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# Regional Disparities in the Efficacy of Renewable Energy Development for Alleviating Energy Poverty in Indonesia: An In-depth Analysis

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**ABSTRACT**

Existing studies have primarily focused on factors influencing energy poverty (EP), with limited attention given to the specific role of renewable energy advancements (REA). This study addresses this gap by employing a moment quantile regression model to evaluate the energy poverty index system, exploring the impact of REA on EP. Data is sourced from a 30-province panel in Indonesia from 2003 to 2019. The study reveals that REA contributes to alleviating EP, particularly in regions with low climate vulnerability. Both linear and non-linear models indicate that the climate vulnerability index (CVI) moderates this relationship, with REA reducing EP in low CVI regions, but showing the opposite effect under high CVI conditions. This effect is geographically concentrated in western Indonesia, with no significant impact in central and eastern regions. These findings provide valuable insights for strategies aimed at reducing energy poverty and promoting sustainable energy growth.

**Keywords:** Renewable Energy, Energy Poverty, Climate Vulnerability, Indonesia
**JEL Classifications:** P18; P22; P23

## 1. INTRODUCTION

Energy is a crucial component of economic and social progress. The growth and investigation of renewables to substitute non-renewable power, which has been too much, has recently become the prevalent advancement orientation of government in asset utilization due to the global energy crisis and the rising focus of numerous nations on pollution prevention. The change of resource Infrastructure is speeding up due to carbon pollution Industrial Growth (IND Growth). As there is growing agreement on the need for global action on environmental warming and low-carbon energy, increasing numbers of nations are proactively proposing laws and initiatives to encourage the growth of the renewables IND Growth, which has promising futures. World resource consumption has decreased generally as a result of the (COVID-19) epidemic; according to the International Energy Agency (2020), green energy production and use are more resistant. Around 80% of the growth in the world's power consumption is expected to come from renewable power sources between 2020 and 2030 (Lazaroiu et al., 2020).

The absence of contemporary, high-quality, pure, and eco-friendly power is called power deprivation. Power deprivation is a significant obstacle to achieving equal accessibility to power and is now a global issue for household energy usage (Bienvenido-Huertas et al., 2020; Zhao et al., 2021; Wirawan and Gultom, 2021). There is already more than one billion IND Growth without access to reliable, primary power, and this number is expected to rise by 2030 (Hills, 2011). For instance, about 44.5 million IND Growth in the Eu; 2-14% of homes in Australia; and 14% of homes in the US got an energy outage warning from their energy providers in 2015 because almost one-third of families were not able to pay their power bills (Fathoni et al., 2021; Setyowati, 2021; Bienvenido-Huertas et al., 2020). According to Zhao et al. (2021) and Li et al. (2021) the Association of Southeast Asian Nations (ASEAN) part, for dining and warming, over 16 billion people heavily rely on conventional biomass fuelwood, carbon, crop residues, and animal wastes.Excessive reliance on cellulosic biofuels is referred to as resource deprivation that presents two issues: (1) Interior environmental contamination and severe impairment to people's well-being are caused by combusting resources, which release nitrogen and sulfur oxides, inhalable particles, and particulate matter. (2) gathering conventional energy sources takes a long time. Women and kids often perform this task, which restricts women's ability to engage in other human services and causes a loss of time that kids could be engaging in academic endeavors (Purnama, 2024; Setyowati, 2020; Ciupăgeanu et al., 2017; Wang and Zhan, 2019; Liu et al., 2015). Power deprivation has drawn much interest from the global population since it is intimately related to IND Growth wellness and social progress.

There is currently little research on how to address the energy Crisis from a technical standpoint, especially when it comes to green innovations, but it studies numerous approaches to do so from the perspectives of family economic class and energy Strategy (Dong et al., 2021; Habiba et al., 2022). Technology in green energies innovation (here in after referred to as renewable energy and access initiative (REAI) can raise the availability of renewables, lower the cost of producing renewables, and improve family accessibility to energy, all of which could help to alleviate energy Crisis (Meng et al., 2022; Robinson and Mattioli, 2020). To supplement this theoretical background, this study investigates the effect of renewable energy and access initiative (REAI) on energy poverty. Energy insecurity is a problem that affects people all around the world. This study utilizes Indonesia as the work subject to increase the research IND Growth applicability and representativeness. The development of sustainable power has emerged as a critical concern since Indonesia is the globe's most significant generator of co two and has profound environmental and sustainability issues. Indonesiahas the highest demographic and energy consumption, yet it also has the lowest energy stores. Chinese families are more prone to utilize fuel oil due to inadequate power generation (Hosan et al., 2024; Wang et al., 2015). There is much practical usefulness in assessing Indonesia's energy Crisis and looking for solutions. While Indonesia's low revenue has significantly decreased in earlier decades, prior research shows that power deprivation continues to be a significant barrier to economic progress (Agyekum, 2020; Barnes et al., 2011; Aneslagon et al., 2024).

Additionally, since Indonesia's liberalization, its economic system has proliferated, creating an ideal setting for the research and experimental development (R&D) and conversion of power Technology (Churchill et al., 2020; Halkos and Gkampoura, 2021; Churchill and Smyth, 2020). Does the economic liberalization (hereinafter referred to as machine learning (ML) in this situation affect how renewable energy and access initiative (REAI) affects the energy Crisis? There is still no clear answer to this query. Therefore, this research utilized pertinent information from the CFPS on 8939 families from 25 Districts. First, we assess Indonesia's home power deprivation, considering family financial status, power usage, and pricing. Secondly, a two-way variable factors model is used to investigate how machine learning (ML) alters the impact of renewable energy and access initiative (REAI) on reducing family power deprivation. To account for the varied impacts of REAI on domestic power deprivation across various machine learning system (MLs), the partly linear functional-coefficient (PLFC) model is used. Our scholarly efforts are four times more than those of the current research. To accurately identify energy Cases, the current approach for detecting micro-level suffering is first enhanced. Both power usability and power cost are considered, and family financial level is differentiated to prevent high families from being mistakenly labeled as resource-poor. Secondly, the alleviating impact of REAI on home power deprivation is comprehensively analyzed for the initial time from the standpoint of ML, considerably enhancing the theories of REAI's alleviating of domestic power deprivation. Thirdly, the IND Growth are rational and scholarly because they account entirely for the innovation transmission and devaluation impacts of copyrights, in contrast to prior studies that used patent awards to quantify technical development (Song et al., 2023; Hills, 2011; Ahmad et al., 2019; Beddu et al., 2024).

Fourth, the partly linear functional-coefficient (PLFC) model is used to encapsulate the sequential and geographic homogeneity of the minimization impact of REAI on domestic power deprivation, in contrast to the ordinary impact acquired in the current writings utilizing data analysis prediction model, such as Ordinary Least Square (OLS), IND Growth a new strategy for upcoming studies on this topic.

This study makes several key contributions to the existing literature on energy poverty and renewable energy. First, it is one of the few studies to examine the regional disparities in the efficacy of renewable energy development in addressing energy poverty, particularly in a country like Indonesia, which has diverse geographical and socioeconomic conditions. Second, the inclusion of climate vulnerability as a moderating factor provides a novel perspective on how environmental conditions affect the success of renewable energy initiatives. Lastly, this research utilizes a mixed-method approach, combining both linear and non-linear regression models, which adds depth to the analysis and enhances the robustness of the findings. The results of this study offer valuable insights for policymakers aiming to develop region-specific strategies to promote sustainable energy and reduce energy poverty. Moreover, the primary objective of this study is to investigate the role of renewable energy advancements (REA) in alleviating energy poverty (EP) in Indonesia, with a specific focus on regional disparities. The study aims to analyze how renewable energy innovations, such as technological advancements in sustainable energy, influence energy accessibility and affordability across various regions in Indonesia. This research also seeks to explore the moderating role of environmental and socioeconomic factors, such as climate vulnerability and industrial growth, in the relationship between REA and EP.

## 2. LITERATURE REVIEW

There has been a lot of work done in the research to comprehend the variables that contribute to power deprivation, like institutional and budgetary circumstances, educational attainment and other societal variables, but little focus has been placed on the role of renewables financial markets, especially from At the time of writing, many nations' major power objectives include implementing power transition and producing renewables, which are driven by sustainability and environmental safety concerns (Kumar et al., 2022; Nussbaumer et al., 2012; Marianti et al., 2023; Henry et al., 2021; Wang and Lee, 2022; Practical Action, 2010; Castaño-Rosa and Okushima, 2017). According to Owusu-Nantwi and Owusu-Nantwi (2021) Development in sustainable power technologies has a big influence on bettering power framework, power efficiency, and pollution control. In order to enhance the production level in the renewables IND Growth discover that a rising renewable energy advancements (REA) development level IND growth is using an increasing proportion of study and production expenditures compared to conventional power technologies. Indonesia's REA development intensity and quantity of patentability have both climbed significantly in previous decades. Both have evolved into essential competencies that make it possible for Indonesia to achieve its significant national global warming obligations. These IND growths provide encouraging chances for additional research into how REA development relates to Indonesia's power deprivation.

There is a growing understanding of the significance of disaster hazard as it pertains to the operations of the power markets while researching the growth of renewables, EP, and their relationship. According to Hidayat et al. (2023) and Moran et al. (2018), environmental change not only IND Growth REA development yet also raises the expense of ecological preservation and power safety (Yrigoy, 2018; Zubi et al., 2019; Okushima, 2017; Robinson et al., 2018). For instance, since REA is not developed because of the presence of climate change effects, the limited innovation faces significant unpredictability (Jiang et al., 2020). It will allow the concerned ministry to cut back on REA spending and raise questions about its dependability. For instance, due to worries about catastrophic disasters, illegal dumping, and global warming, nuclear initiatives have halted or been discontinued in numerous nations throughout the globe.

Considering that there may be several ways for REA development to influence EP, including environmental change effects, the relationship between REA innovation and EP may change depending on the environmental change effects. On the one hand, the influence of environmental change effects on REA development and EP is minimal when the danger is minor (such as tiny cyclones, warmer temperatures, and other climatic calamities). With REA technology, like IND Growth generators and wave power, these areas may still optimize the local power sector and increase efficiency, which will help to promote resource efficiency, decrease pollution, and lessen EP. On the other side, the effect of unfavorable weather and environmental disasters increases while environmental hazard is rather large. (e.g., volcanoes, tropical thunders, and tidal waves) will worsen EP while also impeding REA development. For instance, the Fukushima nuclear energy facility in Japan detonated because it was unable to withstand the effects of climatic threats like devastating tidal waves. Catastrophes like these not only squander a significant lot of energy responding to nuclear mishaps, but they also work against the advancement of renewable power and the reduction of EP. As a result, the effect of REA development on EP differs based on the level of climate change effects.

Three main energy-related issues now facing the globe are power deprivation, power generation stability, and global warming (Ciupăgeanu et al., 2019; Bhide, & Monroy, 2011). Among these, researchers pay somewhat less emphasis to power deprivation than to global warming and the safety of power generation. Bangladesh, IND Growth, the United States, Spain, Japan, Indonesia, the Philippines, and Europe make up most of the study samples used by academics to date on power deprivation (Purba et al., 2023; Wang et al., 2021; Böhringer et al., 2017; Chan and Delina, 2023; Fan et al., 2019; Chen and Lei, 2018; Nguyen and Nasir, 2021; Boardman, 2012; Boardman, 1991; Robinson and Mattioli, 2020). In light of the aforementioned debate, we discover that researchers are more concerned about the issue of power deprivation in emerging nations than in IND Growth serialized ones. We next move on to quickly evaluate the pertinent papers on how to quantify power deprivation. The study's first emphasis is mostly on the one IND Growth or assessment of power deprivation that captures some facets of the problem. For example, it has been established that people are deemed to be living in power deprivation if their power costs are greater than 10percent of their family's total income (Du et al., 2019).

The accessibility of renewable power, the standard of power generation, and contentment with the need for power for IND Growth individual existence and growth are other metrics used to determine the level of fuel poverty (Liu et al., 2015; Sadath and Acharya, 2017; Widyastuti et al., 2023). Nevertheless, power poverty is a multifaceted problem that is extremely difficult to understand. As a result, a growing number of academics are inclined to consider fuel poverty from a broad angle. Assessing energy poverty in the European Union (EU) specifically requires the use of three used in energy bill delays, the cost of keeping a house warm enough and the existence of leaky roofs, wet walls, or deteriorating glass. The multimodal power deprivation score, which examines customer scarcity of contemporary power generation, is a regularly used measure for assessing power deprivation (Raihan et al., 2023). Based on this, Böhringer et al. (2017) offer a comparable definition of fuel poverty that is appropriate for IND Growth unsterilized nations and consists of three characteristics (i.e., Power generation, power revenue, and power usage). This metric is also used to assess fuel poverty in Japan, and a research IND Growth indicated that it had been progressively becoming worse. Utilize a range of metrics to assess fuel poverty in addition. They note that various power deprivation IND Growth correspond to varying ratios of fuel poverty, that is substantiated (Yrigoy, 2018; Acharya & Sadath, 2019).

According to Robinson and Mattioli (2020) Researchers frequently evaluate the fundamental socioeconomic effects of power deprivation after accurately quantifying it. According to the literature described before, power deprivation is directly correlated with both business and the ecosystem; in other words, as power deprivation worsens, financial advantages and societal value will be steadily diminished. Therefore, it is essential to quicken the decline of fuel poverty. Accelerating the transition from conventional fossil fuels to clean renewables is essential for addressing fuel poverty (Zhao et al., 2022). Further crucially, the company's quick growth, particularly the more sustainable power system, may help reduce inhabitants' reliance on conventional elevated energy and hasten the achievement of co pollution reductions objectives (Ciupăgeanu et al., 2019; Robinson and Mattioli, 2020; Ciupăgeanu et al., 2017; Bienvenido-Huertas et al., 2020).

### 2.1. Theoretical Framework

This study is grounded in several key theories that support the relationship between renewable energy advancements (REA) and energy poverty (EP), particularly within the context of Indonesia. The theoretical foundations that underpin this research include the Resource-Based Theory, Innovation Diffusion Theory, and Energy Ladder Theory, each offering a unique perspective on how renewable energy innovations impact energy poverty.

The Resource-Based Theory (RBT) emphasizes the critical role of resource development and allocation in achieving sustainable growth and reducing energy poverty. In this context, renewable energy is seen as a valuable resource that, when properly harnessed, can alleviate energy poverty by increasing access to affordable and reliable energy. This aligns with the notion that renewable energy infrastructure plays a pivotal role in optimizing the use of natural resources to promote economic and social progress. Previous studies have shown that countries focusing on renewable energy development have seen significant improvements in energy access and a reduction in energy poverty (Sadath and Acharya, 2017). In Indonesia, where energy poverty remains a pressing issue, the application of RBT underscores the importance of leveraging renewable resources to address energy inequality and enhance overall development (Owusu-Nantwi and Owusu-Nantwi, 2023). The Innovation Diffusion Theory (IDT), introduced by Rogers (1962), provides a framework for understanding how new technologies, including renewable energy technologies (RET), are adopted and spread across different regions. This theory is particularly relevant in examining how the diffusion of renewable energy innovations can contribute to reducing energy poverty. IDT suggests that technological advancements in energy systems, such as solar and wind power, can make a significant impact when they are widely adopted and integrated into energy infrastructure. The adoption and diffusion of these technologies in Indonesia, however, are shaped by regional disparities, government policies, and infrastructural limitations (Fan et al., 2019; González-Eguino, 2015). Studies have shown that regions with more robust support for renewable energy innovation tend to see greater reductions in energy poverty as these technologies become more accessible (Moran et al., 2018; Pesaran, 2004).

The Energy Ladder Theory (ELT) offers a different lens through which to view the relationship between energy poverty and renewable energy advancements. This theory posits that as household income and living standards rise, families transition from traditional, inefficient energy sources—such as biomass and firewood—to more modern, cleaner energy sources, like electricity. Renewable energy innovations play a crucial role in facilitating this transition, enabling households to move up the "energy ladder" and access more reliable and environmentally friendly energy sources (Barnes et al., 2011). In Indonesia, where many rural households still rely on biomass for their energy needs, the expansion of renewable energy technologies offers an opportunity to significantly reduce energy poverty by promoting access to modern, efficient energy solutions (Wang and Zhan, 2019; Teräväinen et al., 2011). Empirical evidence from various studies supports these theoretical perspectives. For instance, research by Liu et al. (2015) and Widyastuti et al. (2023) aligns with the Resource-Based Theory by demonstrating how renewable energy development contributes to alleviating energy poverty in regions with limited access to conventional energy. Similarly, the Innovation Diffusion Theory is validated by Robinson and Mattioli (2020), who highlight the role of technology diffusion in promoting the adoption of renewable energy technologies in emerging economies, including Indonesia. Furthermore, Aristondo and Onaindia (2018) provide evidence for the Energy Ladder Theory, showing how solar PV initiatives have enabled households to transition from traditional energy sources to modern electricity, improving living conditions and reducing energy poverty.

## 3. RESEARCH METHODOLOGY

The report initially suggests the accompanying model approach in accordance with the prevalent norm in earlier works on EP as represent in equation 1.

$$EP_{i,t} = \varphi_i + \beta_1 RET_{i,t} + \sum_{k=2}^{5} \beta_k X_{k,t} + \tau_i + v_t + \varepsilon_{i,t} \quad (1)$$

While I stand for the region, and "t" stands for the time f"a"e (i = 1 ⋯, 30; t = 2003 ⋯, 2019). Power deprivation is represented by the predictor variables EP, t. The key predictive factor, referred to as REA, stands for REA innovation as represented by renewables patents. A variety of covariates, comprising technical innovation, IND Growth added value (IND GROWTH), IND Growth optimization forward strategy for resource (FSTR), degree of E-OPENESS (E-OPEN), and financial development rate, are represented by the phrase Xk, t. gross domestic product (GDP). The error term is represented by *i*, while *vt* reflects the time-fixed effect. Lastly, I represent the region's fixed effect. The study claims that REA development has an influence on EP under environmental hazards, in addition to influencing power sustainability (Neyman & Scott, 1948). We employ the interactions term among REA Technology and the environment hazard IND Growth climate vulnerability index (CVI) to demonstrate the mitigating influence of environmental hazard among REA technology and EP in order to test the aforementioned assumption we have the equation 2:

$$EP_{i,t} = \varphi_i + \beta_1 RET_{i,t} + \sum_{k=2}^{5} \beta_k X_{k,t} + \beta_6 RET_{i,t} \times CRI_{i,t} + \tau_i + v_t + \varepsilon_{i,t} \quad (2)$$

In a linear model, the median impact of the affecting variables on the explanatory factors is performed using the conventional ordinary least squares (OLS) method. Various consequences of the dependent variable as a whole are not taken into consideration. As a reason, the related empirical IND Growth can be too high or too low for the genuine correlations of deciles, or they might even be unable to establish a link among the factors. The Multivariate Mixed Quantile Regression (MMQR) model is thus used in the research to investigate how REA development impacts EP under various EP patterns. Eq. (2) analyzes the mediating impact of environmental hazard among REA development and EP, and Eq. (1) can help to show if a region's REA development actually affects EP. These calculations, meanwhile, are unable to determine if these effects change depending on the degree of environmental hazard. Since it could suggest various growth plans for cities and nations with various EP levels, scientists are still curious about the whole range of the regress IND Growth. This led to the creation of the MMQR technique; the standard prediction model is significantly optimized, and all variables with EP-dependent distributions are produced. By doing this, we are able to understand the whole impact of REA development on the spread of EP globally. According to Wang et al. (2015), this approach is resilient to deviation, homoscedasticity, and extremism. Thus, the fundamental model is representeding in equation 3 as follows:

$$R_{y_t}\left(\omega|x_t\right)=\varphi_\omega+x_t^T\gamma_\omega \tag{3}$$

We observed that 0 < ω < 1, in which Ryt (ω|xt) displays the ωth conditional quantile in yt, xt stands for all impacting elements together., and γω and ϕω are parameters in the $\omega^{th}$ percentile and undetached activity, accordingly. By using a quantile analysis in the conventional ordinary least squares (OLS) model, the effect of IND growth pendent factors on the situational allocation of reliant factors is frequently presented. Here, γω is an actual function of the dependent variables at *th* quantiles of the situational allocation. In comparison, the relative impact of IND Growth pendent variables exhibits location shift, IND Growth that the average effect is mirrored over the whole range of the explanatory factor (Ciupăgeanu and Lăzăroiu, 2018).

The key benefits of panel data over time series data are the fair correction of information and the decrease of noises brought on by the regressive impact of an individual temporal sequence (Du et al., 2019). As a result, Eq. (4) in quintiles regressions of board information is optimized in this study:

$$R_{y_{it}}\left(\omega|\varphi_i,x_{it}\right)=x_{it}^{'}\gamma_\omega+\varphi_i \tag{4}$$

However, the endogeneity issue has not been addressed in the aforementioned model, and the majority of the research only takes into account the geographical transfer of people and ignores the conditional distribution of dependent variables as a whole. The MMQR technique was developed to address these issues since it can effectively address the endogeneity issue and completely assess each IND Growth individual fixed effect in the model (Sadath and Acharya, 2017). According to the methodology of Obeng et al. (2008), We suggest the below equation 5:

$$y_{it}=\varphi_i+x_{it}^{'}\gamma+\theta\left(\sigma_i+W_{it}^{'}\tau\right)B_{it} \tag{5}$$

Here, Wit′/Wit denotes the distinctive modification of $x_{it}$; θ (•) presents the *C2* role like P(θ(σi + Wit′ τ) > 0) = 1; and Uit represents an arbitrary unobserved factor, in that E(B) = 0 and E(|B|) = 1. Upon Eq. (6), the preceding eq. is gained:

$$R_{y_{it}}\left(\omega|x_{it}\right)=\varphi_i+x_{it}^{'}\gamma+\theta\left(\sigma_i+W_{it}^{'}\tau\right)r\left(\omega\right) \tag{6}$$

Here, r(ω) = FW − 1 (ω), P(W < q(ω)) = ω, and Wit = xit, where θ(•) denotes the recognizing role. So, Eq. (7) could be presented as:

$$R_{y_{it}}\left(\omega|x_{it}\right)=\left(\varphi_i+\sigma_i r\left(\omega\right)\right)+x_{it}^{'}\gamma+x_{it}^{'}\tau r\left(\omega\right) \tag{7}$$

Where ϕi (ω) = ϕi + σir (ω) denotes the FE of town *i* at ω*th* quintiles. In conclusion, the framework enables the allocation of yet (the EP degree throughout this paper) in regions to be Strongly affected by IND Growthividual attributes that are time-invariant. The ordinary effect of $X_{it}$, k factor on yit at ωth quintile. So, Eq. (8) could be presented as:

$$\gamma_k+r\left(\omega\right)\times\rho\theta\left(\sigma_i+W_{it}^{'}\tau\right)/\rho x_{it,k} \tag{8}$$

This model's fundamental flaw is the way the fixed effect transforms extra factors, which causes the regression analysis to diverge (Zhao et al., 2022a). Additionally, Wang et al. (2017) contend that even though the panel data model only contains a finite number of cross-sections at any given moment, the total value of a unit is unlimited. Considering the aforementioned, we employ Sequential Estimating Method to the Moments Quintiles Approach.

### 3.1. Data Description

We created a balanced panel dataset for Indonesia's Thirty regions and cities from 2003 to 2019 in order to take data accessibility into account. Due to conflicting statistical Criteria and a high number of measurement errors, Tibet was excluded from our sample. The data of several EP IND Growth cations, such as gas penetration statistics and methane emission markers, which are only accessible after 2003, constrain the start date of our sample. Additionally, this paper chooses the study period of 2003-2019 since the primary explanation factor —REA invention—is unavailable after 2019, which may have a negative impact on this study. There are 512 samples in the whole sample size. The Chinese Scientific and Technological Statistic Yearbook (SYB), the Chinese Power SYB, the Chinese SYB, the Indonesia Economic SYB, the Indonesia Economic SYB, the Chinese Nationwide Climatic Centers, the Chinese Ecological SYB, and the Chinese Meteorologic Management were all used as the references for the report's data. Table A1 provides a summary of all pertinent data on variable definitions and the accompanying standard deviations.

### 3.2. Dependent Variable: Energy Poverty

EP refers to the accessibility of power generation as well as the dearth of good accessibility to and secure usage of power for human preservation and growth, particularly reasonably priced, adequate, environmentally friendly, and high energy. It also refers to financial growth and the advancement of time. A thorough monitoring of EP IND Growth is necessary in order to effectively reduce EP and thoroughly examine the effect of REA Technology

EP. There is no standardized method for estimating the EP IND growth, nevertheless, because its significance varies depending on the local market situation and growth level. Therefore, this research offers an IND growth method to quantify EP while taking into account the power stability and EP growth level in Indonesia's regions.

We focus on the preceding four aspects of EP in Chinese regions: resident pollution and accessibility (RPA), humanist capitals (HC), green cleansing (GC), and service access. We do this by referring to previous real-world applications of the resource growth IND Growth system developed by Habiba et al. (2022) and Wang and Zhan (2019), and the International Energy Agency (IEA) Scenarios and Analysis (SA). Thus, there are four basic factors, eight subsidiary markers, and seventeen subordinate markers in the EP assessment IND growth system as a whole. The National Statistical Yearbook of Indonesia served as the primary source of information for all of these measures. Table A2 provides a thorough explanation of each of these metrics. Figure 1 provides a clearer and more complete view of the developments in EP in the previous 17 years as well as the disparities in EP between areas by displaying the spatial patterns of Indonesia's EP status in 2004, 2010, 2016, and 2022.

Electricity generation (EL) and the pattern of consumed renewables of european commission (EC) are two additional single variables that are often utilized in the research as metrics of EP for authenticity testing. While the latter is approximated by the ratio of power usage to total power usage, the other is determined by the percentage of power generation used by Gross domestic product (GDP) (measured in units of 100 million yuan/100 million kWh) (Ciupăgeanu et al., 2019).

## 3.3. Major Explaining Factors: RE Technological Innovations

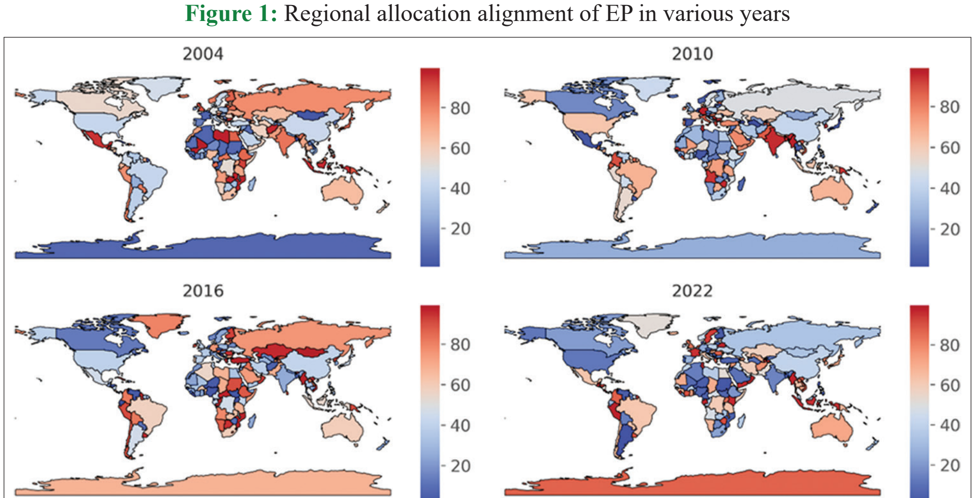
$$RET_{it} = \sum_{k=0}^{t} REP_{ik} e^{\left[-\sigma_1(t-k)\right]} \bullet \left\{1 - e^{\left[-\sigma_2(t-k)\right]}\right\} \quad (9)$$

According to Aristondo and Onaindia (2018) The number of approved renewables patents expressed here by renewable energy portfolio REP is derived from Indonesia's patent Retrieving'and processing systems as shown in equation 9. The degradation rate one and the rate of technological dissemination two are chosen at 0.36 and 0.3, correspondingly, based on criteria. The system has a huge number of power statistics and includes power patent data in 103 nations, organizations, and areas. It also offers easy, quick, rich, and quick analytical techniques and retrieving services for green energy. Its user-friendly interface features and services are also a great aid for research and study on the subject of power. Among the green technologies in the system, ocean power, IND Growth turbines, hydroelectric power, photovoltaics, geothermal heat, and power storage are all included. We apply the same measuring approach to build two alternative IND Growth to see if the results are responsive to different measurements of inventive REAs via separate aspects of renewables. First, hydroelectric contributes significantly to the growth of sustainable power and enhances the power system (Bienvenido-Huertas et al., 2020). We also reevaluate renewable energy advancements (REA) to represent the significance of alternative renewable energies more accurately in the growth of green energy. According to Barnes et al. (2011) Without hydropower's assistance, innovate, and note this new signal as REA H. Second, we further modify the measuring system of REA Technology using only photovoltaic and Growth power and record this introducing new as photovoltaic and growth innovation because photovoltaic and growth energies are acknowledged as significant renewables parts and have a good possibility for developing renewables system reliability index (SRI).

## 3.4. Arbitrating Factors and Other Control Factors

We examine the relationship between REA development and EP using climate risk Growth (CVI) as the moderator factor in the study of the mechanisms. Indonesia is experiencing escalating environmental threats because of environmental change (Agyekum, 2020). The Chinese authorities have also been working to create numerical markers that may be used to assess environmental hazards brought on by unfavorable climates and severe climates. This growth, which is published by Indonesia's National Climate Center, includes six different factors: likely to flood, droughts, storms, intense heat, cold temperatures, and cold. It also includes a composite climate risk growth that is rated from low (low) to high (high) (10). The danger associated

**Figure 1:** Regional allocation alignment of EP in various years



with environmental change increases with value. Other elements impacting environmental threats also occur in Indonesia because of the effect of the typhoon and the significant seasonal variations in weather. For example, in Indonesia, floods brought on by warm altitudes, tropical storms, and rainfall are the main variables that affect the environmental threats in the first 6 months, whereas cold temperature and dryness are the main factors that affect the environmental threats in the second half of the year. The climatic hazard in Indonesia is low in the winters than it is in the summers because of the climatological differences. According to a statistical review of the 10 years' worth of climatic catastrophes in Indonesia, the months of September to June have a much-increased climatic hazard compared to the other months.

We incorporate a variety of controlled factors that Strengthen the validity of our empirical growth things by drawing on prior studies (Wang et al., 2021). For instance, Meng et al. (2022) propose that the level of market liberalization (divided by the total quantity of exports and imports) and Technology advancements, as growth by the number of patents, have a positive impact on the environment. Cumulative energy power generation, i.e., that market inclusiveness and technical invention, are key factors in ensuring access to energy and environmental sustainability. Based on this, our article incorporates the market E-OPEN and innovation and Technology levels (TA) into our regression model. In a similar vein, we also include the economic processes, evaluated by the production of additional value, and the enhancement and updating of growth determined by the ratio of the secondary sector, into the model, pursuing the study of Liu et al. (2015) and Nussbaumer et al. (2012). Additionally, integrate per capita income into the model since they think that growth has a significant influence on the pattern of power use. In keeping with this, we utilize per capita income to account for the degree of IND Growth progress (Böhringer et al., 2017).

## 4. EMPIRICAL ANALYSIS

It is helpful to do a few basic analyses of the study data before examining the impact of REA development on EP. Table A3's results for the variation inflating factor (VIF) and the correlations among the factors reveal that there is no cointegration among the factors and that the correlations are not very high. Second, Table A4 displays the unit root results for each variable from, Limited Liability Company (LLC) and Integrated Power Supply (IPS) (Yrigoy, 2018; Practical Action, 2010). The quantitative results are discovered to regularly demonstrate that the factors rejected the null hypothesis, suggesting typical steady factors. As a result, we draw the conclusion that the report's factors are reliable and meet several checks; as a result, they may be employed in the Growth study that follows.

### 4.1. Standard Linear Regressive Framework

After confirming the safety of the study IND Growth and factors, we use standard OLS techniques, as shown in Eq, to examine the general impact of REA development on EP (1). The model Growth that is shown in Column (1) of Table 1 shows that REA development has a noticeably detrimental effect on EP and is statically important at the 1% level, supporting Hypothesis 1. The REA's ongoing development has allowed Indonesia's renewables sector to grow and become a significant, organized development Growth (Tang and Liao, 2014). In addition to increasing power generation, REA Technology may ensure the development of renewable energy (Wang et al., 2017). One benefit is that it boosts the production of electricity from sustainable sources; the second is that it lowers the cost of electricity generation, somewhat easing EP. Additionally, through enhancing the growth base, the growth of REA may guarantee the growth of renewable power (Robinson and Mattioli, 2020). It also effectively addresses issues related to energy, ecology, and Growth viability, which are all crucial for enhancing power frameworks and lowering EP. The finite element (FE) measurement outcomes in the standard regressive framework shown in Table 1.

The use of big data, geographical data models, microgrids, and cloud technology in the green sector, as mentioned by Habiba et al. (2022), may increase digitalization levels while also boosting energy consumption, fostering energy supplies, and sustaining growth. Additionally, REA technology may promote financial development by generating sustainable employment and promoting the usage of lower-carbon or carbon-free power. This increases co-output, which further increases power efficiency and lowers EP (Wang and Zhan, 2019). The standard regression's primary random variables, renewable energy advancements and analysis (REAA), are then switched out for renewable energy advancements and analysis - hybrid (REAA-H) and system reliability index (SRI) to perform the resilience test. As was already established, SRI exclusively considers photovoltaic and IND growth power, whereas REAA-H measures REAA without the addition of hydroelectric. Columns (2) and (3) of Table 1 show the results. The outcomes are comparable to the exogenous variables REAA, and the linear outcomes are Technically meaningful at the 1percent level. This shows that regardless of the factors that are taken into consideration, REAA development continues to have a detrimental impact on EP. The IND Growth shows that REAA invention significantly reduces EP. The outcomes for additional factors are consistent with the previous logistic analysis's industrial growth or industrial development group (INDG). In conclusion, the benchmark model's extrapolation results hold up well against a variety of innovative REAA metrics.

### 4.2. The Transmissive Sources of REA Invention and EP

We next add the interactions variable renewable energy assessment and climate variability index (REACVI), as shown in Eq. 1, to investigate if and how climate risk influences the link between REA technology and EP (2). The likely outcome is shown in Column (4) of Table 1. The data shows that the predictor value of REACVI is considerably favorable at a statistical relevance value of 1%, but the value of REA stays negative at that level, INDG that climatic hazard reduces the mitigating impact of REA on EP. This conclusion, which is nearly like Hypothesis 3, demonstrates that climatic hazard is a transmitting pathway for REA to impact EP. The results demonstrate that involved parties cannot build REA and IND Growth without taking the effects of environmental change into account since this will only raise EP and be harmful to ecological growth and electricity stability. The best mix of low-carbon technological development is highly unpredictable when

**Table 1: The FE measurement outcomes in the standard regressive framework**

| Variable | −1 | −2 | −3 | −4 | −5 | −6 |
|---|---|---|---|---|---|---|
| REA | −0.0052*** | | | −0.0093*** | | |
| | (−2.97) | | | (−4.48) | | |
| TA | 0.0057*** | 0.0057*** | 0.0058*** | 0.0064*** | 0.0064*** | 0.0065*** |
| | (−6.43) | (−6.42) | (−6.63) | (−7.29) | (−7.28) | (−7.44) |
| Growth | 0.0119 | 0.0119 | 0.0101 | 0.0043 | 0.0042 | 0.0017 |
| | (−0.94) | (−0.94) | (−0.82) | (−0.35) | (−0.34) | (−0.14) |
| SR | −0.3219*** | −0.3220*** | −0.3176*** | −0.3301*** | −0.3303*** | −0.3292*** |
| | (−3.06) | (−3.07) | (−3.03) | (−3.15) | (−3.15) | (−3.14) |
| EE-OPEN | −0.0005 | −0.0005 | −0.0006 | 0.002 | 0.002 | 0.0018 |
| | (−0.05) | (−0.06) | (−0.07) | (−0.23) | (−0.23) | (−0.21) |
| GDP | −0.0161*** | −0.0161*** | −0.0156*** | −0.0163*** | −0.0163*** | −0.0159*** |
| | (−4.58) | (−4.58) | (−4.48) | (−4.90) | (−4.91) | (−4.78) |
| REA-H | | −0.0052*** | | | −0.0093*** | |
| | | (−2.96) | | | (−4.48) | |
| SRI | | | −0.0067*** | | | −0.0111*** |
| | | | (−3.65) | | | (−5.34) |
| REA×CVI | | | | 0.0013*** | | |
| | | | | (−3.16) | | |
| REA-H×CVI | | | | | 0.0013*** | |
| | | | | | (−3.16) | |
| SRI×CVI | | | | | | 0.0016*** |
| | | | | | | (−3.23) |

REA is in its infancy owing to climatic hazards, which will cause key agencies to restrict investments in REA and raise concerns about its dependability (Thomson and Snell, 2013). For instance, because of worries about fatal failures, waste management, and global warming, nuclear programs in several nations throughout the globe have stagnated or even been discontinued (Ciupăgeanu et al., 2019). REA growth in Japan is a concern that needs to be considered, particularly in previous years. Due to the comparatively high following danger, catastrophes like tidal waves and tremors might easily occur in Japan. Nevertheless, despite the danger to the environment, important Japanese businesses have aggressively pushed for green sources, such as nuclear power, which has resulted in the implosion of a nuclear power plant. It does not just necessitate significant funds to deal with mishaps, but it also undermines power stability and worsens EP. Additionally, this acts as a rem IND Growth to pertinent agencies to consider the influence of disaster risks while creating renewable energies to effectively advance power conservation and environmental sustainability.

We additionally repeat the study by substituting Renewable Energy Advancement - Hybrid (REA-H) and system reliability index (SRI) for the primary uncontrolled variables REA in order to demonstrate the validity of the aforementioned IND Growth. The outcomes are displayed in Table 1's Columns (5) and (6). At a predictive validity threshold of 1%, we IND Growth that the correlations of REA-H CVI and SRI CVI are still positive, and IND Growth that climate risk will have a favorable impact on the association among REA innovations and EP. The IND Growth above is resilient since their value and significant values are identical as previously. Our calculations above lead us to the conclusion that climatic hazard is a significant factor influencing the applicability of REA technology for EP. Given how important they are to developing REA and renewable energy policy, the consequences of this IND Growth deserve careful consideration.

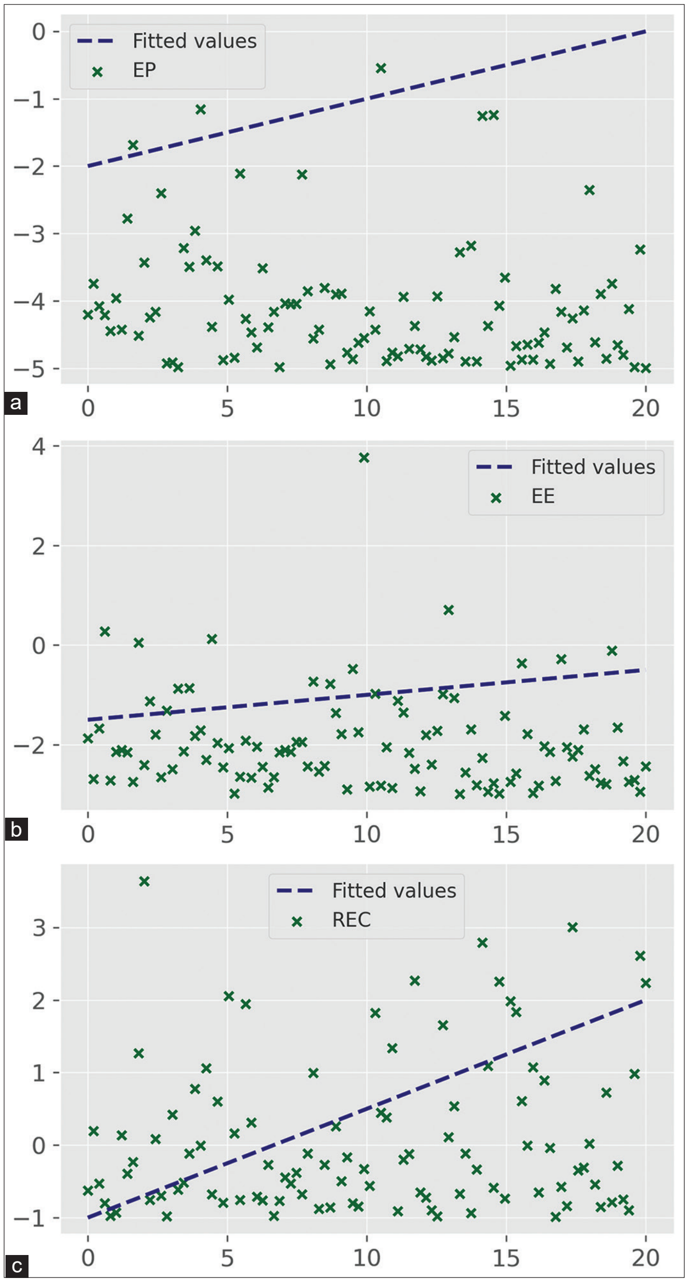
### 4.3. Methodology of Moment Quintile Regression (MMQR) with FE

#### *4.3.1. Empirical outcomes of MMQR framework*

The influence of REA technology on EP could not be linear, despite the fact that the empirical research presented above uses a linear regression method. A scatterplot connecting the REA innovative degree and EP is shown in Figure 2a, and it may show a non-linear relationship between the two. This corroborates the publication's claim that REA technology is a possibly important factor in EP and that it generally helps to lessen EP. Additionally, we see that for the power demand pattern European commission (EC) and energy generation (EG), the explaining factor EP takes the position of the core variable of energy loss (EL). The IND Growth, shown in Figure 2b and c, are consistent with predictions that REA innovation and EP have a non-linear relationship and that REA technology can lower EP. We use the MMQR with explanatory variables to investigate this irregular connection for Thirty Chinese cities in order to account for potential substantial specific features and an exogenous variables issue as well as to deepen our understanding of the non-linear impact of REA development on EP. With the help of this technique, we may perform more thorough and reliable calculations by addressing personal impacts and the exogenous variables issue.

The related variable values at various deciles of the EP dispersion are shown in Table 2. At a proportional rate of 5%, the model values of our primary random factor, REA, are noticeably low from the 25th to the 75th deciles. This confirms Hypothesis 2 since it shows that an increase in REA development reduces EP and that there is a non-linear link between both. Additionally, we discover that the unfavorable effect loses some of its statistical importance at extremely low or very high parametric levels, INDG indicating that it has less of an influence in regions with very low or very high EP. It is clear from contrasting the empirical INDG to earlier research that this IND Grow diverges from our analysis of IND Growth (Dong et al., 2021; Robinson and Mattioli, 2020). The coefficient

**Figure 2:** (a-c) REA and EP in various explanatory factors




statistical IND Growth is found to IND Growth quite evidently the power of this effect when EP is at various levels, despite the fact that they all show that REA technology can start reducing EP. To a significant degree, this aids legislators and the authorities in focusing on lowered EP to accomplish renewable power growth. As was previously IND Growth, the majority of low- and middle-EP regions make significant investments in REA innovations to reduce their EP and pursue renewable power growth, which has an FSTRonger influence on EP. Additionally, we do a stability test by swapping out the primary explanation factor, REA. The initial two rows of Table 3 include the outcomes. The methodology of this research meets the robust test, as shown by the experiment IND Growth which holds true even after the primary predictors REA-H and SRI have been replaced. The more REA for regions with moderate EP levels, the easier it is to reduce EP and achieve renewable power growth.

### *4.3.2. Moderating effect results of the MMQR model*

Since COVID-19 has been spreading continuously during the past two decades, volatility and urbanization have increased, and worldwide financial progress has been erratic. There is a lot of ambiguity around the world market for sustainable power. The increased degree of global warming has had a substantial effect on REA growth and, as a result, on EP and energy markets. Varied global warming situations may result in various effects of REA development on EP. Furthermore, although they are all based on linear models, the empirical analysis results in Section 4.2 contribute to the conclusion that global warming is a significant factor in the influence of REA development on EP. We added the interactions term REACVI to MMQR for more exploration of the moderate impact of environmental change.

The essential empirical IND Growth is shown in Table 4. The data IND Growth that, at a statistical relevance level of 5%, the computed values of this interactions factor, REACVI, are substantially favorable from the 50th percentile. This is similar to other studies Aristondo and Onaindia (2018) and Ciupăgeanu et al. (2017) that confirms Assumption 3 that unfavorable weather patterns have diminished the positive impact of REA development on EP. The growth of REA may not be helpful to the reduction of EP when influenced by climate change effects. This circumstance is present in nations and areas with high EP. According to Bienvenido-Huertas et al. (2020), environmental change has a significant impact on technical advancement for renewables like nuclear power. It harms the growth of alternative power sources and exasperates the volatility of nuclear power. Additionally, a significant number of people living in Western nations have expressed their disapproval of the unsustainable expansion of REA under the concern of rising environmental risks. According to Barnes et al. (2011), the power safety sector is not impervious to climatic hazards, and the advancement of alternative power sources, such as nuclear power, has even prompted IND Growth unsterilized European nations to reintroduce safety concerns to the general discourse. Therefore, instead of pushing REA development recklessly and disregarding the effects of environmental risks, nations should logically create REA in accordance with the current scenario because the impact of REA development on EP's ability to mitigate environmental risks may be impacted. Table 4 shows the Panel quintile measurement outcomes with consideration of interaction terms amid Renewable Energy Advancements (REA) and Climate Vulnerability Index (CVI).

Table 4 presents the panel quintile measurement outcomes considering the interaction terms between Renewable Energy Advancements (REA) and the Climate Vulnerability Index (CVI) on energy poverty (EP) across different quintiles (Q10, Q25, Q50, Q75, Q90). The results show that REA has a negative and statistically significant impact on EP across all quintiles, with the effect becoming stronger in higher quintiles. For example, at Q10, REA has a coefficient of −0.0055 (P-value not significant), but this increases to −0.0136 ($p < 0.01$) at Q90, indicating that REA more effectively reduces EP in higher quintiles. The interaction term REA × CVI is positive and statistically significant at Q50 and Q75, suggesting that higher CVI levels diminish the positive impact of REA on EP. Other variables like Technology levels (TA) and GDP are consistently significant and show positive and negative effects,

**Table 2: Panel quintile measurement outcomes of the primary framework**

| Variable | −1 | −2 | −3 | −4 | −5 |
|---|---|---|---|---|---|
| | Q10 | Q25 | Q50 | Q75 | Q90 |
| REA | −0.0051* | −0.0054** | −0.0058*** | −0.0062** | −0.0066* |
| | (−1.83) | (−2.52) | (−3.35) | (−2.37) | (−1.72) |
| TA | 0.0068*** | 0.0065*** | 0.0061*** | 0.0056*** | 0.0052** |
| | −4.44 | −5.61 | −6.55 | −3.9 | −2.48 |
| IND GROWTH | 0.0048−0.26 | 0.0065−0.47 | 0.009−0.81 | 0.0124−0.72 | 0.015−0.6 |
| SR | −0.1325 | −0.1851* | −0.2624*** | −0.3669*** | −0.4468** |
| | (−1.01) | (−1.86) | (−3.26) | (−2.98) | (−2.49) |
| E-E-OPEN | −0.0045 | −0.0042 | −0.0040 | −0.0036 | −0.0033 |
| | (−0.33) | (−0.41) | (−0.48) | (−0.28) | (−0.18) |
| GDP | −0.0239*** | −0.0207*** | −0.0184*** | −0.0249*** | −0.0096 |
| | (−5.15) | (−6.08) | (−6.32) | (−3.09) | (−1.67) |
| n | 510 | 510 | 510 | 510 | 510 |

**Table 3: Validity check: Replacement of main explaining factor**

| Variable | −1 | −2 | −3 | −4 | −5 | −1 | −2 | −3 | −4 | −5 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q10 | Q25 | Q50 | Q75 | Q90 | Q10 | Q25 | Q50 | Q75 | Q90 |
| REA-H | −0.0051* | −0.0054** | −0.0058*** | −0.0063** | −0.0066* | | | | | |
| | (−1.83) | (−2.52) | (−3.34) | (−2.37) | (−1.73) | | | | | |
| SRI | | | | | | −0.0061** | −0.0067*** | −0.0076*** | −0.0087*** | −0.0096** |
| | | | | | | (−2.11) | (−3.12) | (−4.39) | (−3.32) | (−2.53) |
| TA | 0.0068*** | 0.0065*** | 0.0061*** | 0.0056*** | 0.0052** | 0.0070*** | 0.0067*** | 0.0063*** | 0.0057*** | 0.0053*** |
| | −4.44 | −5.6 | −6.54 | −3.89 | −2.48 | −4.77 | −6.1 | −7.09 | −4.21 | −2.7 |
| IND | 0.0048 | 0.0065 | 0.009 | 0.0125 | 0.0151 | −0.0001 | 0.0029 | 0.0071 | 0.0126 | 0.0168 |
| GROWTH | −0.26 | −0.47 | −0.81 | −0.72 | −0.6 | (−0.01) | −0.21 | −0.64 | −0.75 | −0.69 |
| SR | −0.1326 | −0.1850* | −0.2625*** | −0.3676*** | −0.4470** | −0.1506 | −0.2055** | −0.2803*** | −0.3808*** | −0.4554** |
| | (−1.01) | (−1.86) | (−3.26) | (−2.98) | (−2.49) | (−1.12) | (−2.05) | (−3.46) | (−3.09) | (−2.56) |
| E-E-OPEN | −0.0044 | −0.0043 | −0.0040 | −0.0036 | −0.0033 | −0.0024 | −0.0027 | −0.0031 | −0.0036 | −0.0039 |
| | (−0.33) | (−0.41) | (−0.48) | (−0.28) | (−0.18) | (−0.17) | (−0.26) | (−0.37) | (−0.28) | (−0.22) |
| GDP | −0.0228*** | −0.0206*** | −0.0173*** | −0.0129*** | −0.0095 | −0.0224*** | −0.0201*** | −0.0169*** | −0.0127*** | −0.0095 |
| | (−5.15) | (−6.08) | (−6.32) | (−3.07) | (−1.56) | (−4.98) | (−5.96) | (−6.20) | (−3.05) | (−1.59) |
| n | 510 | 510 | 510 | 510 | 510 | 510 | 510 | 510 | 510 | 510 |

**Table 4: Panel quintile measurement outcomes with consideration of interaction terms amid REAA and CVI**

| Variable | −1 | −2 | −3 | −4 | −5 |
|---|---|---|---|---|---|
| | Q10 | Q25 | Q50 | Q75 | Q90 |
| REA | −0.0055 | −0.0069*** | −0.0089*** | −0.0115*** | −0.0136*** |
| | (−1.60) | (−2.61) | (−4.22) | (−3.60) | (−2.88) |
| TA | 0.0067*** | 0.0066*** | 0.0065*** | 0.0064*** | 0.0063*** |
| | −4.06 | −5.29 | −6.51 | −4.2 | −2.76 |
| IND GROWTH | 0.0052 | 0.0048 | 0.0042 | 0.0034 | 0.0027 |
| | −0.28 | −0.34 | −0.37 | −0.2 | −0.11 |
| SR | −0.1276 | −0.1821* | −0.2642*** | −0.368*** | −0.4553** |
| | (−0.98) | (−1.83) | (−3.32) | (−3.06) | (−2.55) |
| E-E-OPEN | −0.0054 | −0.0040 | −0.0020 | 0.0006−0.05 | 0.0028−0.15 |
| | (−0.40) | (−0.39) | (−0.24) | | |
| GDP | −0.0230*** | −0.0206*** | −0.0170*** | −0.0125*** | −0.0087 |
| | (−5.19) | (−6.10) | (−6.25) | (−3.04) | (−1.43) |
| REA×CVI | 0.0005 | 0.0007 | 0.0011** | 0.0016* | 0.002 |
| | −0.55 | −1.09 | −2.05 | −1.93 | −1.62 |
| n | 510 | 510 | 510 | 510 | 510 |

respectively, while IND GROWTH and SR show varying levels of significance across the quintiles. These findings underscore the importance of considering climate vulnerability when evaluating the effectiveness of REA in reducing EP, particularly in regions with high EP levels.

The Figure 3 below illustrates the interaction effects between Renewable Energy Advancements (REA) and the Climate Vulnerability Index (CVI) on energy poverty. The graph shows how the impact of REA on energy poverty varies at different levels of CVI low, medium, and high. It clearly demonstrates that as CVI increases, the positive effects of REA on reducing energy poverty diminish, indicating the critical moderating role of environmental risks in this relationship.

Table 5 presents the panel quintile measurement outcomes considering the interaction term by changing the main explaining factotr (REA-H and SRI) across different quintiles (Q10, Q25,

**Figure 3:** Interaction effects of REA and climate vulnerability index on energy poverty

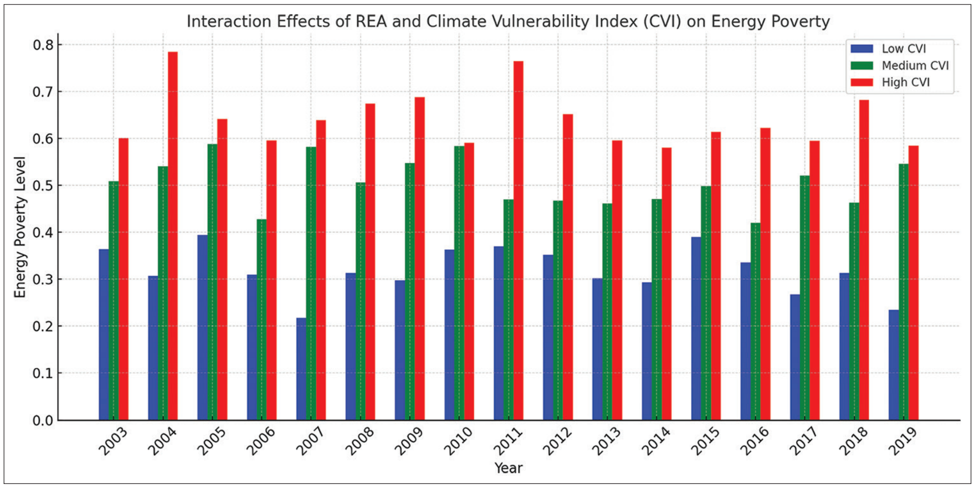



**Table 5: Panel quintile measurement outcomes with consideration of the interaction term by changing the main explaining factor**

| Variable | −1 | −2 | −3 | −4 | −5 | −1 | −2 | −3 | −4 | −5 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q10 | Q25 | Q50 | Q75 | Q90 | Q10 | Q25 | Q50 | Q75 | Q90 |
| REA-H | −0.0055 | −0.0069*** | −0.0089*** | −0.0115*** | −0.0137*** | | | | | |
| | (−1.59) | (−2.61) | (−4.22) | (−3.61) | (−2.88) | | | | | |
| SRI | | | | | | −0.0059 | −0.0080*** | −0.0109*** | −0.0149*** | −0.0181** |
| | | | | | | (−1.59) | (−3.02) | (−3.93) | (−2.82) | (−2.34) |
| TA | 0.0067*** | 0.0066*** | 0.0065*** | 0.0064*** | 0.0063*** | 0.0069*** | 0.0068*** | 0.0066*** | 0.0064*** | 0.0063* |
| | −4.06 | −5.29 | −6.51 | −4.21 | −2.76 | −4.24 | −5.89 | −5.46 | −2.77 | −1.85 |
| IND | 0.0052 | 0.0048 | 0.0042 | 0.0034 | 0.0027 | 0.0029 | 0.0025 | 0.002 | 0.0013 | 0.0007 |
| GROWTH | −0.28 | −0.34 | −0.37 | −0.2 | −0.11 | −0.15 | −0.18 | −0.14 | −0.05 | −0.02 |
| SR | −0.1274 | −0.1820* | −0.2643*** | −0.3681*** | −0.4558** | −0.1485 | −0.2041** | −0.2824*** | −0.3884** | −0.4730 |
| | (−0.98) | (−1.83) | (−3.32) | (−3.07) | (−2.55) | (−1.07) | (−2.07) | (−2.72) | (−1.96) | (−1.63) |
| E-E-OPEN | −0.0054 | −0.0040 | −0.0019 | 0.0006 | 0.0028 | −0.0042 | −0.0029 | −0.0012 | 0.0012 | 0.003−0.1 |
| | (−0.40) | (−0.39) | (−0.24) | −0.05 | −0.15 | (−0.29) | (−0.29) | (−0.11) | −0.06 | |
| GDP | −0.0230*** | −0.0206*** | −0.0170*** | −0.0125*** | −0.0087 | −0.0225*** | −0.0201*** | −0.0167*** | −0.0120* | −0.0083 |
| | (−5.19) | (−6.10) | (−6.26) | (−3.06) | (−1.43) | (−4.83) | (−6.04) | (−4.74) | (−1.80) | (−0.85) |
| REA-H×CVI | 0.0005 | 0.0007 | 0.0011** | 0.0016* | 0.002 | | | | | |
| | −0.55 | −1.09 | −2.06 | −1.94 | −1.62 | | | | | |
| SRI× CVI | | | | | | 0.0003 | 0.0007 | 0.0013 | 0.0021 | 0.0027 |
| | | | | | | −0.26 | −0.89 | −1.54 | −1.31 | −1.17 |
| n | 510 | 510 | 510 | 510 | 510 | 510 | 510 | 510 | 510 | 510 |

Q50, Q75, Q90). The results show that REA-H has a negative and statistically significant effect on energy poverty (EP) across all quintiles, with a stronger effect in higher quintiles. At Q10, REA-H has a coefficient of −0.0055 (not statistically significant), while it becomes −0.0137 ($P < 0.01$) at Q90, indicating that the impact of REA-H on reducing EP is more pronounced in higher quintiles. system reliability index (SRI) shows a similar negative trend, with coefficients becoming more significant in higher quintiles, reaching −0.0181 at Q90 ($P < 0.05$). The interaction terms between REA-H and CVI, as well as SRI and CVI, are positive and statistically significant in some quintiles, particularly at Q50 and Q75, suggesting that higher levels of CVI moderate the effect of REA-H and SRI on EP. Other variables like Technology levels (TA) and GDP remain consistent in significance across all quintiles, indicating their substantial influence on EP. These results reinforce the notion that both REA-H and SRI reduce EP, though their impact is moderated by climate vulnerability.

### *4.3.3. Heterogeneity analysis*

Indonesia is a huge nation with a complicated geography, and there are clear regional variations in the REA level, EP, and environment. The present work initially separates the research population into three provinces, central and eastern—and performs a logistic study to explore whether the impacts of REA development on EP also reflect the geographical variation. Table 6 shows that at a statistic relevance degree of 5%, REA development in the western and eastern parts significantly reduces EP. There is geographical variation in the impact of REA development on EP, as seen by the lack of significance of REA innovation's effects on EP in central Indonesia. Additionally, in the western area of Indonesia, the association terms among REA development and CVI are statistically important and favorable from the $50^{th}$ to the $90^{th}$ deciles at a degree of 5%. This IND Growth confirms Assumption 3 by IND Growth that the harmful effects of REA development on EP have been mitigated by unfavorable climatic circumstances as shown in Table 6. This outcome can be linked to its detrimental effects on REA development as well as the expense

**Table 6: Analysis of regional disparities**

| | Dependent variable: EP | | | | | |
|---|---|---|---|---|---|---|
| **West** | **Variable** | **Q10** | **Q25** | **Q50** | **Q75** | **Q90** |
| | REA | −0.0074 | −0.0263 | −0.0482** | −0.0734** | −0.0951** |
| | | (−0.21) | (−1.09) | (−2.32) | (−2.37) | (−2.13) |
| | REA×CVI | 0.0051 | 0.0088 | 0.0130*** | 0.0179** | 0.0221** |
| | | −0.62 | −1.52 | −2.63 | −2.42 | −2.06 |
| | **Control** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| | n | 153 | 153 | 153 | 153 | 153 |
| **Central** | **Variable** | **Q10** | **Q25** | **Q50** | **Q75** | **Q90** |
| | REA | 0.0049 | 0.0025 | −0.0019 | −0.0080 | −0.0105 |
| | | −0.05 | −0.13 | (−0.01) | (−0.02) | (−0.02) |
| | REA×CCI | 0.0006 | −0.0001 | −0.0013 | −0.0030 | −0.0036 |
| | | −0.03 | (−0.02) | (−0.03) | (−0.03) | (−0.03) |
| | **Control** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| | n | 153 | 153 | 153 | 153 | 153 |
| **East** | **Variable** | **Q10** | **Q25** | **Q50** | **Q75** | **Q90** |
| | REA | −0.0070** | −0.0075*** | −0.0080*** | −0.0087*** | −0.0094** |
| | | (−2.06) | (−2.94) | (−3.93) | (−2.81) | (−1.97) |
| | REA×CVI | 0.0005 | 0.0006 | 0.0008 | 0.0009 | 0.0011 |
| | | −0.54 | −0.88 | −1.35 | −1.1 | −0.84 |
| | **Control** | **Yes** | **Yes** | **Yes** | **Yes** | **Yes** |
| | n | 187 | 187 | 187 | 187 | 187 |

of pollution prevention and power stability (Radmehr et al., 2021). Nevertheless, the middle and eastern area of the mediating variable among REA and CVI reveals no discernible impact on EP under varied climatic risks.

According to the hypothesis, there are several causes for these variations. On the one hand, the severity of EP in the western area is greater than in the middle and eastern areas. By depending on REA, the regional power sector can grow and reduce EP in such regions. For instance, the utilization of renewable power generation in Western Indonesia efficiently reduces EP, encourages the growth of renewable energy, and decreases energy bills. However, the western area is more severely impacted by climatic hazards. The creation of REA is unlikely to lessen EP in locations where it is particularly severe because of the effects of climatic factors. On the other hand, because of the large capital expenses and climatic hazards, it will be harmful to power stability. In conclusion, Indonesia's western area can reduce EP via REA development, but in order to properly accomplish renewable power growth, they must carefully evaluate the effects of environmental risks.

The Figure 4 below presents the energy poverty trends across the western, central, and eastern regions of Indonesia between 2003 and 2019. The graph highlights the disparities in energy poverty levels across the regions, with the eastern region consistently showing higher levels compared to the central and western regions. This visualization provides a clear comparison of how energy poverty has evolved across different regions over time, supporting the analysis of regional differences in the impact of renewable energy advancements.

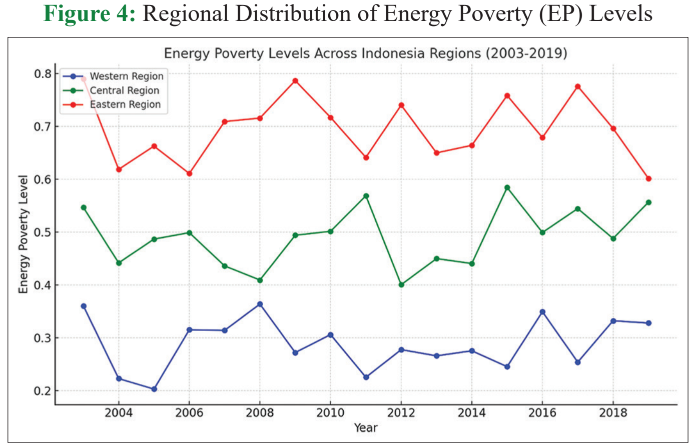
## 4.4. Threshold Effect Analysis

We utilize the panel data approach to perform econometric testing to see if the preceding econometric IND Growth is contradictory because various variants were used. Using Sea and Shin's Bootstrapping algorithms approach, we evaluate the barrier impact

**Table 7: Measured outcomes utilizing the threshold framework**

| Threshold variable | CVI | | |
|---|---|---|---|
| **Dependent variable** | **EP** | **EL** | **EC** |
| REA (Th≤r) | −0.012** | −0.852** | −0.004 |
| | −0.006 | −0.354 | −0.003 |
| REA (Th>r) | 0.019** | 1.868*** | 0.002 |
| | −0.009 | −0.385 | −0.002 |
| Cons | 1.013*** | −2.550 | −0.017 |
| | −0.3 | −6.048 | −0.045 |
| Control | Yes | Yes | Yes |
| Year | Yes | Yes | Yes |
| Province | Yes | Yes | Yes |
| Threshold value | 2.472*** | 2.300*** | 1.396*** |
| | −0.319 | −0.502 | −0.162 |
| Bootstrap test (P-value) | 0 | 0 | 0 |
| 95% C.I. | (1.846, 3.098) | (1.315, 3.285) | (1.079, 1.712) |

**Figure 4:** Regional Distribution of Energy Poverty (EP) Levels



(2016). For variable impact analyses, we explicitly use the climatic risk IND Growth (CVI) as a barrier factor. Table 7 shows the results of our model; they IND Growth that, at a statistically significant level of 5%, REA development has a significantly bad effect on EP when the barrier is lower and a favorable impact on EP whenever the barrier is higher, with respect to the CVI factor. As a result, there is a barrier impact in the effect of REA development on EP that is influenced by environmental risks. This could be the case since REA is largely unaffected by environmental risks while it is low, which helps EP by encouraging the growth of REA.

One Illustration is that REA growth has not been impacted by the very small-scale global warming, despite the fact that certain coastlines in eastern Indonesia are severely afflicted by storms and other high IND Growths. Through REA development, like renewable power and photovoltaic power, these regions can still reduce EP. Furthermore, the effect on REA will grow as climate risk does as well. When this happens, the worsening of the weather will encourage REA development and exacerbate EP. For instance, REA has been intensively promoted by the Japanese government despite the effect of previous severe climatic events, such as tidal waves and tremors, which led to the now-famous nuclear energy plant incident in 2011.This has a negative impact on the growth of renewable power because it not only uses up enormous amounts of people and physical assets but also worsens the power stability dilemma. We change the explanatory factor EP and re-estimate the barrier model using power generation and energy usage patterns, ensuring the robustness of the barrier impact. Columns (2) and (3) of Table 7 display the pertinent empirical IND Growth rings. The IND Growth rings to demonstrate that the threshold effect persists regardless of as to if EL or EC is used as the explanatory parameter, suggesting that REA Technology has a pessimistic impact on EP when the limit is low but a favorable impact on EP whenthe limit is higher. This implies that observational IND Growth is robust.

## 5. DISCUSSION

The result of this study will help fill the existing literature gap in understanding the contribution of renewable energy advancements (REA) towards energy poverty (EP) reduction across various regions of Indonesia. The moment quantile regression model established shows that REA affects EP with varying patterns in climate vulnerability index and region-specificity. This section discusses the consequences of these findings and contextualises them based on the current studies. The study finds evidence to support the hypothesis that REA decreases energy poverty to a larger extent especially in areas of low climate risk. From the results obtained from the standard linear regression framework shown in Table 1 it is clear that hypothesis under investigation is real since there is negative relationship between REA and EP that indicates renewable energy innovation has a central role in enhancing energy access and affordability. These findings support previous research on applying renewable energy to eliminate energy poverty meaning increasing the generation of clean energy while decreasing the cost of electricity generation (Wang et al., 2017; Robinson and Mattioli, 2020). More specifically, the regression results indicate that technological advancement in renewable energy made it possible to extend the structure of energy infrastructure in Indonesia and increase energy security and lessen the total cost of EP.

Nevertheless, this research confirm that influence of REA on EP differs in all regions of Indonesia. These results are illustrated in Table 6 which shows that the western provinces have a more dramatic response to REA since the EP reduction is significant at all quantiles. However, when the regions are split between the central and eastern regions, the results are either weaker or nonsignificant. This geographic disparity could be as a result of differences in infrastructure, economic development, and or government policies that either support or retard the use of renewable energy technologies. These findings are in tandem with Moran et al. (2018), recognising that variations existing in physical chemistries as infrastructure and policy the support may cause variations in the advancement of the renewable energy technologies as a factor of the impact of REA to energy povety line. The second main result of this research is that climate vulnerability (CVI) has a moderating impact on the REA and EP association. As shown in Table 4, the interaction term REA × CVI shows that although REA has a positive effect on the reduction of EP in low CVI environments, its effectiveness is decreased in high CVI environment which poses threat to the production of renewable energy as epitomized by situations such as extreme weathers, calamities and climate related disasters. As evidenced by current scholarly studies, extreme weather conditions have lead to operational inefficiencies of renewable energy technologies (Aristondo and Onaindia, 2018; Ciupăgeanu et al., 2017). While reinvigoration of renewable energy can reduce EP level in higher climate risk zones, including cyclone, tidal wave, or volcanic prone areas, it is severely impaired. Because infrastructures may be damaged and energy production disrupted in these regions, energy poverty is made even worse.

The results of the panel quintile regression (Table 2), also support the above notion indicating that the magnitude of REA's effect on EP weakens the moment we get to the higher quantile levels of CVI. This implies that, households in areas that are prone to climate change risks are those that will not benefit from the advancement in renewable energy sources. These implications have significant policy implications and mean that renewable energy schemes must be developed bearing in mind environmental conditions of specific regions. Concerning high CVI areas, it will require the establishment of resilient structures in policy making with reference to climatic calamities and reliability of renewable energy systems. Besides this, from the analysis presented in Table 7 containing the result of the threshold analysis, it has been revealed that the relationship between the REA and EP is non-linear and both these constructs are conditioned or moderated by the CVI. The studies provide an indication that at a Climate and Energy Investment (CEI) above a certain level the effect of REA on EP is actually negative. That is why, we must fold climate resilience measures into renewable energy development processes to achieve and sustain positive results in mitigating energy poverty levels. With rising impacts of climate change on Indonesia, the country will need to focus on building energy infrastructure and technologies that can overcome impeding challenges hence sustaining the pace of REA's impacts on energy security and poverty defeat.

## 6. CONCLUSIONS AND POLICY SUGGESTIONS

This study aims at identifying the effects of "Advancements in Renewable Energy (REA)" on the reduction of "Energy Poverty (EP)" in Indonesia with aconsideration of "Regional Disparity and Climate Vulnerability Index (CVI)." In order to provide significant findings in accordance with both the methodology and results in this research, this moment quantile regression model investigate data from 30 provinces of Indonesia during 2003-2019.

The study validates that REA has a central role to perform in combating energy poverty especially to the areas that are not so much exposed to the negative impacts of climate change. Technologies in the renewable energy sector enhance energy supply, reduce the cost of electricity generation and enhance energy security. Nevertheless, REA is not evenly distributed across the country where the western provinces get the most benefits of renewable energy development than the central and eastern provinces. This has given credence to the fact that there are disparities across the regions most probably due to variation in infrastructure growth in various regions, government policies and the overall economic factors.

In addition, the study establish that climate vulnerability moderates the relationship between REA and EP. Though the outcome of the current study reveals that REA has modest positive impacts on decreasing the possibility of energy poverty in the most affected world regions, it has significant negative effects where CVI levels are high, including the areas that are more vulnerable to hurricanes, cyclones, and tsunamis. This implies that renewable energy systems reduces energy poverty impacts than relied energy sources in environmentally stable regions than the high climate risk regions, which we can infer as regions that experience shocks and climate variability most intensely.

To eradicate the challenges that have been highlighted in this research study, there is need for government to embrace the regional convergence plan in tackling renewable energy problems especially in the areas of climate change vulnerability. Hazard impacts in climate vulnerable areas call for increased renewable energy resilience especially in the eastern provinces of Indonesia. There must be adequate investments in applications of intelligent technology and energy systems that are resilient to avoid situations where these areas are denied advancement in renewables due to catastrophic effects of climate change. These undertakings will enable policy makers ensure that there is reliability on energy sources in regions which are at the frontier of the adverse effect of climate change such as floods, cyclones, and increasing sea levels which pose a major threat to energy resources.

Moreover, it should also be noted that, in addition to the climate risks, there is a need for the improvement of the specific crucial factors for the advancement of renewable energy sources that work on the regional basis For that the state infrastructure work has to be concentrated primarily in the regions with the least favored from the standpoint of the access to the renewable energy sources. These provinces that have relatively low REA effect on EP, need enhancements on energy structure investments to increase the dissemination of renewable technologies. Therefore, extending the energy grid, strengthening the local renewable energy programs and stimulating engagement of both commercial and government interest are some important actions toward improving energy availability in these areas. By promoting the localized renewable energy systems, the government can help localized area to eradicate regional energy disparity and come up with ways of selling the renewable energy initiatives for economic development. Also national energy planning has to take climate risks into account. The partial mediating of the climate vulnerability index (CVI) results shows that the impact of REA towards EP should consider the regional climate conditions. If there is need for climate change and variability the country would have to adopt a mix of renewable energy sources to include solar, wind and hydropower to increase their capacity and diversify from a single energy source so as reduce the impact of climate change. By adopting this procedure, renewable energy projects will be more sustainable and capable of bringing stable energy supply despite of the environmental adversities.

In addition, the promotion of Technology Transfer (TT) and Capacity Building (CB) will be another vital factor that will ensure that the REA encompasses a continuous impact on the reduction of energy poverty. Public support for Research and Development (R&D) in renewable energy technologies is required so as to enhance efficiency and reduce costs of power production. Technical education and training targeting the energy sector human resource should be the cornerstone of capacity building particularly in the developing countries where there is limited knowledge on renewable energy resources. To supplement the sustainability of energy infrastructure Indonesia can support a skilled workforce to manage and maintain renewable energy systems. Last of all, a higher focus on developing regional cooperation to reach other Indonesian provinces will also be important when it comes to the unequal distribution of renewable energy usage. Proper examples of renewable energy management in the developed regions, including the western Indonesia, should be replicated across the country by using common resources based on benchmarking best practices. This approach of partnership will assist in avowering the distribution of renewable energy in a way that they bring more equality in the energy poverty of Indonesia.

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