption and population density in India, Pakistan and Bangladesh: a panel investigation. *International Journal of Finance & Economics*, *27*(1), 18-31, https://doi.org/10.1002/ijfe.2134

Anwar, A., Sharif, A., Fatima, S., Ahmad, P., Sinha, A., Khan, S. A. R., & Jermsittiparsert, K. (2021). The asymmetric effect of public private partnership investment on transport CO2 emission in China: Evidence from quantile ARDL approach. *Journal of Cleaner Production*, *288*,125282, https://doi.org/10.1016/j.jclepro.2020.125282

Bai, J., & Ng, S. (2005). Tests for skewness, kurtosis, and normality for time series data. *Journal of Business & Economic Statistics*, *23*(1), 49-60, https://doi.org/10.1198/073500104000000271

Baldwin, M. P., & Lenton, T. M. (2020). Solving the climate crisis: Lessons from ozone depletion and COVID-19. *Global sustainability*, *3*, e29, https://doi.org/10.1017/sus.2020.25

Bandyopadhyay, A., & Rej, S. (2021). Can nuclear energy fuel an environmentally sustainable economic growth? Revisiting the EKC hypothesis for India. *Environmental Science and Pollution Research*, *28*, 63065-63086, https://doi.org/10.1007/s11356-021-15220-7

Bauer, N., Mouratiadou, I., Luderer, G., Baumstark, L., Brecha, R. J., Edenhofer, O., & Kriegler, E. (2016). Global fossil energy markets and climate change mitigation–an analysis with REMIND. *Climatic change*, *136*, 69-82, https://doi.org/10.1007/s10584-013-0901-6

Ben Mbarek, M., Saidi, K., & Rahman, M. M. (2018). Renewable and non-renewable energy consumption, environmental degradation and economic growth in Tunisia. *Quality & Quantity*, *52*, 1105-1119, https://doi.org/10.1007/s11135-017-0506-7

Berger, E. M. (2010). The Chernobyl disaster, concern about the environment, and life satisfaction. *Kyklos*, *63*(1),18, https://doi.org/10.1111/j.1467-6435.2010.00457.x

Bisconti, A. S. (2018). Changing public attitudes toward nuclear energy. *Progress in Nuclear Energy*, *102*, 103-113, https://doi.org/10.1016/j.pnucene.2017.07.002

Brodeur, A., Gray, D., Islam, A., & Bhuiyan, S. (2021). A literature review of the economics of COVID-19. *Journal of Economic Surveys*, *35*(4), 1007-1044, https://doi.org/10.1111/joes.12423

Caglar, A. E. (2020). The importance of renewable energy consumption and FDI inflows in reducing environmental degradation: bootstrap ARDL bound test in selected 9 countries. *Journal of Cleaner Production*, *264*,121663, https://doi.org/10.1016/j.jclepro.2020.121663

Chen, C., Lu, Y., & He, G. (2022). Driving mechanisms for decoupling CO2 emissions from economic development in the ten largest emission countries. *Ecosystem Health and Sustainability*, *8*(1), 2059016, https://doi.org/10.1080/20964129.2022.2059016

Coakley, J., & Fuertes, A. M. (1997). New panel unit root tests of PPP. *Economics Letters*, *57*(1),17-22, https://doi.org/10.1016/S0165-1765(97)81874-5

Covert, T., Greenstone, M., & Knittel, C. R. (2016). Will we ever stop using fossil fuels?. *Journal of Economic Perspectives*, *30*(1), 117-138, https://doi.org/10.1257/jep.30.1.117

Danish., Ozcan, B., & Ulucak, R. (2021). An empirical investigation of nuclear energy consumption and carbon dioxide (CO2) emission in India: Bridging IPAT and EKC hypotheses. *Nuclear Engineering and Technology*, *53*(6),2056-2065, https://doi.org/10.1016/j.net.2020.12.008

Das, J., Manikanta, V., & Umamahesh, N. V. (2022). Population exposure to compound extreme events in India under different emission and population scenarios. *Science of The Total Environment*, *806*,150424, https://doi.org/10.1016/j.scitotenv.2021.150424

Das, N., Murshed, M., Rej, S., Bandyopadhyay, A., Hossain, M. E., Mahmood, H., ... & Bera, P. (2023). Can clean energy adoption and international trade contribute to the achievement of India's 2070 carbon neutrality agenda? Evidence using quantile ARDL measures. *International Journal of Sustainable Development & World Ecology*, *30*(3),262-277, https://doi.org/10.1080/13504509.2022.2139780

Ehsanullah, S., Tran, Q. H., Sadiq, M., Bashir, S., Mohsin, M., & Iram, R. (2021). How energy insecurity leads to energy poverty? Do environmental consideration and climate change concerns matters. *Environmental Science and Pollution Research*, *28*(39), 55041-55052, https://doi.org/10.1007/s11356-021-14415-2

EPI. (2021). *Environmental Performance Index*. https://epi.yale.edu/. Accessed on 1 April 2023

Estrada, M. A. R., Park, D., Tahir, M., & Khan, A. (2020). Simulations of US-Iran war and its impact on global oil price behavior. *Borsa Istanbul Review*, *20*(1),1-12, https://doi.org/10.1016/j.bir.2019.11.002

Fuhrmann, M. (2009). Spreading temptation: Proliferation and peaceful nuclear cooperation agreements. *International security*, *34*(1), 7-41. https://doi.org/10.1162/isec.2009.34.1.7

Ghosh, S., & Kanjilal, K. (2020). Non-fossil fuel energy usage and economic growth in India: A study on non-linear cointegration, asymmetry and causality. *Journal of Cleaner Production*, *273*, 123032, https://doi.org/10.1016/j.jclepro.2020.123032

Gibba, A., & Khan, M. K. (2023). Modelling the causal dynamics among energy consumption, economic growth and oil import prices: a panel co-integration analysis for EU economies. *Frontiers in Environmental Economics*, *2*,4. https://doi.org/10.3389/frevc.2023.1114175

Goswami, B., Mandal, R., & Nath, H. K. (2021). Covid-19 pandemic and economic performances of the states in India. *Economic Analysis and Policy*, *69*, 461-479. https://doi.org/10.1016/j.eap.2021.01.001

Grover, R. B. (2017). Opening up of international civil nuclear cooperation with India and related developments. *Progress in Nuclear Energy*, *101*, 160-167. https://doi.org/10.1016/j.pnucene.2016.09.016

Guo, H., Chang, Z., Wu, J., & Li, W. (2019). Air pollution and lung cancer incidence in China: Who are faced with a greater effect?. *Environment international*, *132*,105077, https://doi.org/10.1016/j.envint.2019.105077

Guo, J., Zhou, Y., Ali, S., Shahzad, U., & Cui, L. (2021). Exploring the role of green innovation and investment in energy for environmental quality: An empirical appraisal from provincial data of China. *Journal of Environmental Management*, *292*, 112779, https://doi.org/10.1016/j.jenvman.2021.112779

Gupta, M., Mohanta, R., Rao, A., Parameswaran, G. G., Agarwal, M., Arora, M., ... & Bhatnagar, S. (2021). Transmission dynamics of the COVID-19 epidemic in India and modeling optimal lockdown exit strategies. *International Journal of Infectious Diseases*, *103*, 579-589. https://doi.org/10.1016/j.ijid.2020.11.206

Gussmann, G., & Hinkel, J. (2021). A framework for assessing the potential effectiveness of adaptation policies: Coastal risks and sea-level rise in the Maldives. *Environmental Science & Policy*, *115*, 35-42, https://doi.org/10.1016/j.envsci.2020.09.028

Hassan, S. T., Baloch, M. A., & Tarar, Z. H. (2020). Is nuclear energy a better alternative for mitigating CO2 emissions in BRICS countries? An empirical analysis. *Nuclear Engineering and Technology*, *52*(12), 2969-2974, https://doi.org/10.1016/j.net.2020.05.016

Hassler, U., & Wolters, J. (2006). Autoregressive distributed lag models and cointegration (pp. 57-72). Springer Berlin Heidelberg, https://doi.org/10.1007/3-540-32693-6_5

He, F., Chang, K. C., Li, M., Li, X., & Li, F. (2020). Bootstrap ARDL test on the relationship among trade, FDI, and CO2 emissions: Based on the experience of BRICS countries. *Sustainability*, *12*(3), 1060, https://doi.org/10.3390/su12031060

Hossain, M. S., Fang, Y. R., Ma, T., Huang, C., Peng, W., Urpelainen, J., ... & Dai, H. (2023). Narrowing fossil fuel consumption in the Indian road transport sector towards reaching carbon neutrality. *Energy Policy*, *172*, 113330, https://doi.org/10.1016/j.enpol.2022.113330

IEA (2023). *International Energy Agency. India energy Outlook 2021. World Energy Outlook Special Report.* https://www.iea.org/reports/india-energy-outlook-2021. Accessed on 1 April 2023

Jackson, R. B., Friedlingstein, P., Andrew, R. M., Canadell, J. G., Le Quéré, C., & Peters, G. P. (2019). Persistent fossil fuel growth threatens the Paris Agreement and planetary health. *Environmental Research Letters*, *14*(12), 121001, https://doi.org/10.1088/1748-9326/ab57b3

Jaiswal, K. K., Chowdhury, C. R., Yadav, D., Verma, R., Dutta, S., Jaiswal, K. S., & Karuppasamy, K. S. K. (2022). Renewable and sustainable clean energy development and impact on social, economic, and environmental health. *Energy Nexus*, *7*, 100118. https://doi.org/10.1016/j.nexus.2022.100118

Jayanthakumaran, K., Verma, R., & Liu, Y. (2012). CO2 emissions, energy consumption, trade and income: a comparative analysis of China and India. *Energy Policy*, 42, 450-460, https://doi.org/10.1016/j.enpol.2011.12.010

Jena, P. R., Majhi, R., Kalli, R., Managi, S., & Majhi, B. (2021). Impact of COVID-19 on GDP of major economies: Application of the artificial neural network forecaster. *Economic Analysis and Policy*, *69*, 324-339. https://doi.org/10.1016/j.eap.2020.12.013

Jiang, K., Yu, H., Chen, L., Fang, M., Azzi, M., Cottrell, A., & Li, K. (2020). An advanced, ammonia-based combined NOx/SOx/CO2 emission control process towards a low-cost, clean coal technology. *Applied Energy*, *260*,114316,https://doi.org/10.1016/j.apenergy.2019.114316

Jie, D., Xu, X., & Guo, F. (2021). The future of coal supply in China based on non-fossil energy development and carbon price strategies. *Energy*, *220*,119644,https://doi.org/10.1016/j.energy.2020.119644

Johansen, S. (1991). Estimation and hypothesis testing of cointegration vectors in Gaussian vector autoregressive models. *Econometrica: journal of the Econometric Society*, 1551-1580, https://doi.org/10.2307/2938278

Joshi, A., Bhaskar, P., & Gupta, P. K. (2020). Indian economy amid COVID-19 lockdown: A prespective. *Journal of Pure and Applied Microbiology*, *14*, 957-961. https://doi.org/10.22207/JPAM.14.SPL1.33

Joy, A., & Qureshi, A. (2023). Reducing mercury emissions from coal-fired power plants in India: Possibilities and challenges. *Ambio*, *52*(1),242-252, https://doi.org/10.1007/s13280-022-01773-5

Kanitkar, T. (2020). The COVID-19 lockdown in India: Impacts on the economy and the power sector. *Global transitions*, *2*, 150-156, https://doi.org/10.1016/j.glt.2020.07.005

Kartal, M. T. (2022). The role of consumption of energy, fossil sources, nuclear energy, and renewable energy on environmental degradation in top-five carbon producing countries. *Renewable Energy*, *184*,871-880, https://doi.org/10.1016/j.renene.2021.12.022

Kartal, M. T., Pata, U. K., Depren, S. K., & Depren, Ö. (2023). Effects of possible changes in natural gas, nuclear, and coal energy consumption on CO2 emissions: Evidence from France under Russia's gas supply cuts by dynamic ARDL simulations approach. *Applied Energy*, *339*, 120983, https://doi.org/10.1016/j.apenergy.2023.120983

Kopas, J., York, E., Jin, X., Harish, S. P., Kennedy, R., Shen, S. V., & Urpelainen, J. (2020). Environmental justice in India: incidence of air pollution from coal-fired power plants. *Ecological Economics*, *176*, 106711, https://doi.org/10.1016/j.ecolecon.2020.106711

Kozak, M. (2009). What is strong correlation?. *Teaching Statistics*, *31*(3), 85-86, https://doi.org/10.1111/j.1467-9639.2009.00387.x

Kumar C. R, J & Majid, M. A. (2020). Renewable energy for sustainable development in India: current status, future prospects, challenges, employment, and investment opportunities. *Energy, Sustainability and Society*, *10*(1), 1-36, https://doi.org/10.1186/s13705-019-0232-1

Lau, L. S., Choong, C. K., Ng, C. F., Liew, F. M., & Ching, S. L. (2019). Is nuclear energy clean? Revisit of Environmental Kuznets Curve hypothesis in OECD countries. *Economic Modelling*, *77*, 12-20, https://doi.org/10.1016/j.econmod.2018.09.015

Lenzen, M. (2008). Life cycle energy and greenhouse gas emissions of nuclear energy: A review. *Energy conversion and management*, *49*(8), 2178-2199, https://doi.org/10.1016/j.enconman.2008.01.033

Lin, B., & Xu, B. (2020). How does fossil energy abundance affect China's economic growth and CO2 emissions?. *Science of the Total Environment*, *719*, 137503, https://doi.org/10.1016/j.scitotenv.2020.137503

Ludovici, G. M., de Souza, S. O., Chierici, A., Cascone, M. G., d'Errico, F., & Malizia, A. (2020). Adaptation to ionizing radiation of higher plants: From environmental radioactivity to chernobyl disaster. *Journal of Environmental Radioactivity*, *222*, 106375, https://doi.org/10.1016/j.jenvrad.2020.106375

Maddala, G. S., & Wu, S. (1999). A comparative study of unit root tests with panel data and a new simple test. *Oxford Bulletin of Economics and statistics*, *61*(S1), 631-652, https://doi.org/10.1111/1468-0084.0610s1631

Magazzino, C., Mele, M., & Schneider, N. (2021). A machine learning approach on the relationship among solar and wind energy production, coal consumption, GDP, and CO2 emissions. *Renewable Energy*, *167*, 99-115, https://doi.org/10.1016/j.renene.2020.11.050

Martins, F., Felgueiras, C., & Smitková, M. (2018). Fossil fuel energy consumption in European countries. *Energy Procedia*, *153*, 107-111, https://doi.org/10.1016/j.egypro.2018.10.050

Martins, F., Felgueiras, C., Smitkova, M., & Caetano, N. (2019). Analysis of fossil fuel energy consumption and environmental impacts in European countries. *Energies*, *12*(6), 964, https://doi.org/10.3390/en12060964

Mbah, R. E., & Wasum, D. F. (2022). Russian-Ukraine 2022 War: A review of the economic impact of Russian-Ukraine crisis on the USA, UK, Canada, and Europe. *Advances in Social Sciences Research Journal*, *9*(3), 144-153, http://doi.org/10.14738/assrj.93.12005

Mohamad, A. H. H., Zainuddin, M. R. K., & Ab-Rahim, R. (2023). Does Renewable Energy Transition in the USA and China Overcome Environmental Degradation?. *International Journal of Energy Economics and Policy*, *13*(6), 234-243, https://doi.org/10.32479/ijeep.14840

Mohammad, P., & Goswami, A. (2019). Temperature and precipitation trend over 139 major Indian cities: An assessment over a century. *Modeling Earth Systems and Environment*, *5*, 1481-1493, https://doi.org/10.1007/s40808-019-00642-7

Mujtaba, A., & Jena, P. K. (2021). Analyzing asymmetric impact of economic growth, energy use, FDI inflows, and oil prices on CO 2 emissions through NARDL approach. *Environmental Science and Pollution Research*, *28*, 30873-30886, https://doi.org/10.1007/s11356-021-12660-z

Ntanos, S., Skordoulis, M., Kyriakopoulos, G., Arabatzis, G., Chalikias, M., Galatsidas, S., ... & Katsarou, A. (2018). Renewable energy and economic growth: Evidence from European countries. *Sustainability*, *10*(8),2626, https://doi.org/10.3390/su10082626

Orcan, F. (2020). Parametric or non-parametric: Skewness to test normality for mean comparison. *International Journal of Assessment Tools in Education*, *7*(2), 255-265. https://doi.org/10.21449/ijate.656077

Ortega-Ruiz, G., Mena-Nieto, A., Golpe, A. A., & García-Ramos, J. E. (2022). CO2 emissions and causal relationships in the six largest world emitters. *Renewable and Sustainable Energy Reviews*, *162*, 112435, https://doi.org/10.1016/j.rser.2022.112435

OWiD. (2023). *Our World in Data. CO2 emission data.* https://ourworldindata.org/. Accessed on 1 April 2023

Ozgur, O., Yilanci, V., & Kongkuah, M. (2022). Nuclear energy consumption and CO2 emissions in India: Evidence from Fourier ARDL bounds test approach. *Nuclear Engineering and Technology*, *54*(5),1657-1663, https://doi.org/10.1016/j.net.2021.11.001

Pachiyappan, D., Ansari, Y., Alam, M. S., Thoudam, P., Alagirisamy, K., & Manigandan, P. (2021). Short and long-run causal effects of CO2 emissions, energy use, GDP and population growth: evidence from India using the ARDL and VECM approaches. *Energies*, 14(24), 8333, https://doi.org/10.3390/en14248333

Pal, S. C., Chowdhuri, I., Saha, A., Ghosh, M., Roy, P., Das, B., ... & Shit, M. (2022). COVID-19 strict lockdown impact on urban air quality and atmospheric temperature in four megacities of India. *Geoscience Frontiers*, *13*(6), 101368. https://doi.org/10.1016/j.gsf.2022.101368

Pata, U. K., & Samour, A. (2022). Do renewable and nuclear energy enhance environmental quality in France? A new EKC approach with the load capacity factor. *Progress in Nuclear Energy*, *149*, 104249, https://doi.org/10.1016/j.pnucene.2022.104249

Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of applied econometrics*, *16*(3), 289-326, https://doi.org/10.1002/jae.616

Piecuch, C. G. (2020). Likely weakening of the Florida Current during the past century revealed by sea-level observations. *Nature Communications*, *11*(1), 3973, https://doi.org/10.1038/s41467-020-17761-w

Pradhan, B. K., & Ghosh, J. (2021). COVID-19 and the Paris Agreement target: A CGE analysis of alternative economic recovery scenarios for India. *Energy Economics*, *103*, 105539. https://doi.org/10.1016/j.eneco.2021.105539

Ratner, B. (2009). The correlation coefficient: Its values range between+ 1/− 1, or do they?. *Journal of targeting, measurement and analysis for marketing*, *17*(2), 139-142, https://doi.org/10.1057/jt.2009.5

Rehm, T. E. (2023). Advanced nuclear energy: the safest and most renewable clean energy. *Current Opinion in Chemical Engineering*, *39*, 100878. https://doi.org/10.1016/j.coche.2022.100878

Rehman, A., Ma, H., Ahmad, M., Ozturk, I., & Işık, C. (2021). Estimating the connection of information technology, foreign direct investment, trade, renewable energy and economic progress in Pakistan: evidence from ARDL approach and cointegrating regression analysis. *Environmental Science and Pollution Research*, *28*(36), 50623-50635, https://doi.org/10.1007/s11356-021-14303-9

Rehman, S., & Hussain, Z. (2017). Renewable energy governance in India: challenges and prospects for achieving the 2022 energy goals. *Journal of Resources, Energy and Development*, *14*(1), 13-22, https://doi.org/10.3233/RED-14102

Roy, B., & Schaffartzik, A. (2021). Talk renewables, walk coal: The paradox of India's energy transition. *Ecological Economics*, *180*, 106871, https://doi.org/10.1016/j.ecolecon.2020.106871

Sadatshojaie, A., & Rahimpour, M. R. (2020). CO2 emission and air pollution (volatile organic compounds, etc.)–related problems causing climate change. In *Current trends and future developments on (bio-) membranes* (pp.1-30).Elsevier, https://doi.org/10.1016/B978-0-12-816778-6.00001-1

Sadekin, S., Zaman, S., Mahfuz, M., & Sarkar, R. (2019). Nuclear power as foundation of a clean energy future: A review. *Energy Procedia*, *160*,513-518, https://doi.org/10.1016/j.egypro.2019.02.200

San-Akca, B., Sever, S. D., & Yilmaz, S. (2020). Does natural gas fuel civil war? Rethinking energy security, international relations, and fossil-fuel conflict. *Energy Research & Social Science*, *70*, 101690, https://doi.org/10.1016/j.erss.2020.101690

Sasmaz, M. U., Sakar, E., Yayla, Y. E., & Akkucuk, U. (2020). The relationship between renewable energy and human development in OECD countries: A panel data analysis. *Sustainability*, *12*(18), 7450, https://doi.org/10.3390/su12187450

Shah, S. M. H., Mustaffa, Z., Teo, F. Y., Imam, M. A. H., Yusof, K. W., & Al-Qadami, E. H. H. (2020). A review of the flood hazard and risk management in the South Asian Region, particularly Pakistan. *Scientific African*, *10*, e00651, https://doi.org/10.1016/j.sciaf.2020.e00651

Shahbaz, M., Sharma, R., Sinha, A., & Jiao, Z. (2021). Analyzing nonlinear impact of economic growth drivers on CO2 emissions: Designing an SDG framework for India. *Energy Policy*, *148*, 111965, https://doi.org/10.1016/j.enpol.2020.111965

Sharif, A., Mishra, S., Sinha, A., Jiao, Z., Shahbaz, M., & Afshan, S. (2020). The renewable energy consumption-environmental degradation nexus in Top-10 polluted countries: Fresh insights from quantile-on-quantile regression approach. *Renewable Energy*, *150*, 670-690, https://doi.org/10.1016/j.renene.2019.12.149

Sharma, R., & Kautish, P. (2020). Examining the nonlinear impact of coal and oil-based electricity production on CO2 emissions in India. *The Electricity Journal*, *33*(6), 106775, https://doi.org/10.1016/j.tej.2020.106775

Shin, Y., Yu, B., & Greenwood-Nimmo, M. (2014). Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. *Festschrift in honor of Peter Schmidt: Econometric methods and applications*, 281-314, https://doi.org/10.1007/978-1-4899-8008-3_9

Sikder, M., Wang, C., Yao, X., Huai, X., Wu, L., KwameYeboah, F., ... & Dou, X. (2022). The integrated impact of GDP growth, industrialization, energy use, and urbanization on CO2 emissions in developing countries: evidence from the panel ARDL approach. *Science of the Total Environment*, *837*, 155795, https://doi.org/10.1016/j.scitotenv.2022.155795

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, https://doi.org/10.1007/s11356-022-19597-x

Stokes, C. R., Abram, N. J., Bentley, M. J., Edwards, T. L., England, M. H., Foppert, A., ... & Whitehouse, P. L. (2022). Response of the East Antarctic Ice Sheet to past and future climate change. *Nature*, *608*(7922),275-286, https://doi.org/10.1038/s41586-022-04946-0

Udemba, E. N., Güngör, H., Bekun, F. V., & Kirikkaleli, D. (2021). Economic performance of India amidst high CO2 emissions. *Sustainable Production and Consumption*, *27*, 52-60. https://doi.org/10.1016/j.spc.2020.10.024

Uzair Ali, M., Gong, Z., Ali, M. U., Asmi, F., & Muhammad, R. (2022). CO2 emission, economic development, fossil fuel consumption and population density in India, Pakistan and Bangladesh: a panel investigation. *International Journal of Finance & Economics*, *27*(1), 18-31, https://doi.org/10.1002/ijfe.2134

Qayyum, M., Yu, Y., Nizamani, M. M., Raza, S., Ali, M., & Li, S. (2022). Financial instability and CO2 emissions in India: evidence from ARDL bound testing approach. *Energy & Environment*, https://doi.org/10.1177/0958305X211065019

Voumik, L. C., & Ridwan, M. (2023). Impact of FDI, industrialization, and education on the environment in Argentina: ARDL approach. *Heliyon*,e12872, https://doi.org/10.1016/j.heliyon.2023.e12872

Vyas, M. (2020). Impact of lockdown on labour in India. *The Indian Journal of Labour Economics*, *63*(1), 73-77, https://doi.org/10.1007/s41027-020-00259-w

Wang, H., Asif Amjad, M., Arshed, N., Mohamed, A., Ali, S., Haider Jafri, M. A., & Khan, Y. A. (2022). Fossil energy demand and economic development in BRICS countries. *Frontiers in Energy Research*, *10*, 335, https://doi.org/10.3389/fenrg.2022.842793

Wang, Q., & Song, X. (2019). Indias coal footprint in the globalized world: evolution and drivers. *Journal of Cleaner Production*, *230*, 286-301, https://doi.org/10.1016/j.jclepro.2019.05.102

Wang, Q., & Song, X. (2021). Why do China and India burn 60% of the world's coal? A decomposition analysis from a global perspective. *Energy*, *227*,120389, https://doi.org/10.1016/j.energy.2021.120389

WDI. (2023). *World Development Indicators. GDP per capita.* https://databank.worldbank.org/source/world-development-indicators. Accessed on 1 April 2023

Wolde-Rufael, Y. (2010). Bounds test approach to cointegration and causality between nuclear energy consumption and economic growth in India. *Energy Policy*, *38*(1), 52-58, https://doi.org/10.1016/j.enpol.2009.08.053

Xie, K. (2021). Reviews of clean coal conversion technology in China: Situations & challenges. *Chinese Journal of Chemical Engineering*, *35*, 62-69, https://doi.org/10.1016/j.cjche.2021.04.004

Yarzábal, L. A., Salazar, L. M. B., & Batista-García, R. A. (2021). Climate change, melting cryosphere and frozen pathogens: Should we worry? *Environmental Sustainability*, *4*(3), 489-501, https://doi.org/10.1007/s42398-021-00184-8

Yitzhaki, S. (2003). Gini's mean difference: A superior measure of variability for non-normal distributions. *Metron*, *61*(2), 285-316.

Yurtkuran, S. (2021). The effect of agriculture, renewable energy production, and globalization on CO2 emissions in Turkey: A bootstrap ARDL approach. *Renewable Energy*, *171*, 1236-1245, https://doi.org/10.1016/j.renene.2021.03.009

Zhang, X., Geng, Y., Shao, S., Wilson, J., Song, X., & You, W. (2020). China's non-fossil energy development and its 2030 CO2 reduction targets: The role of urbanization. *Applied Energy*, *261*, 114353, https://doi.org/10.1016/j.apenergy.2019.114353

Żuk, P., & Żuk, P. (2022). National energy security or acceleration of transition? Energy policy after the war in Ukraine. *Joule*, *6*(4), 709-712, https://doi.org/10.1016/j.joule.2022.03.009