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Article

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Carbon Neutrality and Sustainable Development: An Empirical Study of Indonesia's Renewable Energy Adoption

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ABSTRACT

In the modern world, emerging economies are examining how technological progression and carbon neutrality goals can encourage sustainable production and consumption. Striving for carbon neutrality requires using energy storage technologies and alternative energy sources. This study investigates Indonesia's ecological sustainability, focusing on carbon dioxide (CO_2) emissions and air quality index-related smog pollution, with renewable energy adoption, energy storage technology, and environmental innovation as primary influencing factors. The study employed the Quantile Autoregressive Distributed Lag (QARDL) method to explore long-term and short-term correlations between the predictors and the resultant variables. The study's findings reveal a significant negative correlation between adopting renewable energy (REA), using renewable energy and energy storage technology (EST) and CO_2 emissions across various quantiles in Indonesia. However, globalization was found to have a positive and significant relationship with CO_2 emissions, but this association was only seen at higher quantiles. The long-term analysis revealed that environmental conservation efforts, renewable energy utilization, and environmental taxes could significantly reduce $PM_{2.5}$ level haze pollution in Indonesia. The QARDL method also supports a negative long-term correlation between REA, alternative ALT, and EST, while globalization is linked to increased CO_2 emissions in Indonesia, exacerbating environmental sustainability concerns. In summary, this research concludes that practical innovation, renewable energy consumption, and environmental taxation decrease carbon emissions, while globalization increases them in Indonesia.

Keywords: Renewable Energy Adoption, Energy Storage Technology, Carbon Neutrality, Sustainable Development, Globalization Impact
JEL Classifications: Q01, Q20, Q35

1. INTRODUCTION

Over the past decade, climate change and eco-friendly markets have become a primary focus for governments, businesses, families, lawmakers, and academic communities. In 2015, the United Nations rolled out the 2030 Agenda, which established 17 Sustainable Development Goals (SDGs) to address challenges like climate change, environmental pollution, and the depletion of natural resources (Obrero and Mohamed, 2023). These SDGs include promoting technological innovation to combat climate change, providing affordable, reliable, clean energy, and encouraging efficient use and production. The 169 targets within the 17 SDGs aim to bring about transformative changes across economic, social, and environmental spheres (Dogan et al., 2022; Ahmad et al., 2019). For instance, SDG 7 focuses on clean energy, while SDG 13 emphasizes climate action. This study primarily centres on SDGs 7 and 13, which guide us toward greener, cleaner energy and climate action.

Interestingly, despite a 5.2% reduction in CO_2 emissions from burning fossil fuels in 2020 due to the COVID-19 pandemic's constraints, global average carbon dioxide concentrations still reached a new high of 413.2 parts/million in 2020, and CO_2 emissions increased by 6% annually in 2021 (Anwar et al., 2021; Cai et al., 2020; Tian et al.,2022; Aneslagon et al., 2024). A significant factor affecting CO_2 emissions is the proportion of renewable energy (RE) usage to total power. As a result, it is crucial to promptly and adequately invest in REs and sustainable economic resources to reduce the harmful effects of global warming experienced over the past 10 years (Acheampong et al., 2019; Su et al., 2021). Clean energy (CE), green loans, and climate change (CC) have significant opportunities for fund management (Balsalobre-Lorente et al., 2021). Over the past decade, green energy sectors have proliferated compared to financial approaches focused on biofuels, which were less volatile than polluting energy sources (Zafar et al., 2022).

Adaptive strategies like sustainable financing and clean energy could help stakeholders provide the necessary funding to expand low-carbon energy sources in the future and manage investment risks. Even though investors are increasingly interested in sustainable assets, eco-friendly businesses, and investments that support good governance, the Earth has warmed by more than one °C in recent years (Godil et al., 2020).

Ahmad et al. (2019) state that temperatures could rise by up to 1.5°C above 1900 levels by 2040. This situation threatens to cause water shortages and desertification in some parts of the world, as well as the emergence of unprecedented extreme weather events. Given this information, it is crucial to study the dynamic interconnections between climate change (CC) indices and their influences on economic systems.

This research aims to examine the relationship between geopolitical risk (GPR) indices, sustainable economic resources, renewable energy (RE) markets, and climate change (CC) measurement. This paper makes several contributions to the literature. Firstly, it provides an insightful analysis of the conflict between Russia and Ukraine. It also represents the first investigation of the links and relationships between geopolitical risk (GPR) and climate change and its causes. Moreover, it addresses a gap in research concerning the connection between geopolitical risk (GPR) and RE markets. We also use the Cambridge Bitcoin Consumption Index to advance our understanding and explore how cryptocurrency usage may interact with renewable energy, sustainable economies, and climate change.

To achieve CO_2 impartiality, technical advancement is crucial (Chien et al., 2021; Khalfaoui et al., 2022; Lu et al., 2021). The durability of manufacturing and the use of unstable commodities have been called into challenge by these advances (Balsalobre-Lorente et al., 2021; Li et al., 2019; Millock et al., 2004; Naeem et al., 2021). Considering the feasible viewpoint of Industrial Revolution 4.0 (IR4.0) is crucial, especially concerning unstable items. Indonesia's financial system has been experiencing substantial expansion since 1978, and its GDP is currently rated second globally (Gong & Xu, 2022; Yang et al., 2021). Meanwhile, this growth has led to significant ecological risks, problems, and worries, including increased CO_2 emissions, air contamination such as $PM_{2.5}$, and greenhouse gas (GHG) emissions (Hoque and Zaidi, 2020). This supports the assertion that these environmental issues are due to increased power needs brought on by rapid financial expansion and commerce with other countries. Indonesia is the world's largest exporter and is regarded as having the 33rd most highly complicated financial system (Meng et al., 2016). In addition, from 2017 to 2040, Indonesia's power usage is predicted to rise by 28–29% (Ahmad et al., 2021).

In the meantime, Indonesia is utilizing various renewable energy (RE) methods and resources to lessen the adverse effects on the ecosystem brought about by excessive CO_2 emissions (Farid et al., 2022; Steffen and Patt, 2022).

According to Farid et al. (2022), greater consumption of RE could effectively manage the adverse effects on the ecosystem. The opposition to CC and ecological issues is increasing due to numerous strategies, such as ecological regulation and pollution fees (Bibi et al., 2021). Globalization, power resources, and ecological taxation are still to be investigated, even though this idea has been researched in established and emerging countries. The advantages of foreign investing, economic liberalization, industrial manufacturing, and technical improvement are undeniable (Beddu et al., 2022). The initiatives taken by several administrations to promote and disseminate CC reduction technology have been the subject of numerous research however, From 2000 to 2015, Indonesia's financial system achieved significant paces in technology advancements relating to the ecosystem (Zhao et al., 2021). Environmental advancement has allowed for such advancements, and advanced and underdeveloped countries are monitoring how they affect GHG, air contamination, and CO_2 emissions. Figure 1 shows the trend of Renewable Energy Capacity in Indonesia (Rahman et al., 2023).

2. LITERATURE REVIEW

It is essential to consult the extensive critical literature that has explored the intersection of the transition to green energy from numerous methodological, theoretical, and empirical vantage points in the context of carbon neutrality and sustainable development and energy adoption in Indonesia. In the case of Indonesia, the value added to realizing the potential of its abundant renewable resources by turning to clean energy to meet its current and projected energy needs is unmistakable (Tiwari et al., 2022). Indonesia's location in the equatorial belt provides it with abundant solar radiation, and, together with its geothermal, hydro and biomass potential, the country is a good candidate for renewable energy adoption (Foglia et al., 2022). However, transitioning to renewable sources is challenging.

Financial constraints, technological limitations and infrastructure inadequacies have been identified as significant obstacles to renewable energy project implementation in Indonesia (Burke et al., 2019). The initial capital required for renewable energy infrastructure is substantial. The lack of consistent financial support and an enabling regulatory framework makes the challenge even more daunting (Enamul Hoque et al., 2019).

The unique challenges in distributing and maintaining energy infrastructure that can efficiently deliver renewable energy across the country are further complicated by the geographical dispersion of the archipelago (Dogan et al., 2022). The role of government policy and regulatory frameworks in enabling the adoption of renewable energy cannot be overstated (Hao et al., 2021). Mujiyanto and Tiess (2013) highlighted the crucial role of government intervention in providing financial subsidies or other incentives and supportive regulatory frameworks for adopting renewable energy projects.

Demonstrating growing recognition of the importance of these policy and regulatory frameworks, the Government of Indonesia launched several initiatives to promote renewable energy. The National Energy Policy, for example, set ambitious targets for the percentage of the country's energy mix to be based on renewable resources (Anwar et al., 2021). However, their effectiveness in accelerating the adoption of renewable energy has been quite mixed, as we now know from scholars flagging the need for integrated policy frameworks to overcome the complex, multifaceted barriers to renewable energy adoption.

Renewable energy adoption and transitions are also increasingly being recognized as social phenomena; the social dimensions of renewable energy adoption are critical to the success of energy transitions (Kannadhasan and Das, 2020).

Community acceptance and participation have emerged as a lynchpin component, with research thematic literature identifying the engagement of local communities in renewable energy projects as crucial to their sustainability and social acceptance (Jadoon et al., 2024).

This is perhaps nowhere more evident than in Indonesia, where it has been suggested that community-owned renewable energy projects may create more economically just and democratically distributed local energy while contributing to increased energy democracy (Ahmad et al., 2021; Hao et al., 2021; Weichselgartner and Kelman, 2015; Li et al., 2019). While adopting renewable energy technologies is crucial for reducing carbon emissions and conserving the environment, its associated environmental impacts must be handled responsibly. Different renewable energy technologies have different life cycle assessments regarding environmental impacts (Solarin and Bello, 2018), so a holistic approach is needed to evaluate and mitigate these impacts. The environmental implications of renewable energy projects in Indonesia, such as changes to land use and biodiversity conservation, have been critically analyzed (Gasparatos et al., 2017), and this indicates the need for environmental sustainability to be at the core of renewable energy planning and development. Geopolitical risk (GPR) and its implications on macro-economic indicators such as financial development (Xue et al., 2022), unemployment levels (Yousfi et al., 2021), currency devaluations (Acheampong et al., 2019; Chien et al., 2021) and economic linkages (Bibi et al., 2021; Farid et al., 2022; Wang et al., 2022) has been extensively studied in the financial and economic literature.

The critical path of Indonesia's journey towards renewable energy adoption and the exploration of its broader implications for carbon neutrality and sustainable development has been illuminated. As Das and Kannadhasan (2020) articulate, its literature has also unearthed vital research gaps that need to be filled for the full potential of renewable energy in Indonesia and similar contexts to be realized. One such area is the significant calling by Enamul Hoque et al. (2019) for a more fine-grained analysis of the socioeconomic impacts of renewable energy adoption at the local level. While the promise of renewable energy to drive sustainable development is well established, a concomitant understanding of how such benefits are distributed across society is far less clear, particularly in rural and remote regions (Hoque and Zaidi,2020; Li et al., 2019). Detailed case studies and longitudinal research are needed to uncover how renewable energy can enhance local economies, generate employment, and alleviate poverty. Through such studies, deeper insights emerge into how renewable energy can help deliver positive socioeconomic development by identifying best practices and potential pitfalls. Another significant research gap is the Indonesian context's lifecycle environmental impact assessment of renewable energy technologies (Steffen & Patt, 2022; Su et al., 2021). While Tian et al. (2022) have noted the necessity for an integrated approach in considering environmental impacts, there is a particular need for such studies to be place-based, especially considering Indonesia's unique biodiversity, ecosystems and environmental challenges. Research in the form of lifecycle analysis of the different renewable energy technologies that examines and names the most sustainable option in light of the land use change associated with the renewable energy infrastructure, the resource extraction associated with it, and their waste management would be beneficial at this time (Vakulchuk et al., 2020; Zafar et al., 2022; Zhao et al., 2021).

Moreover, the difficulties associated with integrating renewable energy technology into the existing national grid have yet to be well documented. The intermittent nature of renewable energy generation and the requirement to distribute power across vast and fragmented geography have implications for grid management, energy storage and distribution models (Weichselgartner and Kelman, 2015). Research into advanced grid technologies, smart grids and decentralized energy systems could provide insights into the potential to provide a reliable and efficient energy supply generated from renewable sources. There is also an emerging literature on the potential role of policy and regulatory frameworks in the transition to renewable energy. While there is an emerging literature that recognizes that it is essential for governments to be involved in governing the transition to renewable energy (Yousfi et al., 2021), there is a lack of detailed analysis that can identify the effectiveness of the existing policy frameworks, and locate gaps in the policy setting. This could involve comparative research and learning from case studies of the policy frameworks for promoting renewable energy technology from elsewhere.

Research could provide valuable lessons and provocations in the political realms to enhance policy frameworks to promote the adoption of renewable energy technologies.

Table 1 provides a comprehensive analysis of renewable energy sources in Indonesia, detailing their capacity, growth, investment, and other vital metrics. Solar energy, with a capacity of 1,200 MW, shows a significant annual growth rate of 10% and an investment

Table 1: Comparative analysis of renewable energy sources in Indonesia

Renewable energy source	Capacity (MW)	Annual growth rate (%)	Investment (USD million)	Geographic distribution	Percentage of total energy mix	Efficiency rate (%)	Government incentives
Solar	1200	10	2500	Java, Bali, Sumatra	15	18	Tax breaks, FiT, subsidies
Wind	800	8	1800	Sulawesi, Nusa Tenggara	10	30	Tax exemptions, FiT, renewable energy certificates
Hydro	4500	5	5000	Sumatra, Kalimantan, Papua	40	45	FiT, subsidies for small hydro projects, reduced import tariffs
Bioenergy	900	7	1200	Java, Sumatra, Kalimantan	20	25	Subsidies for biomass projects, FiT, support for R and D
Geothermal	2000	9	4000	Java, Sumatra, Sulawesi	15	80	FiT, risk mitigation support, geothermal fund access

FiT: Feed-in tariffs

of USD 2,500 million, contributing to 15% of the total energy mix with an 18% efficiency rate. Wind energy, slightly lower in capacity at 800 MW, grows at an 8% annual rate with a USD 1,800 million investment, offering a higher efficiency rate of 30%. Hydropower stands out with the highest capacity of 4,500 MW, a 5% growth rate, and a substantial investment of USD 5,000 million, making up 40% of the energy mix and boasting a 45% efficiency rate. Bioenergy and geothermal energies also play crucial roles, with capacities of 900 MW and 2,000 MW, growth rates of 7% and 9%, investments of USD 1,200 million and USD 4,000 million, efficiency rates of 25% and 80%, and contributing 20% and 15% to the energy mix, respectively.

The government supports these renewable sources through various incentives, including tax breaks, Feed-in Tariffs (FiT), subsidies, and support for research and development. This highlights Indonesia's commitment to diversifying its energy portfolio and enhancing its renewable energy efficiency.

3. RESEARCH METHODOLOGY

Information on dependent and independent factors in this research was gathered from various sources, including the World Development Indicator (WDI), with annual datasets from 1980 to 2018. it is to give the balance needed to explore the tendencies in information; the information was converted into a regular log. According to Weichselgartner and Kelman (2015), this research used the QARDL method to investigate the nonlinear associations among various ecological problems, such as carbon release, air contamination from air quality index (AQI), and CO_2 with EST, GDP, EST, and ENV. Figure 2 shows the correlation matrix of renewable energy adoption factors.

Numerous cutting-edge techniques have become increasingly important in the present literature to assure dependability and reduce bias in experimental results. As the conventional techniques depend upon average regression outcomes against QARDL's application of various quantiles over brief and prolonged periods for research's explaining and result in factors, provide an additional argument for its use. Using varied quantile-based non-periodic asymmetrical associations has advantages for addressing the shifting effects of time sequence across multiple quantiles (Nawaz et al., 2021). Additionally, the QARDL approach aids in capturing how the influence changes throughout lower, moderate, and higher quantiles in time sequence. It also acknowledges the influence of explaining factors on ecological durability over longer and shorter terms. Additionally, the Wald Test was applied for the shorter term and the prolonged period, enclosing the reliability of the variable in every quantile. The equation may be used to describe the conventional ARDL framework (1).

$$Y_t = \alpha + \sum_{i}^{p} 1\beta_1 Y_{t-i} + \sum_{i}^{q} 1\beta_2 X1_{t-i}$$
$$+\sum_{i}^{m} 1\beta_3 X2_{üüüü} + \sum_{i}^{n} 1\beta_4 X3\_ + \sum_{i}^{r} 1\beta_5 X4\_ + \varepsilon \quad (1)$$

where ε_t is the white noise error as expressed by the lowest field created by $\{CE_t, Y_t, GDP_t, ALT_t, EST_{t-1}, INV_{t-1}, \ldots\}$ and p, q, m, n, and r are the lag orders designated by the Schwarz Info Criterion (SIC). Moreover, ($RE\ AQI$, CO_2, GDP, ALT, EST_t, and ENV_t) consideration should be given to the naturally occurring sequence of environment, CO_2 emissions, ultrafine particle 2.5, sustainable inventiveness, and clean power. The second stage was to modify the equation. (1) in light of the quintile setting, which is shown as follows:

$$Q_{Y_t} = \alpha(\tau) + \sum_{i}^{p} 1\beta_1(\tau) Y_{t-i} + \sum_{i}^{q} 1\beta_2(\tau) X1_{t-i} + \sum_{i}^{m} 1\beta_3(\tau) X2_{t-i}$$
$$+\sum_{i}^{n} \beta_4(\tau) X3_{t-i} + \sum_{i}^{r} \beta_5(\tau) X4_{t-i} + \mu_t(\tau) \quad (2)$$

The following quintiles, which fall within the ranges of 0.5, 0.10, 0.20, 0.30, 0.90, and 0.95, were used to analyze the information. The QARDL structure in equation 3 is complete in the following ways because of the likelihood of consecutive connection in white noise mistake;

$$Q_{\Delta Y_t} = \alpha(\tau) + \rho Y_{t-i} + \phi_1 X1_{t-i} + \phi_2 X2_{t-i} + \phi_3 X3_{t-i}$$
$$+\phi_4 X4_{t-i} + \sum_{i}^{p} \beta_1(\tau) Y_{t-i} + \sum_{i}^{q} \beta_2(\tau) X1_{t-i}$$
$$+\sum_{i}^{m} {}_3 X2_{üüüü} + \sum_{i}^{n} {}_4(\ ) X3\_ + \sum_{i}^{r} {}_5(\ ) X4\_ + \varepsilon(\ ) \quad (3)$$

Additionally, the Equation (3) was altered to give the following Mistake correcting simulation evaluation for the QARDL model:

$$Q_{\Delta \ddot{u}j\ddot{u}i} = \alpha(\tau) + \rho(\tau)(Y_{-} - \omega_1(\tau)X1_{-} - \omega_2(\tau)X2_{-}$$
$$-\omega_3(\tau)X3_{t-i} - \omega_4(\tau)X4_{t-i}) + \sum_{i=1}^{p-1}\beta_1(\tau)\Delta Y_{t-i}$$
$$+\sum_{i=0}^{q-1}\beta_2(\tau)\Delta X1_{t-i} + \sum_{i=0}^{m-1}\beta_3(\tau)\Delta X2_{t-1} + \sum_{i=0}^{n-1}\beta_4(\tau)\Delta X3_{t-i}$$
$$+\sum_{i=0}^{r-1}\beta_5(\tau)\Delta X4_{t-i} + \varepsilon_t(\tau) \quad (4)$$

When utilizing Δ method, accumulating brief-term impact of the previous coefficient for three estimates of ecological problems (i.e., carbon releases, AQI, and CO_2) on its present coefficients were mainly perceived by $(\beta_* = \sum_{i=1}^{p-1}\beta_1)$ In the meantime, the joint brief-term impact of modern and past descriptive factors on the current phase of carbon release, AQI, and CO_2 was also perceived as utilizing $(\beta_* = \sum_{i=1}^{q-1} 1\beta_2)$. The remainder of term impacts were also computed using the same process. The Wald Testing was also used to examine the asymmetries in shorter and more prolonged effects of globalization, ecological taxation, environmental innovations, and RE.

4. RESULTS AND DISCUSSION

Table 2 gives explanatory stats for factors in consideration, including average values, information spans, standard deviations (SD), and Jeremy Balka's statistics (J-B statistics). When comparing the various observed factors, the average scoring tendency shows that RE has the most significant average rating. Whereas the average tendency for AQI was 7.02, the ENV average rating was 6.301, placing it third overall. This implies that RE consumption is more significant than the preceding factors. Additionally, ENV shows an average tendency of 6.301 and an SD of 5.005. With the highest rating of 9.51, RE has the strongest tendency right now, trailed by AQI and ENV. The SD also shows that of the investigation's factors, the AQI had the most significant volatility, whereas RE showed the smallest SD at 0.010. Last but not least, Jeremy Balka's statistics (J-B statistics) outcomes demonstrate that all numbers have substantial ratings, rejecting the null speculation about the regular dispersion of information for all factors at a 1% importance degree. This suggests that the QARDL method should be heavily utilized in the current investigation to forecast the shorter and prolonged connection using a variety of quintiles (Diebold and Yılmaz, 2014; Enamul Hoque et al., 2019; Solarin and Bello, 2018; Umar et al., 2018).

Table 2: Estimation of descriptive test

Factors	Average	Minimum	Maximum	SD	J-B statistics
RE	3.02	2.224	4.404	0.02	34.897***
AQI	7.021	6.301	8.147	1.006	18.010***
CO2	4.114	3.01	5.055	0.004	16.009***
REA	5.005	4.014	6.001	0.105	20.121***
ALT	8.01	7.056	9.516	0.568	35.003***
EST	2.546	1.981	2.791	0.564	16.050***
ENV	6.301	5.005	7.171	0.021	19.010***

RE: Renewable energy , SD: Standard deviation, AQI: Air quality index, REA: Renewable energy Adoption, EST: Energy storage technology

The outcomes of unit root (UR) testing for each factor in this research are also shown in Table 3. As recommended in experimental research, the ADF and ZA UR tests were used to perform the unit root testing. Although ZA considers the structure breakdowns in information, ADF is regarded as a traditional technique for examining the UR of factors in research Vakulchuk et al. (2020). Results of Table 2 show that at an essential stage of development of 5%, the ADF and ZA testings show that gathered information is constant. This indicates that all the investigation's factors showed a single sequence of incorporation, that is, I. (1).

Table 4 presents the QARDL framework's outcomes. It demonstrates that, except for the quantiles of 0.80, 0.90, and 0.95, the predicted pace of adjusting value is considered meaningful at a harmful level for all quantiles. The findings suggest a prolonged balance between carbon release and factors such as GDP, ALT, EST, and ENV has been reached. In this research, it was also shown that the initial quantile had the fastest pace of modification for value, and the 0.50^{th} quantile had the slowest. Additionally, all quantiles apart from the smallest quantiles, 0.05 and 0.10, showed adverse significance for correlation value for REA. This indicates that for 9 out of 11 quantiles, the prolonged correlation between REA and CO_2 release is decreasing. As a result, it supports the claim that GDP and CO_2 emissions have a prolonged relationship that is reversed U-shaped since Indonesia's financial system is characterized by upper ranks of ecological advancement that eventually result in reduced levels of carbon releases. Previous research has noted a similar link.

Fethi and Rahuma (2019) examined the experimental relationship between REA and CO_2 release among Japanese production enterprises. They discovered that a more excellent GDP rating is associated with reduced CO_2 release levels in the country's financial system. According to Saint Akadiri et al. (2020), environmental advancement in G7 nations contributes to decreased carbon releases. Fethi and Rahuma (2019) investigated if the dynamical approach relating to correlation amid ecological advancement and CO_2 release included an ecological Kuznets curve. Their results supported the notion that the two factors had an adverse relationship.

Table 5 results for the initial five quantiles of the RE-CO_2 release connection reveal that it is adversely critical. It promotes the claim that increased ALT use results in decreased CO_2 releases in Indonesian regions, increasing ecological resilience.

Daw (2017) verified that RE is a means of decreasing CO_2 emissions and observed a comparable link in previous investigations. Therefore, a two-directional connection between carbon release and RE was discovered in the shorter term. In the meantime, Zhao et al. (2021) investigated how RE affected CO_2 emissions using

Table 3: Estimations of unit-root statistics

Factors	ADF (°)	ADF (Δ)	ZA (°)	Break years	ZA (Δ)	Break years
RE	0.347	−5.347***	0.287	2009 Q1	−7.349***	2011 Q1
AQI	−1.217	−5.028***	−0.811	2012 Q2	−8.456***	2013 Q2
CO2	−0.785	−5.109***	−2.156	2008 Q4	−7.258***	2011 Q1
REA	−0.432	−7.248***	−0.465	2017 Q1	−9.617***	2017 Q1
ALT	−2.306	−6.982***	−2.54	2011 Q1	−7.216***	2011 Q1
EST	−2.12	−5.619***	−2.219	2006 Q2	−12.205***	2011 Q4
ENV	−0.872	−4.782***	−0.563	2009 Q1	−8.178***	2009 Q4

RE: Renewable energy , SD: Standard deviation, AQI: Air quality index, REA: Renewable energy Adoption, EST: Energy storage technology

Table 4: Quantile autoregressive distributed lag results for CO2 emission

Quantiles (τ)	Constant	ECM	Long-run estimations			
	α∗(τ)	ρ∗(τ)	βGDP(τ)	βALT(τ)	βEST(τ)	βENV(τ)
0.05	0.101 0.010)	−0.515*** (−3.555)	−0.120 (−0.003)	−0.215*** (−3.010)	−0.101 (−0.030)	0.101 (0.100)
0.1	0.201 (0.001)	−0.451*** (−4.051)	−0.133 (−0.020)	−0.289*** (−4.098)	−0.105 (−0.010)	0.102 (0.020)
0.2	0.120 (0.021)	−0.460*** (−5.706)	−0.253** (−2.135)	−0.312*** (−5.012)	−0.140 (−0.002)	0.101 (0.120)
0.3	0.031 (0.013)	−0.389** (−2.010)	−0.258** (−1.666)	−0.318** (−2.011)	−0.116 (−0.011)	0.134 (0.714)
0.4	0.024 (0.140)	−0.350** (−2.101)	−0.254** (−2.054)	−0.264** (−2.004)	−0.124* (−1.700)	0.205 (0.810)
0.5	0.0033 (0.017)	−0.211** (−1.988)	−0.257*** (−3.513)	−0.243 (−0.008)	−0.148* (−1.784)	0.213 (1.003)
0.6	0.124 (0.010)	−0.212* (−1.655)	−0.271*** (−4.716)	−0.247 (−1.017)	−0.132** (−2.030)	0.204 (1.020)
0.7	0.010 (0.033)	−0.321* (−1.733)	−0.267*** (−4.066)	−0.191 (−1.009)	−0.152** (−2.020)	0.151 (1.505)
0.8	0.0245 (0.055)	−0.345 (−1.015)	−0.317*** (−6.010)	−0.172 (−1.117)	−0.161*** (−5.010)	0.223** (2.010)
0.9	0.015 (0.105)	−0.456 (−1.006)	−0.331*** (−5.011)	−0.111 (−1.010)	−0.187*** (−4.010)	0.213** (2.010)
0.95	0.107 (0.017)	−0.222 (−1.002)	−0.322*** (−3.226)	−0.120 (−1.030)	−0.209*** (−3.009)	0.243*** (3.060)
Short-run estimations						
Quantiles (τ)	ϕ1(τ)	ω0(τ)	λ0(τ)	θ0(τ)	ἕ0(τ)	ἕ1(τ)
0.05	0.479*** (6.999)	−0.035* (−1.735)	−0.065** (−2.052)	−0.071*** (−4.076)	0.002 (0.014)	0.071 (0.017)
0.1	0.591** (2.019)	−0.091* (−1.659)	−0.074** (−2.003)	−0.017*** (−3.751)	0.024 (0.042)	0.031 (0.031)
0.2	0.320** (2.010)	−0.087*** (−7.007)	−0.007 (−1.037)	−0.014*** (−3.004)	0.055 (0.033)	0.015 (0.015)
0.3	0.232 (1.310)	−0.089*** (−5.100)	−0.011 (−1.010)	−0.067** (−2.007)	0.086 (0.086)	0.061 (1.001)
0.4	0.248 (1.208)	−0.023 (−0.012)	−0.029 (1.009)	−0.028 (−1.122)	0.068 (0.008)	0.022 (1.002)
0.5	0.277 (1.017)	−0.025 (−0.052)	−0.018 (−0.808)	−0.025 (−1.030)	0.080 (0.010)	0.021 (1.010)
0.6	0.258 (1.001)	−0.015 (−1.005)	−0.025 (−0.705)	−0.069 (−0.043)	0.046 (0.164)	0.020 (1.004)
0.7	0.257 (1.217)	−0.081** (−2.006)	−0.028 (−0.615)	−0.039 (−1.010)	0.024 (0.002)	0.046 (1.016)
0.8	0.315* (1.656)	−0.070** (−2.007)	−0.055 (−0.065)	−0.050 (−1.013)	0.046 (1.061)	0.057 (1.007)
0.9	0.514* (1.884)	−0.063 (−1.036)	−0.016 (−0.001)	−0.059 (−0.920)	0.031 (1.001)	0.076 (1.003)
0.95	0.456* (1.895)	−0.057 (−1.007)	−0.042 (−0.006)	−0.016 (−0.621)	0.066 (1.006)	0.040 (1.001)

Significance indicated by ***, ** and * represent 1%, 5% and 10%. Uantile estimation results are in the table. Enclosed in brackets are the T-statistics

the panel's quantile modelling approach. The investigation verified that two factors exhibit an inverse U-shaped tendency at various quantiles. Ahmad et al. (2021) also revealed that 46 sub-Saharan African nations have lower CO_2 emissions from using RE sources. The correlation value for said association amid ecological taxation and carbon emissions in Indonesia is shown in Table 4. Just for the moderate and top-grade quantiles, do the results in various quantiles demonstrate an adverse association amid both factors (i.e., 0.40–0.95), suggesting that increasing ecological levies will have a long-term, significant adverse effect on carbon emissions?

A study by Zafar et al. (2022) presented comparable results, showing that varying degrees of ecological taxation or carbon tax rates may lessen the severity of CO_2 release in the atmosphere, like how Farid et al. (2022) revealed that ecological taxation aids in improving the ecosystem while reducing CO_2 releases, Bibi et al. (2021) further verified that ecological taxation adversely affects carbon release. Furthermore, Table 3's findings further foretell Indonesia's long-term relationship between GLO and carbon emissions. The higher quantiles (i.e., 0.80-0.95) are the only ones involved in this association, and its favourably considerable value is 5%. This implies that increased ENV causes increased carbon release, and conversely. Numerous earlier investigations likewise support the speculative connection between globalization and carbon emissions. To investigate the connection between globalization and carbon emissions, Solarin and Bello (2018) assessed the EKC of 87 nations. Their results supported the U-shaped relationship amid globalization, and now, the destruction of the ecosystem is caused by carbon emissions, which affect 8% of sampled nations. Umar et al. (2018) noted that expanding commerce-relevant operations causes increased CO_2 emissions. Numerous experimental studies, like those by (Chatziantoniou et al., 2022; Cho et al., 2015; Krause & Tolaymat, 2018), also support this idea (2020).

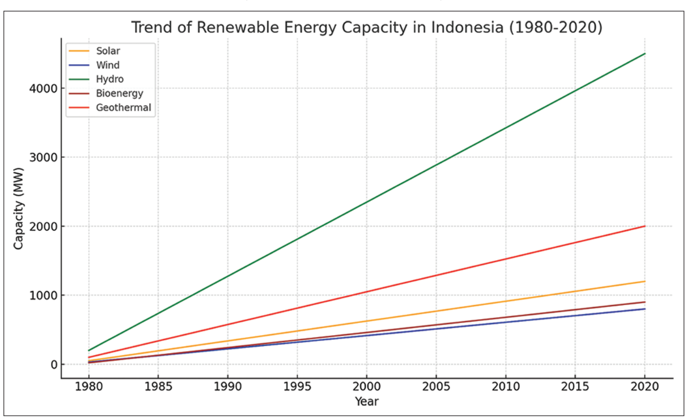
The prolonged dynamical outcomes also show that previous carbon release rates, although limited to the lowest and highest quantiles, have a considerable and immediate influence on the present levels of carbon release. The remaining quantiles, as demonstrated in Table 3, did not see an effect. Additionally, only the initial four and final three quantiles of present amounts of carbon release are negatively and significantly impacted by the concurrent

Table 5: Quantile autoregressive distributed lag results for $PM_{2.5}$

Quantiles (τ)	Constant	ECM	Long-run estimations			
	α∗(τ)	ρ∗(τ)	βGDP(τ)	βALT(τ)	βEST(τ)	βENV(τ)
0.05	0.001 (0.001)	−0.425*** (−3.004)	−0.050 (−0.030)	−0.177*** (−6.708)	−0.051 (−0.010)	0.110 (0.003)
0.1	0.226 (0.002)	−0.375*** (−4.006)	−0.267 (−0.027)	−0.175*** (−7.009)	−0.001 (−0.021)	0.246 (0.004)
0.2	0.056 (0.005)	−0.356*** (−5.006)	−0.250** (−2.050)	−0.175*** (−3.055)	−0.040 (−0.004)	0.216 (0.001)
0.3	0.078 (0.070)	−0.412** (−2.001)	−0.281** (−2.008)	−0.146** (−2.006)	−0.187 (−0.005)	0.220 (0.010)
0.4	0.085 (0.015)	−0.346** (−2.010)	−0.226** (−2.006)	−0.168** (−2.018)	−0.179* (−1.779)	0.264 (0.054)
0.5	0.372 (0.002)	−0.332** (−2.010)	−0.189*** (−7.099)	−0.141 (−1.101)	−0.242* (−1.842)	0.153 (0.323)
0.6	0.158 (0.001)	−0.334* (−1.834)	−0.224*** (−7.004)	−0.102 (−1.320)	−0.272** (−2.005)	0.256 (0.823)
0.7	0.006 (0.010)	−0.329* (−1.829)	−0.253*** (−5.035)	−0.124 (−1.340)	−0.275** (−2.006)	0.151 (1.001)
0.8	0.157 (0.005)	−0.282 (−1.002)	−0.253*** (−3.353)	−0.166 (−1.040)	−0.252*** (−7.009)	0.243* (1.703)
0.9	0.412 (0.002)	−0.146 (−1.004)	−0.222*** (−3.002)	−0.180 (−1.070)	−0.246*** (−5.008)	0.250** (2.205)
0.95	0.101 (0.010)	−0.110 (−1.011)	−0.273*** (−2.993)	−0.132 (−1.112)	−0.222*** (−4.011)	0.331*** (3.003)
Short-run estimations						
Quantiles (τ)	ϕ1(τ)	ω0(τ)	ω1(τ)	λ0(τ)	θ0(τ)	έ0(τ)
0.05	0.542*** (3.002)	−0.076* (−1.655)	−0.041 (−1.419)	−0.035 (−0.003)	−0.063*** (−2.993)	0.012 (0.004)
0.1	0.364*** (5.046)	−0.081* (−1.712)	−0.020 (−1.082)	−0.061 (−0.001)	−0.076*** (−3.657)	0.053 (0.030)
0.2	0.318*** (3.011)	−0.081*** (−7.028)	−0.010 (−1.007)	−0.021 (−0.110)	−0.066*** (−4.006)	0.026 (0.002)
0.3	0.326*** (3.001)	−0.071*** (−4.047)	−0.060 (−1.606)	−0.013 (−0.301)	−0.021** (−2.010)	0.062 (0.003)
0.4	0.509*** (3.009)	−0.032 (−0.033)	−0.050 (−0.951)	−0.052 (0.210)	−0.013 (−0.102)	0.062 (0.002)
0.5	0.535*** (3.060)	−0.035 (−0.131)	−0.048 (−1.008)	−0.024 (−0.410)	−0.037 (−0.020)	0.020 (0.030)
0.6	0.638*** (3.009)	−0.022 (−1.002)	−0.055 (−1.405)	−0.039 (−0.700)	−0.068 (−0.060)	0.043 (0.003)
0.7	0.531*** (3.010)	−0.036** (−2.006)	−0.071 (−1.017)	−0.038* (−1.710)	−0.063 (−1.030)	0.075 (0.021)
0.8	0.321** (2.721)	−0.075** (−1.975)	−0.062 (−1.002)	−0.041** (−2.001)	−0.050 (−1.004)	0.067 (1.007)
0.9	0.570* (1.800)	−0.035** (−2.050)	−0.047 (−0.973)	−0.074** (−2.047)	−0.076 (−0.006)	0.088 (1.106)
0.95	0.701* (1.700)	−0.042** (−2.002)	−0.033 (−0.333)	−0.037** (−2.050)	−0.057 (−0.007)	0.021 (1.112)

Significance indicated by ***, ** and * represent 1%, 5% and 10%. Quantile estimation results are in the table. Enclosed in brackets are the T-statistics

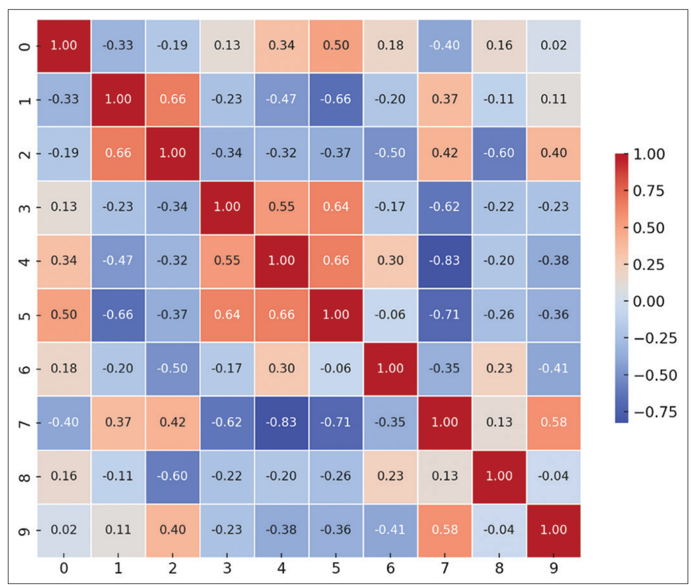
Figure 1: The trend of renewable energy capacity in indonesia (Rahman et al., 2023)



variations in GDP numbers. Additionally, it was discovered that mainly the lowest quantiles of RE have a short-term detrimental effect on carbon release. The results show that EST significantly and negatively affects carbon release for the initial four quantiles of the shorter-term calculation. After examining the correlation between carbon emissions and the main explaining factors, Table 4 displays the results for AQI both prolonged and shorter term. Apart from the final three quantiles, all quantiles show substantial and adverse outcomes from assessing the predicted pace of the adjusting factor, or ρ*.

These results demonstrate that the AQI, GDP, ALT, EST, and ENV have returned to their long-term balance in Indonesian territory. However, the smallest quantile (0.05^{th}, 0.425***) is where this pace of modification is at its peak. Additionally, all quantiles apart from the initial 2 have co-integrating variables for GDP that are

Figure 2: Correlation matrix of renewable energy adoption factors



adversely important at 1%. This corroborates the idea that reduced AQI levels are brought on by greater GDP. GDP must play a part in lowering AQI to encourage greater ecological resilience. Conceptual and experimental proof of the possible connection between environmental advancement and AQI-induced air contamination has been presented in previous works. For instance, Scrimgeour et al. (2005) found a strong correlation between environmental advancement and AQI regarding investigation and progression. (Vakulchuk et al., 2020) assert that Indonesia's financial system experiences a significant decline in AQI due to environmental effects. However, the impact of technology on AQI is constrained.

Figure 3: Comparative impact of renewable versus non-renewable energy on CO_2 emissions

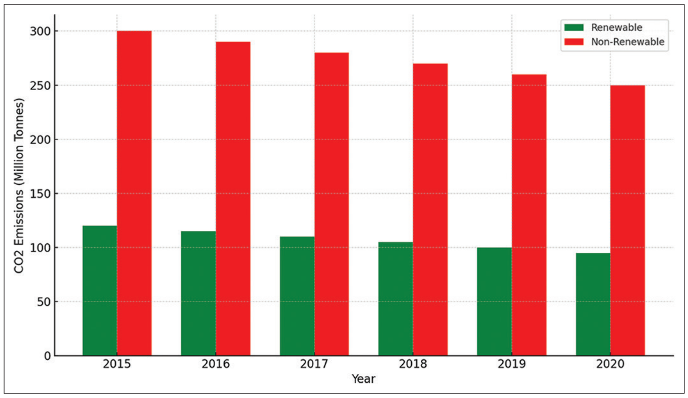


Table 5 shows that the assessment revealed a substantial and adverse relationship between RE and AQI, the pollutant that causes haze. To be less precise, the quantiles of 0.05, 0.10, 0.20, 0.30, and 0.40 correspondingly showed this effect. This asserts that increased RE usage reduces AQI levels and air contamination in Indonesia's regional surroundings. However, the effect of ecological taxation on AQI is negligible for the initial four quantiles yet considerable at 10 for the remaining quantiles. As a result, greater ecological taxation levels can also assist in lowering AQI levels of air contamination. Fethi and Rahuma (2019) claimed that ecological taxation is a valuable source for reducing air contamination and gave an experimental defence.

In contrast, Weichselgartner and Kelman (2015) contend that ecological taxation must play a role in the drive to reduce air contamination. (Godil et al., 2020) likewise looked at how ecological taxation could reduce AQI levels and found a strong correlation between the two. However, the investigation's final three quantiles are the sole ones where the effect of globalization on AQI is significantly substantial.

This indicates that more excellent commerce-relevant operations could increase air contamination in Indonesia, which requires urgent attention. Meng et al. (2016) state that logistics network operations and worldwide usage majorly affect air contamination, especially regarding AQI. Wu et al. (2021) asserted that globalization is favourably and strongly connected with AQI, providing additional backing. Moreover, the results of the shorter-term assessment indicated a favourable and substantial relationship between the historical AQI readings and present AQI readings across all sample quantiles. However, only for the smaller quantiles are the present amounts of AQI negatively and significantly impacted by the prior amounts of EST. Finally, Table 5's findings anticipated the shorter, prolonged relationships amid CO_2 and explaining factors. Except for the final three quantiles, all quantiles with the predicted pace of adjusting the value of ρ^* for ECM show substantial and adverse results. This postulates that the Chinese financial system's CO_2, GDP, ALT, EST, and ENV have returned to their long-term balance. The 10th quantile, though, was shown to have the fastest arrangement rate (0.389***). Apart from quantiles 0.05 and 0.10, the correlation factor of GDP was adversely important in all quantiles. This equation shows that Indonesia's CO_2 emissions will decrease because of increased environmental advancement. Su et al. (2021) have further verified that advancements linked to CC are helping to reduce CO_2 releases for the 70 countries in the group. When investigating the relationship between CO_2 and power-technology advancement in the regions of Canada, Dunyo et al. (2024) likewise observed comparable results.

Table 6 shows the outcomes amid RE and CO_2, indicating a substantial and adverse link between the two factors. Therefore, the initial five quantiles were numerically meaningful for this connection. This indicates that increased RE contributes to decreased CO_2 in Chinese regions. These results are those of (Naeem et al., 2021), who verified that using RE decreases the worth of CO_2. Many writers have also examined the relationship between RE and CO_2 emissions in various areas (Chien et al., 2021; Daw, 2017; Zhao et al., 2021). From the 50th to 95th quantiles, the effect of EST on CO_2 was likewise found to be adversely critical. This suggests that greater ecological taxation suits Indonesia's efforts to reduce CO_2 emissions. Comparable arguments were made by Saint Akadiri et al. (2020), whose experimental results indicate that ecological taxation helps to reduce emissions.

Table 7 shows the effect of globalization on the valuation of CO_2, which shows a significant relationship, and it shows that increased globalization and commerce-relevant operations increase CO_2 emissions. The shorter-term prediction outcomes revealed that previous CO_2 readings have a favourable and substantial influence on existing CO_2 values. This research employed the Wald test to evaluate the consistency of variables for each of the three reliant factors. Considering the results, the null speculation regarding the variable stability of the pace of adjusting variable is disproved for each of the three reliant factors at a 1% probability of error. Additionally, the long-run variables of factors deny the nullity of uniformity throughout the various tails of every quantile. This supports the claim that long-term variables for numerous quantiles in the territory of Indonesia, including RE, AQI, CO_2, GDP, ALT, EST, and ENV, are reported to be naturally dynamic. Additionally, the Walt test's shorter-term estimations disprove the null speculation regarding the uniformity of the shorter-term accumulated effect of previous values for each of the three reliant factors over investigation quantiles.

Table 8 illustrates the progressive impact of renewable energy adoption on Indonesia's economic indicators from 1980 to 2018. Over this period, GDP growth experienced a steady increase from 4.0% in 1980 to 6.2% in 2018, reflecting the positive economic implications of transitioning towards renewable energy sources. Employment within the renewable sector saw a significant uptick, growing from a modest 10 thousand in 1980 to 220 thousand by 2018, indicative of the sector's expanding role in the job market. Correspondingly, investment in renewable energy surged from \$100 million in 1980 to \$3,000 million in 2018, showcasing a robust commitment to renewable energy development. This trend not only underscores the growing economic viability of renewable energy but also highlights its critical contribution to sustainable economic growth and job creation in Indonesia over nearly four decades. The data suggests a strong correlation between increased investment in renewables and positive shifts in GDP growth and

Table 6: Quantile autoregressive distributed lag results for greenhouse gas

Quantiles (τ)	Cofficient	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95
Constant	α*(τ)	0.020	0.115	0.047	0.064	0.076	0.353	0.267	0.026	0.246	0.323	0.202
		(0.030)	(0.007)	(0.005)	(0.004)	(0.006)	(0.003)	(0.076)	(0.006)	(0.006)	(0.030)	(0.001)
ECM	ρ*(τ)	−0.337***	−0.389***	−0.345***	−0.323**	−0.352**	−0.321**	−0.347*	−0.330*	−0.273	−0.179	−0.092
		(−3.030)	(−5.090)	(−3.004)	(−2.003)	(−2.012)	(−2.001)	(−1.847)	(−1.703)	(−0.020)	(−0.095)	(−0.014)
	βGDP (τ)	−0.179	−0.151	−0.143**	−0.171**	−0.139**	−0.189***	−0.116***	−0.105***	−0.142***	−0.144***	−0.168***
		(−0.005)	(−0.010)	(−2.003)	(−2.001)	(−2.030)	(−5.007)	(−3.010)	(−3.005)	(−2.993)	(−3.044)	(−2.994)
Estimations of long-term												
βALT(τ)		−0.166***	−0.164***	−0.162***	−0.235**	−0.257**	−0.231	−0.203	−0.535	−0.067	−0.078	−0.037
		(−5.617)	(−6.004)	(−3.026)	(−2.005)	(−2.075)	(−1.102)	(−1.103)	(−1.005)	(−0.805)	(−0.827)	(−0.523)
βERT(τ)		−0.042	−0.033	−0.003	−0.076	−0.067	−0.131*	−0.161**	−0.164**	−0.241***	−0.235***	−0.311***
		(−0.001)	(−0.013)	(−0.030)	(−0.806)	(−1.664)	(−1.700)	(−2.001)	(−2.005)	(−6.010)	(−4.003)	(−3.022)
βENV(τ)		0.201**	0.335**	0.323**	0.271***	0.253***	0.246***	0.245***	0.242***	0.343***	0.250***	0.302***
		(2.010)	(2.003)	(2.702)	(3.011)	(3.003)	(3.024)	(3.001)	(3.040)	(3.313)	(3.630)	(3.702)
Estimations of short-term												
ϕ1(τ)		0.553***	0.453***	0.319***	0.337***	0.368**	0.144	0.249	0.341	0.401*	0.462*	0.507*
		(3.003)	(4.035)	(3.071)	(3.051)	(2.080)	(0.040)	(0.054)	(0.012)	(1.710)	(1.700)	(1.707)
ω0(τ)		−0.065*	−0.092*	−0.039***	−0.058***	−0.033	−0.041	−0.023	−0.027**	−0.067**	−0.042**	−0.031**
		(−1.664)	(−1.792)	(−6.024)	(−3.022)	(−0.055)	(−0.110)	(−1.030)	(−2.007)	(−1.900)	(−2.022)	(−2.001)
ω1(τ)		−0.032	−0.042	−0.050	−0.050	−0.021	−0.027	−0.032	−0.078	−0.046	−0.040	−0.077
		(−1.231)	(−1.242)	(−1.005)	(−1.405)	(−1.392)	(−1.007)	(−0.993)	(−0.728)	(−0.416)	(−0.605)	(−1.333)
λ0(τ)		−0.046**	−0.072**	−0.030	−0.013	−0.041	−0.026	−0.078	−0.029	−0.018	−0.031	−0.016
		(−2.004)	(−2.020)	(−1.031)	(−1.333)	(1.040)	(−0.650)	(−0.871)	(−1.029)	(−1.040)	(−1.107)	(−1.020)
θ0(τ)		−0.075***	−0.054***	−0.050***	−0.035**	−0.024	−0.046	−0.039	−0.077	−0.050	−0.067	−0.021
		(−3.003)	(−4.321)	(−2.990)	(−2.001)	(−0.101)	(−0.040)	(−0.009)	(−1.007)	(−1.005)	(−0.005)	(−0.001)
έ0(τ)		−0.022	−0.042	−0.315	−0.242	−0.456	−0.202	−0.652	−0.107	−0.454	−0.644	−0.024
		(−0.002)	(−0.002)	(−0.010)	(−0.004)	(−0.050)	(−0.022)	(−0.002)	(−0.103)	(−1.004)	(−1.004)	(−1.102)
έ1(τ)		−0.062	−0.096	−0.027	−0.021	−0.066	−0.101	−0.065	−0.024	−0.074	−0.020	−0.071
		(−0.326)	(−0.326)	(−0.752)	(−1.012)	(−1.006)	(−1.013)	(−1.003)	(−1.020)	(−1.024)	(−1.002)	(−1.017)

Significance indicated by ***, ** and * represent 1%, 5% and 10%. Quantile estimation results are in the table. Enclosed in brackets are the T-statistics

Table 7: Parameter constancy in wald test results

Factors	Wald-stats (RE)	Wald-stats (AQI)	Wald-stats (CO_2)
P	9.887*** (0.000)	7.556*** (0.000)	6.576*** (0.000)
Beco	8.314*** (0.000)	5.788*** (0.000)	6.004*** (0.000)
Bren	4.211*** (0.002)	4.124*** (0.000)	5.246*** (0.000)
Bert	3.224** (0.052)	6.258*** (0.000)	4.524** (0.000)
Bglo	4.897*** (0.000)	16.778*** (0.000)	7.217*** (0.000)
ϕ1	3.114** (0.045)	8.005*** (0.000)	8.213*** (0.000)
ω0	4.867*** (0.000)	1.331** (0.283)	3.214** (0.147)
ω1	–	0.991** (0.453)	2.279 (0.355)
λ0	0.267 (0.897)	2.941*** (0.023)	4.547*** (0.024)
θ0	8.023*** (0.000)	6.111*** (0.054)	5.324*** (0.000)
έ0	0.203 (0.897)	5.155*** (0.000)	8.518*** (0.000)
έ1	6.202*** (0.000)	–	9.406*** (0.000)
Cumulative short-term effect			
ω*	–	2.213 (0.568)	2.523 (0.237)
έ*	0.952 (0.769)	–	2.312 (0.285)

Significance indicated by ***, ** and * represent 1%, 5% and 10%. Squared brackets denote P-values

Table 8: Impact of renewable energy adoption on economic indicators (1980–2018)

Year	GDP growth (%)	Employment in the renewable sector (thousands)	Investment in renewable energy (USD million)
1980	4	10	100
1990	4.5	20	300
2000	5	50	700
2010	5.5	120	1400
2015	5.8	180	2200
2018	6.2	220	3000

Table 9: Environmental impact assessment

Year	Renewable energy capacity (MW)	(lower is better)	CO_2 emissions (Million Tonnes)	GHG emissions (Million Tonnes CO_2e)
1980	500	85	200	250
1990	750	80	190	240
2000	1500	75	180	230
2010	2500	65	160	210
2015	3500	60	150	200
2018	4500	55	140	190

AQI: Air quality index, GHG: Greenhouse gas

employment rates, reinforcing the argument for renewable energy as a catalyst for economic development.

Table 9 showcases the environmental impact of increasing renewable energy capacity in Indonesia from 1980 to 2018, highlighting a clear trend towards improved air quality and reduced emissions. As the renewable energy capacity expanded from 500 MW in 1980 to 4,500 MW in 2018, the AQI showed a notable improvement, decreasing from 85 to 55, indicating better air quality over time. Concurrently, CO_2 emissions significantly reduced, dropping from 200 million tonnes in 1980 to 140 million in 2018. Similarly, overall Greenhouse Gas (GHG) emissions decreased from 250 million tonnes of CO_2 equivalent in 1980 to 190 million tonnes of CO_2 equivalent in 2018. These changes underscore the positive environmental effects of transitioning to renewable energy sources, such as mitigating air pollution and reducing the carbon footprint, aligning with global sustainability and climate change mitigation goals. The numerical data in the table clearly illustrates the pivotal role of renewable energy adoption in driving environmental improvements in Indonesia over nearly four decades.

5. CONCLUSION AND POLICY IMPLICATIONS

Unpredictable things are commodities with a life expectancy of under 3 years on the mean. However, one of the issues with unpredictable items that are becoming more and more of a problem is how these businesses may use their ability to seize the most current technology whilst maximizing their operating skills and examining the impact of environmental advancement, RE, ecological taxation, and globalization on CO_2 emissions, AQI, and CO_2. The main goal of this essay is to explore the Chinese region. The Wald Test and the QARDL approach were used to ascertain the interrelationships between shorter and prolonged periods. The experimental results indicated that environmental advancement, RE, and ecological taxation adversely and considerably impact carb release. However, globalization has a favourable and significant effect on carbon emissions. The findings of this investigation revealed that environmental advancement, RE, and EST are the main elements prominently aiding in reducing air contamination in Chinese regions for a prolonged term about the link between the significant descriptive factors and AQI. GlobalizationHowever, globalization does not significantly or directly affect AQI air contamination. Lastly, the findings of this research have demonstrated the importance of GDP, ALT, and EST in reducing Indonesia's excessive CO_2 release levels in its natural habitat.

However, the same phenomenon was seen in various quantiles. Globalization, on the other hand, was found to be an immediate long-term indication of increasing CO_2 in Indonesia. Thereby, it can be noted that whereas globalization boosts economic expansion and efficiency and consequently enhances carbon emissions in the nation, efficient advancement acceptance in the manufacturing industry, together with efficient utilization of RE and sensible metrics such as ecological taxation, decrease carbon emissions in the state. The research offered several strategic suggestions depending on the experimental results. Firstly, environmental advancement, ecological taxation, and RE hurt the price of CO_2 emissions and AQI. Thus, when concentrating further on environmental advancement and carbon or ecological taxation, administrations in Chinese regions must recognize the importance of such descriptive factors. This would assist in transforming the whole financial system explicitly in favour of the ecosystem and improve and sustainably develop Indonesia's climate. Secondly, globalization favours CO_2 emissions, which mandates that measures must be discriminatorily designed across the Chinese financial system to limit commerce-relevant operations specifically to blame for increasing CO_2 emissions. Thirdly, there is sufficient proof from the existence of AQI and the immediate effects of variables like RE to recommend that governments prioritize RE over non-RE to reduce air contamination in the atmosphere. This report recommends that politicians create appropriate regulations addressing globalization and its contribution to reducing CO_2 emissions.

Additionally, authorities must pay close attention to how emerging and existing laws about ecological solutions are being implemented nationwide. Lastly, this research has several areas for improvement, including the failure to consider non-RE usage and its connection to CO_2, air contamination, and carbon emissions. The focus of this research is mainly restricted to the South Asian Chinese financial system. Another drawback of current research is the need for cross-section analyses in South Asia to identify nations highly susceptible to carbon release, air contamination, and CO_2. The QARDL approach has also been used in this research to investigate the connections among the variables. To solve these issues and examine the connection between the factors in subsequent studies, it is advised to have a deeper grasp of the subject.

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