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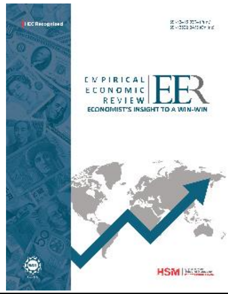

Title:	**Powering Asia's Future: How Energy Infrastructure Investments Drive Renewable Energy Growth in Developing Economies**
Author (s):	Jameel Ahmed Khan, Imam Uddin, and Nayeem Ul Hassan Ansari
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Department of Economics and Statistics, Dr. Hasan Murad School of Management
University of Management and Technology, Lahore, Pakistan

Powering Asia's Future: How Energy Infrastructure Investments Drive Renewable Energy Growth in Developing Economies

Jameel Ahmed Khan*, Imam Uddin, and Nayeem Ul Hassan Ansari

Institute of Business Management, Karachi, Pakistan

Abstract

The current study aimed to assess and compare the impacts of energy infrastructure investment on renewable electricity production in Asia's growing nations (China, India, Indonesia, Malaysia, Pakistan, the Philippines, and Thailand) using Public Private Partnership (PPP). The study used annual data from 1993 through 2017. To do this, specific panel econometric methods were employed: Augmented Mean Group (AMG) and Grouped-Mean Group Estimators (GMGE). The findings in H1 suggest that the impacts of improved energy infrastructure are greater in increasing the production of renewable electricity in developing Asian nations. Additionally, it was also determined that Financial Development (FD), economic expansion, and openness increase the volume of renewable electricity production. Furthermore, the authors suggested new ways in which the investment of energy infrastructure might be encouraged by development agencies and present models for sustainable development in developing Asian nations. For instance, the governmental and private sectors' collaboration towards the construction of cost-effective green energy and renewable energy sources, that are not renewable, would provide tangible steps towards renewable energy.

Keywords: Augmented Mean Group (AMG), energy infrastructure investment, Grouped-Mean Group Estimators (GMGE), Public Private Partnership (PPP), renewable electricity production

Introduction

In the past decade, energy demand has increased worldwide with the highest demand in the developing countries of Asia. Resultantly, it has created new problems of energy insecurity and affordability in developing countries. Based on predictions, by the year 2040, the entire energy demand would increase by 33% in developing countries including Asian countries, (Nepal & Paija, 2019). Furthermore, if left unchecked, the economic development

*Corresponding Author: jameelhakro@gmail.com

and population growth in Asian nations—particularly China, India, and Pakistan—will push energy demand well beyond forecasts (Wolfram et al., 2012). The security threats pertaining to energy in these Asian countries are based on their reliance on imported energy. Surging energy requirements for developing and emerging world necessitates the enhancement of energy infrastructure investments. Despite significant advancements in economic reforms and the globalization of energy trade, investments in energy infrastructure are still crucial for unfinished energy projects in Asian economies. Despite significant advancements in the internationalization of energy commerce, energy infrastructure investments are still significant to complete unfinished energy projects in Asian economies.

For developing countries, there is a need to provide considerable energy capital in order to fulfill surging energy demand in the Asian economies. Such investments would be effective for the economy and promotion of new firm creation as well as reasonable procurement of energy resources. Additionally, it would help to augment traditional investments pertaining to cleaner energy and low carbon technologies which raise the capacity to respond to energy security questions and carbon emissions. Investment in energy infrastructure that aspires to economic development and is environment-friendly would lead towards long-term energy security in the developing countries, resultantly. According to the International Energy Association Independence in 2017, energy investment was down to 6% as compared to 2016, for electricity production, oil and natural gas, coal, energy efficiency, as well as renewable energies (International Energy Agency [IEA], 2018). In recent years, China, India, and Indonesia in addition to others, have developed some power projects under Public Private Partnership (PPP) model. According to the accounts of Atmo and Colin (2014), Asian economies are laying out and planning about $4 trillion of energy-related projects in the upcoming decade. Furthermore, almost all these investments aim to fulfil the dimensions, commonly referred to as Sustainable Development Goals (SDGs), and to promote environmental sustainability. Furthermore, infrastructure improvement is a key component of the 2030 agenda and is specifically tied to three of the seventeen SDGs. Increasing the amount or quality of infrastructure capital is seen as a crucial component of production; it is now a key component of sustainable development strategies (Bhattacharya et al., 2012; Di Liddo et al., 2019). It is important to note that low-income and rising nations (such as Asian economies) lag substantially behind mature market economies in terms of the availability, caliber, and amount of economic infrastructure capital. Notably, the energy generating and electricity sectors are most impacted by the enormous disparity in income, purchasing power, and accessibility (Gurara et al., 2018). According to Anton (2021), variations in the climate and temperature have an impact on the company's success.

Since the world is in a recession, all the Asian countries are facing problems of limited finances which is affecting the expenditures of the government. Power or energy generation projects are primarily impacted by the limited funding issue combined with low revenue or budget problems. This emergency: suitable traditional infrastructure funding sources fall short of expectations, especially for energy and power projects in developing and impoverished countries (Arezki, 2020). The indigent developing nations in the Asia Pacific region that are experiencing difficulties in fulfilling the energy demand include China, India, Indonesia, Malaysia, Pakistan, Philippines, and Thailand. In order to improve and enhance energy security and to lower the carbon footprint, these countries are already finding different ways to increase electricity generation, particularly through more sustainable sources. Over the last few years, there have been large investments in energy-related projects across Asia. Pollution impacts the weaker economics through the globalization’s large-scale exportation of industries which needs power supply more than other industries. The emerging nations already suffering from shortfall of energy may use more imported energy in regard of oil, coal, and other fossil fuels (Shahbaz et al., 2016; Shahbaz, Shahzad, et al., 2018).

Since many upstream renewable technologies are risky and provide low returns, the primary funding source and financial institutions appear to favor non-renewable energy projects (Yoshino et al., 2019). Increasing green financing, PPPs and low carbon investments are necessary to sustain the accomplishment of several UN’s SDGs (Taghizadeh-Hesary & Yoshino, 2019). Investments in energy infrastructure promote renewable electricity and less use of fossil fuel, consequently lowering carbon emissions. Sound PPP is a critical driver of energy infrastructure investments in the governments’ policy agendas aimed at delivering the accessibility of energy (SDG-7), as well as the necessary capacity of power for development and economic growth. PPPs have become more popular due to the previously described limitations of public finance, especially in the creative and renewable energy sectors. This indicates that the roles of public and private sectors have shifted (Di Liddo et al., 2019).

There is a greater likelihood that rules would change renewable energy subsidies and generators since most developing nations have inadequate institutional and administrative environments (Boute, 2020). Additionally, in nations already having difficulty financing clean energy projects, the cost of implementing low-carbon policies is increased due to the rise in the risk premium (Poudineh et al., 2018). Accordingly, the PPP model is frequently seen as one of the best approaches to promote the growth of renewable energy in developing nations. The Middle East and North Africa region (MENA) and China, Kazakhstan, and other Asian nations are the focus of the energy economics literature's study of cleaner energy assistance schemes (Atmo & Colin, 2014; Boute, 2020; Poudineh et al., 2018; Shahbaz et al., 2020). To foster a low-carbon and sustainable economy in China, India, Indonesia, Malaysia, Pakistan, the Philippines, and Thailand, this study focused on the role that PPP investments play in renewable electricity generation. Additionally, increasing the production of renewable electricity in these nations would assist in meeting the demand for affordable electricity and improve energy security.

Researchers and environmental scientists (Shahbaz, Lahiani, et al., 2018; Khan et al., 2019) have examined globalization and Financial Development (FD) in connection with the consumption of renewable and non-renewable energy in the recent past. The "Pollution Haven Hypothesis" illustrates how globalization has affected energy demand and renewable energy. According to this hypothesis, energy-intensive industries that produce pollution in developed countries with onerous environmental regulations are forced to take advantage of the lax environmental regulations in developing or emerging countries. However, to design and reorganize energy mix policies for renewable and non-renewable resources, it is necessary to understand how elements impacting renewable energy can be useful (Gozgor et al., 2020). Nevertheless, recent research suggests that by lowering trade and investment barriers, globalization may promote economic growth and development. It has been noted that foreign businesses have the potential to disrupt domestic businesses when they invest in new projects, build out their facilities, or use renewable resources (Shahbaz et al., 2016).

Thus, three significant discoveries have been added to the body of existing literature by this effort. The effectiveness of energy infrastructure investments, which use the PPP model to boost the production of renewable electricity in well-established, sizable developing Asian nations, is examined first. PPPs are typically thought of as a long-term political instrument to achieve and carry out governments' economic and environmental objectives (Bougrain, 2012). Applying it to the development of renewable power sources, a PPP is considered as a deviation from typical public projects where most of the risk is transferred to private actors. These practices are helpful since the private sector has superior equipment, better services, and optimizes time and cost (Fadly, 2019; Shahbaz et al., 2020). Since these PPPs can make it easier to access money, technology, and risk management for the development and execution of renewable energy infrastructure projects, they also align with the UN's SDG 17: Revitalize Partnerships for Sustainable Development (United Nations Economic Commission for Europe [UNECE], 2020).

Secondly, this study advances previously unpublished conclusions and suggestions pertaining to the energy security of important Asian countries. It describes how the production of renewable energy in these economies is impacted by PPP investments, FD, financial globalization (FINGLB), and income level. The current literature has paid little attention to these aspects. For instance, the study demonstrated that energy infrastructure investments contribute to the reduction of non-renewable energy generation and the adoption of renewable electricity in Asian nations. It supports the concept of SDGs and sustainable development. Firstly, growing consumption from the transportation and industrial sectors may also generate energy security issues for Asian nations (Boute, 2020; Nepal & Paija, 2019; Wolfram et al., 2012). However, environmental externalities cast doubt on the objectives of climate change and sustainability (Vivoda, 2019).

Lastly, based on the literature, the study employed two distinct panel econometrics techniques: Augmented Mean Group (AMG) estimators and grouped mean estimators, which have been employed sparingly in energy economics. Resultantly, the research helped identified Asian countries meet the SDGs and provided suggestions to create energy mix policies for sustainable development.

Section 2 of the current study provides theoretical and empirical studies. The information measurements, empirical techniques, and initial assessments are explained in section 3. Section 4 gives the main results of the empirical analysis and the corresponding discussion. Section 5 focuses on policy relevance and section 6 entails closing statements.

Literature Review

Investments in energy infrastructure and its links with the environment were researched and documented in the literature as demonstrated by this study. Several environmental experts have studied throughout the last ten years. The current study evaluated the new effects of PPP investments in boosting the production of renewable electricity in relation to Asia's energy security issues. The authors thoroughly examined the impact of PPP investment on non-renewable resources. Resultantly, the current research can be separated into two categories. The effects of PPP investments in development were examined in the first strand in specific areas, for instance environmental deprivation and energy security indices (Di Liddo et al., 2019; Erdogan, 2020; Fadly, 2019; Shahbaz et al., 2020). Due to the high rate of energy demand in most Asian countries, the second stream of research primarily focused on factors related to renewable energy in general as far as energy supply is concerned.

Relationship between PPPs Investment, Energy, and Environment

Not much research has been conducted recently on the efficacy of PPP investments, particularly in the fields of energy and carbon emissions. Nonetheless, critical evaluations of related research are included in the body of current literature. Notably, a few studies determined the effects of investments in energy innovation on carbon emissions at local and regional levels. For instance, Shahbaz et al. (2020) used time series data to examine the connection between China's carbon emissions for the time period (1984-2018). The results of a bootstrapping ARDL bound testing approach revealed that, whereas PPP investments in energy typically correspond with carbon emissions, technical developments may lower emissions. This outcome reflects China's transition during the research period from coal and other non-renewable energy sources to renewable systems which raised environmental standards. However, a persistent reliance on coal-driven energy, influenced by marketization tendencies, is partially blamed for the rise in carbon emissions linked to energy infrastructure developments. Furthermore, with the Chinese government's 2002 reform strategy, which removed price limits and liberalized energy pricing, an increase in energy use was noted.

In a similar vein, Usman and Balsalobre-Lorente (2022) demonstrated that FD and reserves are simultaneously influenced by ecological footprint in newly industrialized countries as well. Jahanger et al. (2022) showed that such investments effect negative energy efficiency trends only in Asian not African countries. As such, Jiang et al. (2022) presented a theoretical framework for carbon control in the power heating industry and practice scenarios for electric heating operation. In his 2020 study regarding the effects of infrastructure expenditure on air and transport, Erdogan (2020) used a cross-sectional analysis on 21 Organization for Cooperation and Development (OECD) countries. The study was conducted using Pedroni cointegration and FMOLS method, building from annual data (2000–2015).

The current study analyzed the relationship between rail, air, and road investments and ecological footprint, revealing that the latter is a negative effect of the former. For this case, the previous technologies could be explained by updating more efficient, relatively environmentally-friendly real systems in OECD. A similar study was conducted by Fadly (2019) to ascertain the impact of private sector on renewable energy projects in 134 developing countries. To evaluate the main research hypothesis, the study used several failure time models and annual data of variables for the years 1990–2012. Findings were explained and evidence was found supporting foreign fossil fuel consumption and fuel rents deterring private energy investment, whilst private sector investment supports the development of renewable energy technologies for developing countries. Part of this has to do with the fact that the first investment project under consideration was kicked-off by government policies. This study also examined a paradox on whether the investment in renewable energy or the expenditure on fossil fuel should be higher depending on the income level. This is because those with higher income use more of the exploitation of fossil fuel than renewable energy.

Di Liddo et al. (2019) aimed to analyze the effect of regulatory quality and governance on the parameters of non-financial factors of PPP investments of the MENA countries. From 1990 to 2015, the study used annual data from MENA nations with low and moderate incomes. Panel regressions' empirical results showed that the primary factor influencing the induction of energy infrastructure investments is the quality of regulations.

This is explained by the fact that, as a result of inadequate institutional reforms and political instability, the majority of MENA nations lack solid governmental policies and regulatory frameworks. Taghizadeh-Hesary and Yoshino (2019) performed theoretical and empirical analysis, effecting tax returns on green energy project funding. They stated that green energy projects are critical to meeting SDGs, however, PPP projects need further development with the ability to generate higher returns for private players.

Ganda (2018) analyzed the multitude effects of green energy investments on environmental quality in OECD nations in the light of the backdrop of the years 2000-2014. Moreover, research showed that renewable energy investment reduced pollutants and enhanced the environmental quality. For instance, Alvarez-Herranz et al. (2017) also aimed to verify the EKC hypothesis about the public spending on energy research and use of renewables in 17 OECD countries. The study further added that social investment in research and development leads to an improvement in environmental quality by decreasing the carbon emissions. According to Cedrick and Long (2017), using the PPP model, renewable energy investments provide stimulus to the growth of renewable energy projects. Similar in idea, Strand et al. (2014) noted that the use of forecast and anticipation could cut down on energy costs and may furnish investment potential in the use of energy consumers structures.

Determinants of Renewable Energy

Yang et al. (2020) used data from China's power grid for the time period (2000-2014) to examine how investments in energy infrastructure affected the region's economic growth. The Generalized Method of Moments Technique or system GMM is used for analysis, and the ECI is designed to gauge the advancement of power grid infrastructure. The findings indicated that while power grid infrastructure investments provide greater returns for less developed inland regions in China than for coastal ones, ECI lowers the regional income levels.

Siddiqui et al. (2020) investigated how changes in cross-border energy infrastructure affected North America's local and national markets. Using the DIEM model, their study demonstrated that an increase in natural gas output boosted the transmission of energy between the US and Canada. The report also predicted that increased infrastructure investments would boost the output of renewable energy in North America including the US. By examining data on electricity generation, population, and economic growth, Nepal and Paija (2019) examined how reliance on imported energy may result in difficulties pertaining to energy security in Nepal. According to their ARDL research, a 1% rise in population leads to a 4% increase in electricity usage, making the nation's energy security problem worse. According to Singh (2013), there is a significant discrepancy between supply and demand for energy. According to the report, one strategy to improve the energy system in the area may be regional cooperation which includes bilateral trade and cross-border energy investments. To address the issues of energy security, the authors cite physical links and energy exchange among the nations of the Asia-Pacific region (Cronshaw & Grafton, 2014). According to Vivoda (2019), major Asian importers, such as China, Japan, and South Korea may ensure their energy security by increasing their use of natural gas and various forms of LNG.

Gozgor et al. (2020) used imbalanced panel data for the time period (1970-2015) to analyze how economic globalization affected renewable energy in 30 OECD nations. They discovered that economic globalization, carbon emissions, oil prices, and per capita income all support renewable energy using FMOLS and random effects models. Globalization affected energy use employing the quantile autoregressive distributed lag approach. Additionally, their analysis found that energy consumption in the Netherlands and Ireland is encouraged by globalization.

Shahbaz, Shahzad et al. (2018) used time series and panel data for 25 industrialized economies for the time period (1970-2014) to investigate the causal links between globalization, economic growth, and energy consumption. Their findings demonstrated that economic growth and globalization are the main drivers of energy consumption in most developed nations. Liddle and Sadorsky (2017) found that between 1971 and 2011, power generated in 93 nations using non-fossil fuels resulted in carbon emissions. The empirical findings from AMG and CMG estimators, which use more electricity generated from non-fossil fuels, show that lower carbon emissions translate into better environmental quality. It was discovered that non-OECD economies actually have a greater displacement effect than OECD economies, suggesting that non-fossil fuels have a greater capacity to reduce carbon emissions in non-OECD countries.

Apergis and Payne (2010) examined the relationship between economic growth and use of renewable energy in 13 Eurasian nations between 1992 and 2007. They discovered a two-way causal relationship between economic growth and the use of renewable energy using error correction model. Sadorsky (2009) used annual data from 18 rising economies for the time period (1994-2003) to examine the impact of affluence on the use of renewable energy. According to the study, rising per capita income eventually leads to higher use of renewable electricity.

On this basis, the study discovered that while higher per capita income decreases renewable electricity consumption in the short-run, it enhances the renewable electricity use in the long-run if per capacity income rises.

Shahbaz et al. (2016) aimed to investigate the effects of FD and three dimensions of globalization—economic, social, and overall—on energy consumption and economic growth in India between the years 1971 and 2012. According to a bound test using Bayer-Hanck and ARDL analysis, all globalization factors have a positive relationship with energy consumption, however, FD reduces energy use in India.

Jones (2015) conducted a study that focused on the investors' attitudes concerning the impediments to invest in renewable power projects. The Delphi method was employed to establish that the key problems included the absence of long-term stable public policies and inapt international interest to invest in renewable energy projects. Yet, it also suggested possible policy strategies which could be used to combat these issues.

Three types of Foreign direct Investment (FDI) were identified by Anton and Nucu (2020), based on the consumption of renewable energy in 28 European countries: FD in the banking sector, FD in the bond market, and FD in the capital market. Their panel data showed that all types of FD aided in the promotion of renewable energy in their fixed effects analysis. The study focused on capital deployment in renewable energy to provide consumers with optional deals while filling the identified research gaps in the literature.

Subsequently, Khan et al. (2019) investigated the relationships across 34 high-income nations in Asia, Europe, and the Americas regarding greenhouse gas emissions (GHEm), tourism, FD, energy consumption, trade, and renewable energy. Specifically, they discovered strong feedback links between FD and renewable energy, FD and energy consumption, tourism, trade, and energy using the Dumitrescu and Hurlin non-causality test with annual data for the time period (1995-2017).

Likewise, He et al. (2019) discussed the extent to which green FD can boost the efficiency of Chinese companies' investment in renewable energy. Therefore, based on the Richardson model to assess investment efficiency of businesses, the current research examined 141 Chinese publicly traded renewable companies. The findings revealed that green FD played the role of putting a check on heady investments in renewable energy projects by handling the problems associated with bank credit. Concerning the research questions, it was discovered that green FD helps to decrease the use of funds from bank loans by renewable energy firms, hence supporting the investment in renewable energy systems. The study also concluded that the government should enhance and embark on reforms of financial systems to foster these endeavors.

Analyzing the information from the previous studies concerning the determinants of renewable energy and PPP investments in the energy sector, it could be pointed out that the impact of PPP investments, globalization, financial development, and population income on renewable energy is complex. Alvarez-Herranz et al. (2017), Cedrick and Long (2017), Fadly (2019), Erdogan (2020), and Shahbaz et al. (2020) are the only studies that, to the best of the authors' knowledge, provide insight into PPP investments in energy and present conflicting results regarding renewable energy and the environment.

The above-mentioned studies emphasize that PPP investments must be treated as one of the core approaches to solve the problem of energy deficiency. However, this study is different from the previous studies in certain aspects. Firstly, it aimed to identify if investments in energy infrastructure enhance various forms of energies in South Asia. Secondly, it determined different roles played by FD and FINGLB in improving the energy security as a key component of the South Asian nations' attainment of SDGs.

By examining the results of PPP investments in renewable electricity in Asian nations dealing with energy insecurity issues, this study aimed to close these gaps. Additionally, it clarified how globalization, FDI, and private investments relate to the production of renewable electricity in these economies. The latest literature (e.g., Boute, 2020; Cedrick & Long, 2017; Erdogan, 2020; Fadly, 2019; Nepal & Paija, 2019; Shahbaz et al., 2020; Singh, 2013) emphasizes energy security and PPP investments in Asia due to this. Differences in the variables utilized, such as the narrow definition of globalization, trade, FDI, dimensions of FD, and various estimating techniques, could be the cause of discrepancies in the conclusions of earlier studies.

Methodology

Data Measurement

The current study aimed to examine how PPP investments affect the production and consumption of renewable and nonrenewable energy in seven major Asian emerging nations, that is, China, India, Indonesia, Malaysia, Pakistan, the Philippines, and Thailand. The dataset, spanning the years 1993–2017, was gathered from secondary sources. These nations were selected because, taken as a whole, they rank among the largest carbon emitters and face difficulties in obtaining energy. The dependent variables used in this research included Total Renewable Energy Production (TREP) in quadrillion BTU, Total Renewable Energy Consumption (TREC) in quadrillion BTU, and Renewable Electricity Generation (RENELGEN) in billion Kwh. Moreover, fossil fuel electricity generation in billion Kwh. PPP investment in energy, measured by current US dollars, was the variable of interest.

The report also included several important energy indicator drivers. For instance, a large portion of the analysis was carried out while accounting for the degree of FD): per capita GDP, current US dollars, the FINGLB Index, and domestic credit to the private sector split by GDP. These variables were gathered from various sources. The US Energy Information Administration provided the energy-related data used in this analysis including RENELGEN, FFELGEN, TREP, and TREC. While the World Bank's World Development Indicators (WDI) provided the PPP, FD, and PI records. Gygli et al. (2019) and Dreher (2006) provided information on FINGLB. The current study's major regression analysis also followed the custom of converting each variable to its native log form.

Model Specification

Using annual data for the time period (1993-2017) and a variety of panel econometric techniques, this study investigated how PPP investments affect the production and consumption of renewable and non-renewable energy. Models are created based on relevant theoretical and empirical studies for empirical analysis.

FD stands for financial development, FINGLB for financial globalization, PI for per capita income, PPP for public-private partnership investments, TREP for total renewable energy production, TREC for total renewable energy consumption, FFELGEN for fossil fuel electricity generation, and RENELGEN for renewable electricity generation. The cross-sectional units are denoted by t and i, respectively, and the error term is represented by μ.

$$RENELGEN_{it} = \beta_0 + \beta_1 + FD_{i,t} + \beta_2 + FINGLB_{i,t} + \beta_3 PI_{i,t} + \beta_4 PPP_{i,t} + \mu_{i,t} \quad (1)$$

$$FFELGEN_{it} = \beta_0 + \beta_1 + FD_{i,t} + \beta_2 + FINGLB_{i,t} + \beta_3 PI_{i,t} + \beta_4 PPP_{i,t} + \mu_{i,t} \quad (2)$$

$$TREP_{it} = \beta_0 + \beta_1 + FD_{i,t} + \beta_2 + FINGLB_{i,t} + \beta_3 PI_{i,t} + \beta_4 PPP_{i,t} + \mu_{i,t} \quad (3)$$

$$TREC_{it} = \beta_0 + \beta_1 + FD_{i,t} + \beta_2 + FINGLB_{i,t} + \beta_3 PI_{i,t} + \beta_4 PPP_{i,t} + \mu_{i,t} \quad (4)$$

Table 1

Compounded Annual Growth Rates (CAGRs), 1993-2017(%_

	RENELGEN	FFELGEN	TREP	TREC	FD	FINGLB	PI	PPP
China	10.52	8.33	10.60	10.72	2.03	1.60	14.0	2.88
India	5.41	6.35	5.25	5.35	3.03	4.48	8.17	0.94
Indonesia	5.38	6.83	4.88	5.01	-0.97	-0.43	6.60	14.17
Malaysia	7.52	6.55	6.99	6.92	0.40	-0.12	4.66	-5.27
Pakistan	2.36	5.11	2.82	2.88	-1.51	-0.47	5.14	8.58
Philippines	3.29	7.00	2.83	2.68	3.84	-0.55	5.55	0.22
Thailand	9.24	4.08	8.69	9.39	1.23	0.15	4.65	9.27

Remarkably, previous research on energy economics employed a range of panel data techniques, such as considering both independence and cross-sectional dependence. Therefore, discovering whether the selected variables have cross-sectional dependency or independence is the next step in determining their accuracy. Initially, this was addressed using the CD test developed by Pesaran (2004). CD tests provided conflicting findings, with some indicating cross-sectional dependence and others not. Due to this, it is negligent to limit using panel econometric methods that only use the independence or cross-sectional dependency assumption. Thus, two sets of panel unit root tests were used: the cross-sectional augmented IPS (CIPS) test (Pesaran, 2007), which takes CD into account, and the Fisher ADF test (Maddala & Wu, 1999), which assumes cross-sectional independence. The null hypothesis that a unit root exists is tested by both tests.

In panel dynamic OLS (DOLS) and panel completely modified OLS (FMOLS), two group-mean estimation techniques created by Pedroni (2000, 2001), are among the panel econometric techniques used for empirical study. Nevertheless, cross-sectional dependence in the data is not controlled by the application of the DOLS and FMOLS approaches. While, the FMOLS is based on a semi-parametric approach to endogeneity and serial correlation problems, the DOLS method uses a parametric approach to build the OLS estimator (Sadorsky, 2009). Finally, the AMG estimator is employed which takes CD into consideration and was created by Teal and Eberhardt (2010) and Eberhardt and Bond (2009).

Results

Firstly, compound annual growth rates (CAGRs) are computed between the two eras and across various Asian nations to have a first look at how variables behaved over the whole study period (1993–2017). The CAGR results are displayed in Table 1, with China having a CAGR of 10.09 higher than RENELGEN, followed by Thailand, Malaysia, India, and Indonesia. When compared to the Philippines and Pakistan, the rise in renewable electricity generation is the slowest. In fact, renewable electricity generation surpasses fossil fuel generation and growth rates of fossil fuel electricity generation (FFELGEN) are highest in China. Furthermore, China, Thailand, and Malaysia have growth rates above 10% for both TREP and TREC. With growth rates of less than 3%, Pakistan and the Philippines are two of the few countries with the slowest rates in these categories.

Lastly, the growth rates of primary variable of interest (PPP investments in the energy sector) were determined which showed that only Indonesia exceeded a 10% growth rate and the Philippines and India recorded growth below 1%. China's growth in PPP investment was also under 3% and Malaysia saw a rapid decline in PPP investment growth over the period. Due to the large and varying growth rates of variables' growth rates for these countries, it must be known how PPP investments for the generation of renewable electricity, for the generation of fossil fuel electricity, for TREP, and TREC play a role in these countries for the time period (1993–2017). the findings would inform the making of targeted policy recommendations to help achieve energy security and reduce climate impact on major Asian developing economies.

As indicated in Table 2, the next step of the current study was to provide summary statistics for each country, variable, and the entire panel dataset covering the time period (1993–2017). China and India were the leaders in renewable power generation, fossil fuel electricity generation, TREP, and TREC during the study period, as expected given their respective economic sizes. According to the research, the countries with the lowest levels of renewable energy production and consumption were Malaysia and Thailand. Pakistan has the lowest average FD among the nations, while China, Malaysia, and Thailand have the highest FD. Remarkably, Malaysia has the highest level of FINGLB, while India has the lowest. The average per capita income is highest in Malaysia, while Pakistan and India report the lowest per capita income, both below 1,000 USD. Notably, India's average PPP investment in the energy sector is approximately 2.5 times that of China, whereas Pakistan's PPP investment remains below 1,000 million USD. Table 2 also provides aggregate statistics for the panel dataset across these countries, highlighting the substantial role played by Asian nations in renewable energy generation and consumption, with significant investments in the energy sector via PPP arrangements.

Using log-transformed panel data, the study determined unconditional correlations between a few chosen variables. The correlations for main variables of interest are shown in Table 3, providing a preliminary understanding of the connections between these variables, especially about energy and PPP measures. The correlations show that PPP investments are favorably and strongly correlated with TREP, TREC, renewable electricity generation, and fossil fuel electricity generation. Crucially, the independent variables' (regressors') correlations are not overly high, indicating that the model does not have serious multicollinearity problems. However, these correlations by themselves do not prove that the dependent and independent variables are related; thus, a more thorough analysis is required, accomplished in the next part.

Correlations by themselves do not prove that the dependent and independent variables are related; thus, a more thorough analysis is required, accomplished in the next part.

Table 2

Summary Statistics Table: Consolidated Data (1993–2017)

Country	RENELGEN	FFELGEN	TREP	TREC	FD	FINGLB	PI	PPP
China	594.84	2,209.80	6.42	6.11	117.06	42.05	3,220.71	1,996.59
India	126.44	619.53	1.47	1.53	38.32	34.57	899.27	5,285.09
Indonesia	18.30	113.09	0.20	0.18	34.66	58.81	1,927.81	1,723.43
Malaysia	8.70	80.46	0.09	0.08	120.69	70.59	6,664.03	1,172.16
Pakistan	27.48	51.86	0.30	0.30	22.55	39.76	811.80	991.51
Philippines	17.84	36.67	0.18	0.18	36.85	61.08	1,666.06	1,419.84
Thailand	10.44	110.05	0.12	0.12	122.65	58.92	3,749.22	1,226.62
				Consolidated Statistics				
Statistic	RENELGEN	FFELGEN	TREP	TREC	FD	FINGLB	PI	PPP
Mean	114.86	460.21	1.25	1.21	70.40	52.25	2,705.56	1,973.61
Minimum	3.66	13.19	0.04	0.04	15.39	13.96	301.16	10.50
Maximum	1,647.53	4,397.63	17.56	17.30	166.50	75.56	11,319.08	29,608.76
Std. Dev.	267.06	894.07	2.85	2.78	46.03	13.80	2,582.74	3,448.03
Skewness	3.87	2.94	3.78	3.84	0.44	-0.31	1.54	5.26
Kurtosis	18.64	11.16	18.02	18.53	1.65	2.38	4.77	35.73
Jarque-Bera	2,218.83	736.78	2,061.31	2,188.49	18.87	5.55	92.32	8,617.01
Probability	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00

Note. The above summary statistics were calculated using data before log conversion. PPP is in million

Table 3

Unconditional Correlation Among the Selected Variables

Variable	RENELGEN	FFELGEN	TREP	TREC	FD	FINGLB	PI	PPP
RENELGEN	1.000							
FFELGEN	0.877*** (0.000)	1.000						
TREP	0.999*** (0.000)	0.884*** (0.000)	1.000					
TREC	0.998*** (0.000)	0.878*** (0.000)	0.998*** (0.000)	1.000				
FD	0.036 (0.637)	0.353*** (0.000)	0.034 (0.651)	0.025 (0.746)	1.000			
FINGLB	-0.574*** (0.000)	-0.434*** (0.000)	-0.59*** (0.000)	-0.59*** (0.000)	0.401*** (0.000)	1.000		
PI	-0.139* (0.066)	0.122 (0.108)	-0.14* (0.062)	-0.160** (0.034)	0.678*** (0.000)	0.602*** (0.000)	1.000	
PPP	0.294*** (0.000)	0.284*** (0.000)	0.299*** (0.000)	0.299*** (0.000)	0.130* (0.088)	-0.143* (0.059)	0.104 (0.173)	1.000

Note. The above correlations were calculated using log data; probability values are in parentheses. *, **, and *** indicate significance levels at 10%, 5%, and 1%, respectively.

Table 4

Investigating Cross-Sectional Dependence (CD) and Order of Integration of the Variables

Variable	CD-Test	*p*-Value	Corr	Abs(Corr)	Chi-Sq (Level)	*p*-Value (Level)	Chi-Sq (First Diff.)	*p*-Value (First Diff.)	Zt-Bar (Level)	*p*-Value (Level)	Zt-Bar (First Diff.)	*p*-Value (First Diff.)
RENELGEN	18.890***	0.000	0.824	0.824	11.917	0.613	82.072***	0.000	-0.745	0.228	-7.447***	0.00
FFELGEN	22.200***	0.000	0.969	0.969	14.962	0.381	62.310***	0.000	0.596	0.724	-6.746***	0.00
TREP	19.150***	0.000	0.836	0.836	15.314	0.357	87.200***	0.000	-0.364	0.358	-7.756***	0.00
TREC	18.310***	0.000	0.799	0.799	15.219	0.363	80.991***	0.000	-1.109	0.134	-7.186***	0.00
FD	0.710	0.476	0.031	0.401	7.590	0.910	25.468**	0.030	1.110	0.867	-4.142***	0.00
FINGLB	2.410**	0.016	0.105	0.470	16.660	0.275	49.680***	0.000	1.377	0.916	-8.637***	0.00
PI	22.110***	0.000	0.965	0.965	13.110	0.518	36.779***	0.001	1.248	0.894	-6.729***	0.00
PPP	3.130***	0.002	0.137	0.170	13.276	0.505	71.976***	0.000	0.081	0.532	-8.396***	0.00

Note. ** and *** indicate rejection of the null hypothesis of cross-sectional independence (CD-Test) or unit root (Fisher-ADF and CIPS tests) at the 5% and 1% significance levels, respectively.

Discussion

Based on the preliminary examination, this study demonstrated that there is a good concordance between energy metrics and PPP investment in these important Asian developing economies. Their long-term connection was empirically confirmed within a multivariate model framework using a variety of robust panel econometric methodologies. With the development of panel econometric techniques, it is first important to determine whether or not the variables that have been chosen are cross-sectionally dependent. Researchers would use CD test results to assist them choose the most appropriate econometric techniques for additional empirical study.

Therefore, the CD test is applied to all the variables that were chosen and Table 4 displays the findings. The rejection of the null hypothesis of CD at 1% level of significance suggests that all dependent variables (energy indicators) in this CD test show CD. Of the independent variables, only the FD indicator has the null hypotheses rejected. According to the findings, there is a high CD relationship between all variables except FD.

The first-generation Fisher ADF test and the second-generation CIPS test are the two panel unit root tests that were used considering the conflicting empirical findings of CD among variables. In the first-generation panel unit root tests, CD is already considered; in the second-generation testing, CD is necessary. To determine their order of integration and if they are stationary, these variables are subjected to these tests. None of the variables reject the null unit root (non-stationary) at the level data using both approaches, according to the unit root test results in Table 4. All of the chosen variables are found to be integrated of order I (1), confirming the rejection of the null hypothesis, based on evidence from these tests of the first differenced data series.

Due to conflicting data regarding CD, panel econometric techniques that may handle both CD and independence, must be chosen. In particular, DOLS and FMOLS methods were employed which successfully handle endogeneity and serial correlation but do not take CD into account. However, FMOLS employs a semi-parametric technique to enhance the OLS estimation, whereas DOLS uses leads and lags. Additionally, the AMG estimator is incorporated which takes CD into consideration. This offers the chance to assess whether the regression coefficients from these techniques are sensitive or stable using various methodologies. Table 5 displays the outcomes of various techniques.

The CEMADOLS and CFMOLs methods are used to estimate the long-term elasticities. PPP investments, in renewable electricity generation, yield an elasticity of 0.108 for both methods utilizing the DOLS approach. While FMOLS yields an elasticity of 0.007 which is significant at 10% level. In comparison to 1% PPP investments, this translates into an increase in renewable electricity, generating capacity of 0.108 to 0.007%. Additionally, the findings indicate that PPP investments have a negative impact of -0.041% to -0.023% on the generation of energy from fossil fuels. PPP investments have a beneficial impact on both TREP and TREC, according to both approaches. Electricity generation from fossil fuels is unfavorably impacted by FD growth, whereas renewable energy metrics are positively impacted. However, FINGLB results in a decrease in renewable energy and an increase in fossil fuels. Additionally, PI's long-term elasticities are considerable and favorable. The findings show that PPP investments, FD, FINGLB, and PI have a significantly detrimental impact on the production of energy from fossil fuels and a significantly beneficial impact on TREP, TREC, and renewable power generation.

For OECD economies, these empirical results are in line with those of Gozgor et al. (2020). The AMG estimator results are shown in Table 5 for each model. In contrast to the DOLS and FMOLS approaches, the AMG estimator additionally accounts for CD. According to the data, PPPs have a similar impact on energy indicators as DOLs and FMOLS. However, the effects of energy indicators on the generation of electricity from fossil fuels and renewable sources are negligible, while those from other sources are large and positive. The second important and favorable effect is that of FD, particularly pertaining to the production of renewable power and TREP.

These results are consistent with those of Kutan et al. (2018) and other researchers who discovered that financial markets have the ability to encourage the usage of renewable energy. However, these results are contradictory with that of Khan et al. (2020) who showed that FDI significantly reduces renewable energy in European economies. This is probably because different sample nations, time periods, and estimation methods were used. The per capita income estimates, however, differ greatly from the previous data (DOLS and FMOLS). PPP investments are important factors influencing the production of renewable electricity in the major developing Asian countries and are equally important for the overall production and consumption of renewable energy as supported by the results of long-term projections using all approaches and models. PPP investments also lessen the quantity of electricity produced using fossil fuels and encourage the use of renewable energy sources. These findings have important policy implications for Asian economies.

According to empirical results, PPP investments in the energy sector are crucial to address energy demands, support climate change targets, and encourage the use of renewable energy sources while discouraging the use of fossil fuels. However, for many Asian developing economies working to offer steady access to electricity, energy security continues to be a major worry. Even with advancements, many nations still face challenges to achieve universal coverage. In 2016, for instance, only 71% of Pakistan's population had access to electricity, whereas India had nearly 90%. These difficulties show how Asian nations must put energy availability first before addressing climate changes which is directly related to reliance on fossil fuels.

Table 5

Long-Run Estimates of Renewable Electricity, Fossil Fuel Electricity, and Total Renewable Energy Production (TREP) and Consumption (TREC)

Estimator	Variable	RENELGEN Coefficient (Prob.)	FFELGEN Coefficient (Prob.)	TREP Coefficient (Prob.)	TREC Coefficient (Prob.)
Panel DOLS	FD	0.403 (0.257)	-0.550*** (0.003)	0.251 (0.462)	0.260 (0.501)
	FINGLB	-0.487 (0.604)	0.689* (0.058)	-0.715 (0.401)	-0.328 (0.749)
	PI	0.624*** (0.000)	0.807*** (0.000)	0.671*** (0.000)	0.594*** (0.000)
	PPP	0.108* (0.077)	-0.041** (0.029)	0.107** (0.047)	0.127* (0.055)
Panel FMOLS	FD	0.107*** (0.000)	-0.078*** (0.000)	0.082*** (0.003)	0.083*** (0.006)
	FINGLB	0.374*** (0.000)	0.468*** (0.000)	0.414*** (0.000)	0.366*** (0.000)
	PI	0.717*** (0.000)	0.754*** (0.000)	0.739*** (0.000)	0.696*** (0.000)

Estimator	Variable	RENELGEN Coefficient (Prob.)	FFELGEN Coefficient (Prob.)	TREP Coefficient (Prob.)	TREC Coefficient (Prob.)
	PPP	0.007* (0.097)	-0.023*** (0.000)	0.007** (0.042)	0.007* (0.064)
AMG Estimator	FD	0.207* (0.067)	0.035 (0.727)	0.193* (0.054)	0.176 (0.132)
	FINGLB	-0.072 (0.508)	-0.126 (0.378)	0.056 (0.682)	0.025 (0.779)
	PI	-0.231** (0.038)	0.084 (0.239)	-0.199* (0.077)	-0.200* (0.090)
	PPP	0.016 (0.145)	-0.005 (0.135)	0.018* (0.054)	0.017* (0.080)
	Constant	3.411*** (0.000)	4.137*** (0.000)	-1.850* (0.078)	-1.592* (0.075)

Note. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively

Conclusion

This research focused on the role that PPP investments play in the generation of renewable electricity, coal fired electricity, and TREP and TREC in seven primary Asian developing economies for the time period (1993-2017). The possible causes were empirically tested using robust panel econometric techniques that dealt with CD and independence. It was determined that the PPP investments result in significantly greater renewable electricity generation, a positive influence on TREP and TREC, and a negative influence on fossil fuel generation. This study contributed to previous literature by being the first to analyze the importance of PPP investments in all renewable and nonrenewable energy sectors towards the issues of endogeneity and the serial correlation for more robust results. Furthermore, the study also analyzed the role of critical control factors including FD, FINGLB, and private investment (PI) in energy dynamics.

The study focused on seven key Asian economies, with recently available data which provided a basis for constructive policy suggestions for these countries. It also enhanced the importance of renewable energy and highlighted that such renewable energy projects should be supported through PPP initiatives. The findings are in line with the SDGs. These SDGs include clean and affordable energy (SDG-7), sustainable economic growth

(SDG-8), climate action (SDG-13), and revitalizing global partnerships for sustainable development (SDG-17).

Policy Implications

Considering the ground-level realities and empirical evidence, key policy recommendations are discussed. Many Asian countries, especially developing economies, prioritize energy security by ensuring a stable electricity supply for domestic and industrial use amid rising demand. Nations, such as India and China are significantly investing with private sector participation to enhance energy generation capacities, develop non-conventional energy projects, and improve infrastructure. Resultantly, PPP investments are effectively addressing the growing energy needs by facilitating access to renewable energy sources.

Policymakers, firms, and governments should prioritize renewable energy promotion across economic activities. Governments must implement effective policies to boost investments in renewable projects via PPP schemes and ensure guaranteed returns to attract investors. Additionally, using media to raise awareness about renewable energy and encouraging citizen investment is vital. Developing strong renewable energy markets and distribution channels would address energy shortages, replace conventional sources, and help meet climate change targets. Overall, governments should strengthen policies to enhance PPP investments in renewable energy.

Limitations and Future Directions

However, this study has limitations. It focused on selected Asian countries, which may not reflect the impact of PPP in other nations. Future research could incorporate additional factors, such as climate change and temperature variations, extending the time, and including more countries to yield more robust findings

Conflict of Interest

The authors of the manuscript have no financial or non-financial conflict of interest in the subject matter or materials discussed in this manuscript.

Data Availability Statement

Data associated with this study will be provided by corresponding author upon reasonable request.

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