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How does economic growth moderate the impact of energy consumption on carbon emissions in the evaluation of Sustainable Development Goal 13?

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Abstract

This study aims to examine the impact of non-renewable and renewable energy consumption on carbon emissions while assessing the moderating effect of economic growth. The research focuses on the evaluation of Sustainable Development Goal 13 in Asia-Pacific countries, particularly Indonesia, Australia, and China. The study employs moderated regression analysis using panel data from 2008 to 2024. This methodological approach allows for an in-depth examination of the relationships between energy consumption, economic growth, and carbon emissions. The results indicate that non-renewable energy consumption significantly increases carbon emissions, whereas renewable energy consumption negatively impacts carbon emissions, albeit insignificantly. Additionally, economic growth consistently contributes to higher carbon emissions, both directly and through its interaction with energy sources. The moderation analysis reveals distinct effects: economic growth exhibits quasi-moderation in the relationship between non-renewable energy consumption and carbon emissions, whereas its role in the relationship between renewable energy consumption and carbon emissions follows a pure moderation pattern. The study underscores the critical need for transitioning towards more sustainable energy sources to mitigate carbon emissions. Policymakers should focus on reducing dependence on non-renewable energy by accelerating the adoption of renewable energy through targeted incentives, regulatory reforms, and advancements in clean energy technologies.

Keywords: Carbon emissions, Economic growth, Moderated regression analysis, Non-renewable energy consumption, Renewable energy consumption, Sustainable development goal 13.

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1. Introduction

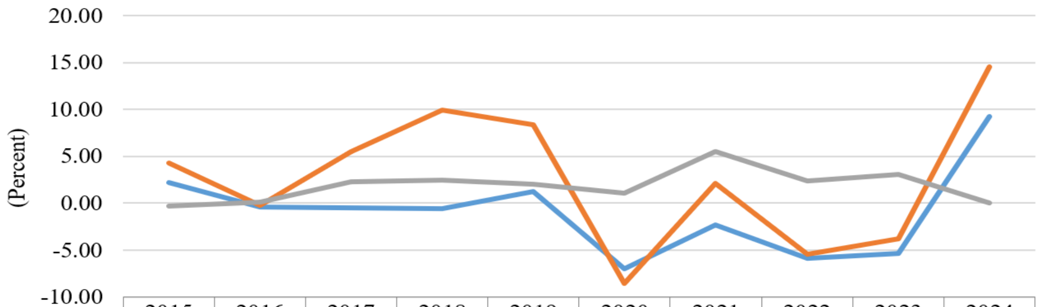
The significance of lowering carbon emissions (CE) and lessening the effects of climate change is emphasized by Sustainable Development Goal (SDG) 13, which is centered on climate action [1, 2]. With its consequences becoming more and more pervasive worldwide, the phenomenon of climate change brought on by CE has emerged as one of humanity's biggest problems [3, 4]. Given the increasing detrimental effects of CE on the environment and human life, stakeholders everywhere must act quickly and together to address this issue [5].

One of the main strategies to mitigate climate change is to control CE from various human activities, especially those associated with energy consumption [6, 7]. The high reliance on non-renewable energy consumption (NREC), which still forms the basis of the world's energy needs, is the biggest obstacle to CE management, nevertheless [8, 9]. Significant CE is produced by energy dominated by NREC, which raises the atmospheric concentration of greenhouse gases [10]. NREC has major long-term effects on the stability of the global climate, while being a staple in many nations because of its affordable prices and widespread availability [11].

The Asia-Pacific region, which continues to rely significantly on NREC and functions as a hub for fossil-based energy activities as well as a region working to transition toward cleaner energy through renewable energy consumption (REC), is inextricably linked to global efforts to control CE [12]. China, Australia, Indonesia, and other nations in this area are important players in the dynamics of global CE. The greatest coal consumer, China, and significant coal exporters, Indonesia and Australia, show a substantial link between NREC and CE [13]. In particular, although actively increasing its usage of REC, such as solar energy, China's high coal consumption highlights its reliance on NREC [14].

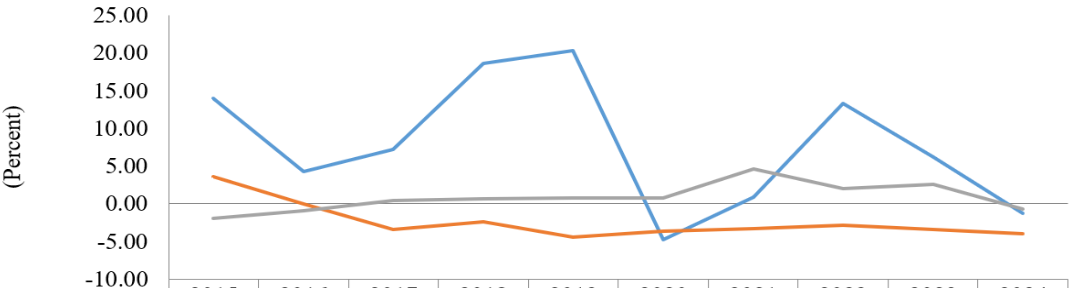
In the meantime, despite having a lower CE per capita than the global average and ranking ninth in terms of global CE, Indonesia still confronts considerable obstacles in lowering its overall CE levels [15]. Furthermore, coal consumption continues to be a key component of China's energy strategy, even in spite of its ongoing efforts to increase its REC capacity [16, 17]. This emphasizes how difficult it will be to make the switch to cleaner energy, especially since NREC is heavily relied upon and is more readily available and reasonably priced. Energy consumption management gets more complicated as the industrial, transportation, and residential sectors drive up energy demand [18].

Examining growth data on CE, NREC (such as coal), and REC (such as solar energy) in important Asia-Pacific nations—China, Australia, and Indonesia—is crucial to comprehending the dynamics of CE regulation. As seen successively in Figures 1, Figure 2 and Figure 3 over the previous ten years, each of these nations has distinct features that add to the difficulties of the global energy transition.



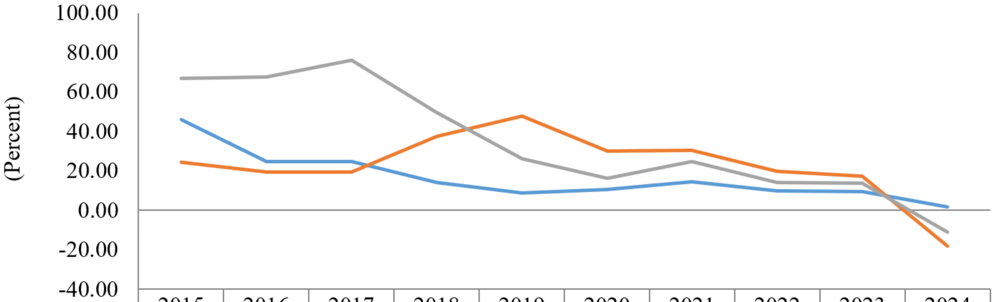
	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Indonesia	2.18	-0.40	-0.46	-0.55	1.26	-6.97	-2.33	-5.91	-5.34	9.21
Australia	4.27	-0.24	5.49	9.90	8.42	-8.55	2.09	-5.42	-3.76	14.55
China	-0.33	0.09	2.28	2.45	1.99	1.07	5.50	2.41	3.04	0.05

Figure 1.
CE growth trends.
Source: BP Statistical Review of World Energy [19].



	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Indonesia	13.96	4.30	7.16	18.60	20.28	-4.72	0.88	13.34	6.22	-1.26
Australia	3.55	-0.06	-3.43	-2.42	-4.42	-3.67	-3.32	-2.87	-3.40	-4.01
China	-1.89	-0.90	0.47	0.61	0.80	0.83	4.61	1.99	2.54	-0.64

Figure 2.
NREC growth trends.
Source: BP Statistical Review of World Energy [19].

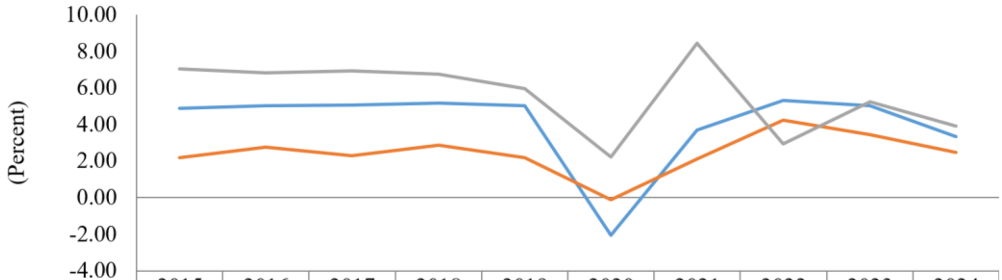


	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Indonesia	45.81	24.69	24.46	13.84	8.66	10.50	14.39	9.73	9.52	1.78
Australia	24.37	19.37	19.16	37.49	47.82	29.83	30.35	19.51	17.12	-18.28
China	66.92	67.51	76.03	49.29	26.16	16.13	24.78	14.04	13.59	-11.08

Figure 3.
REC growth trends.
Source: BP Statistical Review of World Energy [19].

The data illustrate the dynamic link between NREC, REC, and CE in China, Australia, and Indonesia, as shown in Figures 1, Figure 2 and Figure 3. Overall, the connection between these three variables fluctuated significantly between 2015 and 2024. The data from Figures 1, Figure 2 and Figure 3 highlight how important it is to emphasize the congruence between the rise in REC and CE in the context of SDG 13. Even though REC has grown in China, Indonesia, and Australia, its ability to lower CE is still constrained by NREC's dominating negative effect. This emphasizes how urgent it is for all three nations to make a quicker and more sustainable energy transition in order to reach the more aggressive CE reduction goals set forth in SDG 13, which aims to address climate change and its effects.

In keeping with the pressing need for a quicker and more sustainable energy transition, Asia-Pacific nations' main obstacle is striking a balance between maintaining economic growth (EG) and minimizing adverse environmental effects, especially CE. Furthermore, there is a substantial correlation between rapid EG and high CE levels, particularly those emanating from NREC [20, 21]. Asia-Pacific nations, which have seen substantial EG in recent decades, frequently have to choose between preserving EG and reducing its harmful environmental effects. A more thorough overview of the Asia-Pacific region's economic dynamics is given in Figure 4, which focuses on EG data from China, Australia, and Indonesia—all of which are major players in the world economy.



	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Indonesia	4.88	5.03	5.07	5.17	5.02	-2.07	3.70	5.31	5.05	3.35
Australia	2.19	2.76	2.28	2.88	2.17	-0.12	2.11	4.24	3.44	2.49
China	7.04	6.85	6.95	6.75	5.95	2.24	8.45	2.95	5.25	3.92

Figure 4.
EG conditions.
Source: World Bank [22].

With a significant drop in 2020 (-2.07%) as a result of the pandemic, a rebound in 2021–2022, and a minor decline in 2024 (3.35%), Figure 4 illustrates Indonesia's erratic growth. With a slight decline in 2020 (-0.12%) and a moderate recovery, Australia maintained its stability, rising to 3.44% in 2023 and 2.49% in 2024. China experienced a sharp dip in 2020 (-2.24%), a robust recovery in 2021 (8.45%), and a slowdown in 2022–2023. Rapid economic growth can exacerbate carbon emissions by increasing non-renewable energy consumption. Australia faces CE challenges due to its reliance on coal, whereas China and Indonesia confront environmental impacts due to their high EG levels in the absence of REC legislation. The adoption of REC should be sustainable economic growth's top priority for SDG 13.

This focus on sustainable economic growth draws attention to the necessity of a more comprehensive approach to resource management and environmental preservation. Growing awareness of rapid EG's negative effects on the environment, especially its role in CE, is consistent with a broader paradigm shift in the management of natural resources. According to Acheampong [23], resource management has undergone a paradigm shift as a result of growing knowledge of how exploitative behavior in the management of natural resources makes people more vulnerable to natural disasters. Economic development was the main goal initially, but since the 1990s, sustainable development has taken precedence. Political and economic studies have started to acknowledge nature politically, highlighting the need for humans and the environment to coexist as a component of the Earth's ecosystem. This change reflects a greater focus on environmental concerns, which are directly related to initiatives for sustainable development.

The revival of local knowledge as a different strategy for managing natural resources is a concrete example of this political recognition. Local wisdom is viewed from a political ecology perspective as a way to explain how people treat nature as a source of diverse economic demands and to achieve harmony between humans and the natural world [24]. Optimism remains vital despite several obstacles that prevent political ecology from fulfilling its potential as a crucial basis for alternative natural resource management and for allowing local knowledge to be integrated into environmental protection strategies. To protect the Earth as a human home for future generations, it is critical to continue advocating for political justice for nature [25].

From the standpoint of political ecology, the state and its governmental machinery play a critical role in determining the character and dynamics of disputes. The state is an active actor in addition to serving as an impartial facilitator and mediator. Given the varying interests of state actors in managing RE resources, the state's role in promoting equity in policy implementation and decision-making is extremely important. However, when these competing interests intensify already existing conflicts, issues arise. The stances of the government, society, and corporate sector are intertwined in this environment [26]. Environmental management is also influenced by larger market interests, even when local communities have been using the environment for many generations. Since the investment concept was introduced, the market for environmental management has grown increasingly noticeable. In this instance, government policies support the market through investor trade and investment [27, 28].

As a result, the importance of SDG 13, which addresses climate change, in relation to climate change becomes more apparent. According to earlier studies, one of the key strategic areas for promoting sustainable development is regional authority in the energy and environmental sectors, particularly in the use of REC. Additionally, this study is novel since it takes a comprehensive approach to evaluating SDG 13 in the Asia-Pacific region, integrating the analysis of REC and NREC with EG as a moderating variable. The Asia-Pacific region's distinct traits, such as its varied EG dynamics and energy consumption structures, are also highlighted in this paper.

2. Literature Review

The distinctions between the environmental impacts of NREC and REC are well-documented in international research on CE. The relationship between EG and environmental quality is frequently analyzed through the Environmental Kuznets Curve (EKC) hypothesis, which posits that in the early stages of economic development, excessive energy consumption—particularly from NREC sources—contributes to rising CE levels [29, 30]. However, as per capita income increases, improved energy efficiency and the adoption of cleaner technologies mitigate these environmental effects, leading to a decline in CE [31, 32]. EKC-based studies suggest that while developing nations often exhibit a positive correlation between EG and CE, more advanced economies that have reached a certain income threshold can successfully reduce CE through the development and implementation of environmentally friendly energy technologies [33, 34].

Several studies indicate that reliance on NREC significantly exacerbates CE, thereby accelerating climate change [35]. Specifically, research findings highlight that in countries where NREC dominates the energy mix, CE levels are substantially higher [36, 37]. This is primarily due to the combustion process of fossil fuels, which releases substantial amounts of greenhouse gases into the atmosphere, leading to long-term adverse climate effects [38]. Conversely, empirical evidence demonstrates a negative correlation between REC and CE, signifying that an increase in REC adoption leads to a reduction in CE. Even in the presence of sustained EG, transitioning to REC can effectively curb CE, as confirmed by numerous empirical investigations. For instance, research by Chen, et al. [39] asserts that nations that actively invest in REC technologies experience a decline in CE despite maintaining high levels of EG. This underscores the potential of REC to mitigate the environmental consequences of EG, which is often linked to increased NREC consumption and higher CE levels.

In addition, recent literature has increasingly explored the role of EG in shaping the relationship between energy consumption and CE. A study by Mardani, et al. [40] found that in developing countries, rapid EG is frequently accompanied by a surge in NREC consumption, thereby exacerbating CE. However, in industrialized nations with well-developed infrastructure and higher per capita income, EG can drive technological innovations that enhance energy efficiency and facilitate a transition to REC, ultimately reducing CE [41]. Research by Raihan, et al. [42] further corroborates this, indicating that countries successfully shifting toward REC experience simultaneous reductions in CE, despite overall increases in energy consumption driven by EG. This highlights the critical role of energy policies in mitigating the environmental impact of EG. Additional research suggests that the presence of stringent energy efficiency regulations and advancements in clean technology can decouple EG from adverse environmental effects, thereby preventing EG from necessarily leading to higher CE.

While extensive research has examined the interconnections between NREC, REC, CE, and EG, there remains a research gap in studies that explicitly incorporate EG as a moderating variable. Given that increased economic activity raises energy demand—particularly for NREC, which contributes to CE—EG plays a crucial role in this dynamic. However, economies with higher levels of development tend to implement cleaner energy solutions and stricter regulatory frameworks, thereby mitigating the impact of REC on CE. This study seeks to contribute to the existing body of knowledge on energy, EG, and CE within the Asia-Pacific region by developing a comprehensive model that integrates EG as a moderating variable to assess progress toward SDG 13.

3. Methodology

3.1. Data and Variable

This research makes use of secondary panel data, which includes cross-sectional data from Indonesia, Australia, and China, as well as time-series data from 2008 to 2024. With Indonesia being the biggest producer in Asia and Australia occupying a key position in the global coal trade, both countries are significant exporters of NREC, especially coal. Coal is the main energy source in both nations, which greatly contributes to CE. China, on the other hand, imports more coal than any other country in the world, and its rapid EG is largely dependent on coal consumption. Though the degree of implementation differs, these three nations also show a commitment to REC, particularly solar energy. This study is extremely pertinent to assessing efforts to meet SDG 13, which focuses on global activities against climate change, given their important contributions to CE in the Asia-Pacific area. In light of this, CE is the dependent variable in this study's variable analysis, whereas NREC and REC are the independent variables. EG is also included as a moderating variable that affects how energy usage and CE are related. The conceptual framework shown in Figure 5 provides a summary of the connections between these factors.

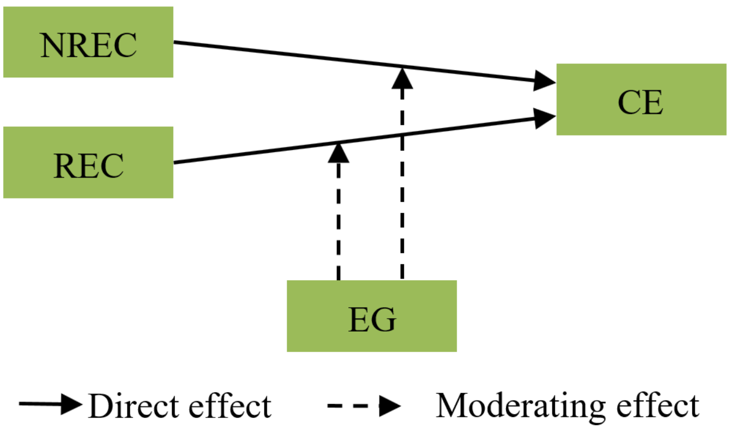


Figure 5.
Conceptual framework of the study.

Table 1 provides thorough descriptions of the indications for each variable based on the data shown in Figure 5.

Table 1.
Information on research variables.

Variable	Explanation
CE	Total CE from energy, measured in million tonnes, are sourced from the BP Statistical Review of World Energy.
NREC	Total annual coal energy consumption, measured in exajoules, is sourced from the BP Statistical Review of World Energy.
REC	Total annual solar energy consumption, measured in exajoules, is sourced from the BP Statistical Review of World Energy.
EG	The annual growth rate of gross domestic product (GDP) based on constant 2015 prices, calculated as a percentage, is sourced from the World Bank.

3.2. Data Analysis Technique

This study uses Moderated Regression Analysis (MRA), a statistical analytic tool focused on analyzing moderation effects. This method is helpful for determining whether a moderator—an additional variable—influences the link between independent and dependent variables. MRA is used in this work to investigate the connection between REC and NREC on CE. Furthermore, EG is examined as a moderating factor that might impact this association. To examine the direct association between NREC and REC on CE without utilizing the moderating variable, EG, Memon, et al. [43] state that the first phase in the MRA analysis process is assessing the main effects. This test provides an early understanding of each independent variable's direct effect on CE. The moderating variable and independent variables are then multiplied to generate an interaction variable. For instance, the interaction variables used in the moderation analysis are created by multiplying NREC and REC by EG. The moderating impact is then assessed by generating a regression model that incorporates the main effects and interaction variables. It can be inferred that EG moderates the link between energy consumption (both NREC and REC) and CE if the interaction variable's coefficient is significant. Finally, to ascertain whether the moderating impact of EG increases (positive) or weakens (negative) the link between the independent factors and CE, the study findings are interpreted in light of the importance of the interaction variables.

3.3. Analysis Model

Equation 1, Equation 2, Equation 3, and Equation 4 provide a sequential summary of the analysis model used to determine if EG functions as a moderator between NREC and REC on CE. The role of EG in regulating the link between

NREC and CE is tested using Equations 1 and 2. Meanwhile, the role of EG in regulating the link between REC and CE is tested using, Equations 3 and 4.

$$CE_{it} = \alpha_0 + \alpha_1 NREC_{it} + \alpha_2 EG_{it} + \varepsilon_{1it} \quad (1)$$
$$CE_{it} = \beta_0 + \beta_1 NREC_{it} + \beta_2 EG_{it} + \beta_3 NREC_{it} EG_{it} + \varepsilon_{2it} \quad (2)$$
$$CE_{it} = \gamma_0 + \gamma_1 REC_{it} + \gamma_2 EG_{it} + \varepsilon_{3it} \quad (3)$$
$$CE_{it} = \delta_0 + \delta_1 REC_{it} + \delta_2 EG_{it} + \delta_3 REC_{it} EG_{it} + \varepsilon_{4it} \quad (4)$$

Explanation:

α_0, β_0, γ_0, δ_0: Regression constants.

α_1, β_1, γ_1, δ_1: Coefficients of the direct effects of NREC and REC on CE.

α_2, β_2, γ_2, δ_2: Coefficients of the direct effect of EG on CE.

β_3, δ_3: Coefficients of moderation demonstrating the impact of EG on the connection between REC and NREC on CE.

i: Cross section.

t: Time series.

ε: Error term reflecting the variation not explained by the model.

The reference for figuring out the moderation impact of EG is based on four different categories, according to the analytical methodology that has been described. First, when EG significantly affects CE and the relationship between EG and REC or NREC is substantial for CE, this is known as quasi-moderation. The second is pure moderation, which occurs when EG has no discernible impact on CE, but when EG and NREC or REC interact to produce a notable impact on CE. Third, when EG is significant for CE, but neither the NREC nor the REC interaction is significant for CE, this is known as predictor moderation. Fourth, homologizer moderation occurs when CE is not significantly impacted by EG or the interaction of NREC or REC.

4. Results

Examining the direction of the coefficient signs and the variables' significance is the main goal of the study. Tables 2, Table 3, Table 4, and Table 5 will provide a summary of the empirical findings in the sequence of the previously described equations. The results of testing Equations 1 and 2 are shown in Tables 2 and 3, while the results of testing based on Equations 3 and 4 are shown in Tables 4 and 5. ** denotes a significant variable at the 5% alpha level, while *** denotes a significant variable at the 1% alpha level. With a focus on both statistical significance and the size of their impacts, this enables a greater comprehension of the relationships between the variables.

Table 2.
Results for equation 1.

Variable	Coefficient	Std. error	t-statistic	Prob.
C	4.295663	0.304796	14.09356	0.0000***
NREC	0.838656	0.021509	38.99171	0.0000***
EG	0.124697	0.030980	4.025136	0.0002***

The results in Table 2 demonstrate that the constant (C), EG, and NREC all significantly affect the model. With a probability of 0.0000, a t-statistic of 14.09356, and a coefficient of 4.295663, C has strong significance. With a probability of 0.0000, a t-statistic of 38.99171, and a coefficient of 0.838656, the NREC variable has a positive and highly significant impact on the dependent variable. Similarly, EG has a strong and positive impact on the dependent variable, as evidenced by its coefficient of 0.124697, t-statistic of 4.025136, and probability of 0.0002. These findings point to a substantial and robust correlation between the model's tested variables.

Table 3.
Results for equation 2.

Variable	Coefficient	Std. error	t-Statistic	Prob.
C	4.699001	0.344320	13.64718	0.0000***
NREC	0.724534	0.055452	13.06602	0.0000***
EG	0.087260	0.034176	2.553231	0.0142**
CC*EG	0.637831	0.287579	2.217933	0.0018***

According to the findings in Table 3, every variable examined significantly affects the model. With a t-statistic of 13.647, a probability of 0.0000, and a coefficient of 4.699, variable C has strong significance. A positive and significant effect is indicated by the coefficient of 0.724 for variable NREC, with a t-statistic of 13.066 and a probability of 0.0000. The EG variable also has a positive and significant influence, with a t-statistic of 2.553, a probability of 0.0142, and a coefficient of 0.087. Lastly, the interaction between CC and EG (CC*EG) shows a positive and significant effect, with a coefficient of 0.637, a t-statistic of 2.218, and a probability of 0.0018. Overall, all examined variables indicate a significant influence.

Table 4.
Results for equation 3.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	8.567619	1.646418	5.203793	0.0000***
REC	-0.128402	0.105376	-1.218504	0.2294
EG	0.129673	0.177476	0.730648	0.4688

The estimated coefficients, standard errors, t-statistics, and probabilities for the variables in the model are displayed in Table 4. With a t-statistic of 5.203793, a highly significant probability of 0.0000, and a coefficient of 8.567619, the variable C is statistically significant. With a probability of 0.2294 and a t-statistic of -1.218504, the variable REC has a coefficient of -0.128402. This implies that there is no statistically significant relationship between REC and the dependent variable. In this model, the variable EG does not have a statistically significant influence, as evidenced by its coefficient of 0.129673, t-statistic of 0.730648, and probability of 0.4688.

Table 5.
Results for equation 4.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	10.04321	1.504832	6.673975	0.0000***
REC	-0.216540	0.131180	-1.650710	0.1059
EG	0.429230	0.175945	2.439568	0.0188**
CC*EG	0.889382	0.239293	3.716707	0.0006***

The impact of the variables on the model is displayed in Table 5. With a probability of 0.0000, a t-statistic of 6.673975, and a coefficient of 10.04321, the C variable has strong significance. With a probability of 0.1059, a t-statistic of -1.650710, and a coefficient of -0.216540, the REC variable does not appear to have a meaningful impact on the dependent variable. With a t-statistic of 2.439568, a probability of 0.0188, and a coefficient of 0.429230, the EG variable clearly has a positive and substantial impact on the dependent variable. Lastly, the coefficient of 0.889382, a t-statistic of 3.716707, and a probability of 0.0006 for the interaction between CC and EG (CC*EG) show that it is statistically significant and has a positive impact on the dependent variable.

5. Discussion

5.1. The Role of EG in Moderating the Relationship between NREC and CE

The research uses two estimating phases based on Tables 2 and 3 to examine the moderating influence of EG in the connection between NREC and CE. To evaluate the individual effects of NREC and EG without considering moderation, the direct influence of these variables on CE is first assessed using Equation 1, which is subsequently expressed as Equation 5. Second, Equation 2, which is recast as Equation 6, is used to evaluate the interaction between NREC and EG on CE. To account for the moderation effect, an interaction variable is included. This method provides a thorough understanding of the direct effects of NREC on CE as well as the moderating role that EG plays in this connection.

$$\mathrm{CE}_{it} = 4.295^{***} + 0.838\ \mathrm{NREC}_{it}{}^{***} + 0.124\ \mathrm{EG}_{it}{}^{***} + \varepsilon_{1it} \tag{5}$$

$$\mathrm{CE}_{it} = 4.699^{***} + 0.724\ \mathrm{NREC}_{it}{}^{***} + 0.087\ \mathrm{EG}_{it}{}^{**} + 0.637\ \mathrm{NREC}_{it}\mathrm{EG}_{it}{}^{***} + \varepsilon_{2it} \tag{6}$$

The positive relationship between NREC and CE is reinforced by Equation 6, which indicates that as EG increases, the influence of NREC on CE also intensifies. These findings align with SDG 13, emphasizing the critical need for transitioning to environmentally friendly energy sources to combat climate change. Without this transition, higher EG may lead to an even greater rise in CE, making SDG 13 more challenging to achieve. Equation 6 identifies EG as a quasi-moderator, directly impacting CE while simultaneously moderating the NREC-CE relationship. Meanwhile, Equation 5 underscores the crucial role of EG, demonstrating how it amplifies the effect of NREC on CE, thereby posing a significant barrier to climate change mitigation.

Coal remains a dominant source of energy, significantly contributing to CE. Indonesia and Australia, as major coal exporters, face challenges from both domestic consumption and global trade impacts. In Indonesia, coal from Kalimantan and Sumatra is vital for steam power plants, balancing export revenues and domestic energy supply but exacerbating CE. As the world's largest coal exporter, Australia extracts coal primarily from Queensland and New South Wales, exporting it to China, which remains heavily reliant on coal for industrial operations and electricity. Despite efforts to increase REC adoption, coal still dominates in China's high-consumption regions, including Shanxi, Inner Mongolia, and Xinjiang, where inadequate infrastructure hinders the transition. The continued dependence on NREC among these three nations directly escalates climate change, presenting a significant challenge to SDG 13 objectives. Studies highlight coal's substantial contribution to CE Saidi and Omri [44], its industrial and energy dominance that intensifies global emissions [45], and the role of Australian coal exports in exacerbating climate challenges [28].

Moreover, EG drives increased transportation, industrial activity, and energy consumption, with NREC—particularly coal—remaining the primary energy source in Indonesia, Australia, and China. As a leading coal exporter, Indonesia has ramped up coal production and exports to sustain industrial and electricity demands, both domestically and internationally, reinforcing reliance on coal despite ongoing REC initiatives, ultimately driving CE higher. Similarly, Australia, despite possessing substantial REC potential, continues to witness increased coal consumption in its industrial and power sectors. Meanwhile, China's rapid economic growth has escalated its energy needs, cementing its status as the world's largest coal importer and deepening its dependence on NREC. This strong positive correlation between economic growth and CE complicates SDG 13's realization, necessitating extensive energy transitions and sustainable development strategies [46, 47].

5.2. The Role of EG in Moderating the Relationship between REC and CE

An analysis based on the given equations is required to examine how EG modifies the relationship between REC and CE. There are two estimating steps involved. First, Equation 3—later recast as Equation 7—is used to estimate the direct effects of REC and EG on CE to evaluate their respective effects independently of moderation. Second, by including their interaction term to determine the moderating effect, Equation 4 which is rewritten as Equation 8, is used to estimate the interaction between REC and EG on CE. This method provides a thorough understanding of how EG alters the direct impact of REC on CE.

$$\mathrm{CE_{it}} = 8.567^{***} - 0.128\ \mathrm{REC_{it}} + 0.129\mathrm{EG_{it}} + \varepsilon_{3\mathrm{it}} \tag{7}$$

$$\mathrm{CE_{it}} = 10.043^{***} - 0.216\ \mathrm{REC_{it}} + 0.429\ \mathrm{EG_{it}}^{**} + 0.889\ \mathrm{REC_{it}EG_{it}}^{***} + \varepsilon_{4\mathrm{it}} \tag{8}$$

Achieving SDG 13, which aims to eliminate CE and promote clean energy, is complicated by the relationship between REC and EG, as demonstrated in Equation 8. While REC has the potential to reduce CE, its effectiveness diminishes in high EG environments, highlighting the intricate dynamics that must be considered in climate mitigation strategies to minimize rebound effects. Equation 8 confirms that EG acts as a pure moderator, influencing the REC-CE relationship solely through interaction. This contrasts with Equation 7, where EG was not significant. Consequently, in rapidly expanding economies, increased REC may coincide with carbon-intensive EG, potentially exacerbating rather than mitigating CE.

Despite its potential, REC's minimal share in the energy mix limits its impact on CE reduction in China, Australia, and Indonesia. In Indonesia, REC expansion remains constrained by high investment costs and inadequate infrastructure, with usage largely confined to isolated regions such as East Nusa Tenggara and Bali. Australia, despite being a global leader in REC adoption—particularly in Queensland and New South Wales—continues to be the world's largest coal exporter due to its reliance on NREC. Similarly, China leads the world in REC production, especially in solar energy, but its heavy dependence on coal significantly curtails REC's effectiveness in reducing CE. As a result, although REC has a negative effect on CE, its impact remains statistically insignificant due to the dominance of NREC. These findings align with studies by Banday and Aneja [48] and Bhat [49], which emphasize REC's limited efficacy due to high costs, infrastructure constraints, and its marginal role in the energy mix.

The relationship between EG and CE in China, Australia, and Indonesia is further shaped by economic policies and mitigation strategies. Government initiatives promoting REC and energy efficiency help counteract CE growth in Indonesia, where EG is primarily driven by the mining and industrial sectors dependent on NREC. In Australia, CE spikes alongside EG expansion; however, stricter regulations and eco-friendly technologies help mitigate these effects. China, despite significant investments in REC, clean technology development, and cap-and-trade programs, still experiences substantial CE due to its large-scale industrial sector. Across all three nations, economic transitions, technological advancements, and climate policies influence the EG-CE relationship. Mitigation measures and a shift toward a low-carbon economy have weakened the positive correlation between EG and CE. Supporting this, Nguyen and Kakinaka [50] confirm that mitigation policies reduce EG's impact on CE, Hanif, et al. [51] highlight REC investments' role in lowering CE intensity, and Alam and Murad [52] underscore the significance of energy efficiency and the transition to REC in curbing CE from NREC sectors.

6. Conclusion

The findings of this study underscore the critical role of transitioning from NREC to REC in achieving SDG 13 targets. By providing empirical insights into the urgency of accelerating REC adoption, this research serves as a valuable reference for policymakers in Asia-Pacific nations. Based on these findings, targeted policy recommendations are proposed to facilitate a more effective and regionally tailored energy transition in China, Australia, and Indonesia, with the overarching goal of reducing CE while ensuring sustainable EG. Collaboration at the regional level—through technology sharing, knowledge exchange, and joint financing—will be essential in driving collective progress toward SDG 13.

To accelerate the transition, each country must adopt strategic REC-based policies aligned with its unique social, economic, and geographic conditions. Indonesia should enhance regulatory frameworks, phase out NREC subsidies, and implement progressive carbon pricing while incentivizing REC adoption through tax breaks and green financing mechanisms. Public-private partnerships should be strengthened to support research and development in clean energy technologies. Additionally, cross-sectoral policies integrating energy, economic, and environmental considerations are crucial to ensuring EG contributes to sustained CE reduction.

Australia, as a leading REC adopter, must further expand investments in solar and wind energy while fostering green infrastructure development and public-private partnerships. Policies aimed at reducing dependence on NREC—such as phasing out coal exports and providing domestic REC incentives—should be prioritized. The advancement of energy-efficient technologies, including energy storage and smart grids, is also imperative. A cross-sectoral approach is necessary to ensure EG facilitates a transition toward a low-carbon economy rather than exacerbating CE.

Meanwhile, China must implement aggressive energy transition policies, including raising REC targets in national development plans and introducing stronger fiscal incentives for wind, solar, and green hydrogen initiatives. Expanding and refining its carbon trading system, along with enforcing stricter emission controls, will be key to mitigating CE. Furthermore, integrating REC into industrial infrastructure through a cross-sectoral strategy is vital to aligning EG with long-term environmental objectives.

While this study provides meaningful insights, certain limitations should be acknowledged. First, the focus on Indonesia, Australia, and China limits the generalizability of findings to other regions with distinct economic structures and energy consumption patterns. Second, although the link between energy consumption and CE has been analyzed, the relatively minor impact of REC on CE suggests potential data constraints or the currently low level of REC adoption in the study area. Lastly, this study does not account for additional moderating factors, such as regulatory frameworks, technological innovations, or consumer behavior, which could influence the relationship between energy transition and CE. Future research should address these gaps by incorporating cross-country datasets, multidisciplinary methodologies, and real-time analysis to provide a more comprehensive understanding of the energy transition's impact on CE.

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