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RESEARCH ARTICLE

Assessing energy efficiency in the Asia-Pacific region and the mediating role of environmental pollution: evidence from a super-efficiency model with a weighting preference scheme

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Abstract

The demand for primary energy resources has increased significantly due to the rapid growth of the global economy and increasing greenhouse gas (GHG) emissions. Therefore, improving energy efficiency levels is essential for global energy, energy security, and environmental sustainability. In the context of the Asia-Pacific region, the study of energy efficiency among different countries can play a role in better energy utilization. These countries also provide a policy for the Asia-Pacific region to improve its energy utilization. This study's primary focus is to investigate the optimal efficiency score of 15 areas of the Asia-Pacific region, and the analysis is based on super-efficiency (radical) and super slacks-based measure (SBM) data in a nonparametric DEA model. Three areas in the Asia-Pacific are selected for energy efficiency measures: South Asia, East Asia, and Australasia. The results suggest that Bangladesh, Pakistan, China, Singapore, New Zealand, the Philippines, Japan, India, Indonesia, Malaysia, Thailand, and Vietnam obtain the most efficient score of 1 in both DEA models throughout the study period. Australia and Sri Lanka receive a low score during all study periods, while Hong Kong does not have data for all study years. The results of the study will help improve energy performance, cost-effectiveness, and environmental sustainability, increasing the competitiveness and scalability of efficient energy sources.

Keywords Energy security · Super radical · Super SBM · Asia-Pacific · Energy efficiency · Optimization

Introduction

The world is facing serious energy efficiency and energy security issues. Continuously rising temperatures globally have been reported, thus necessitating efforts to improve energy security and environmental sustainability to move the world towards greater energy independence. In light of the extreme energy and environmental issues, a low-carbon economy is urgently needed in many countries (Anser et al. 2020i; Anser et al. 2020g; Anser et al. 2020b; Anser et al. 2020j; Anser et al. 2020a). Low-carbon solutions involve technological, structural, and governance approaches. For today's global economy, energy and the environment are one of the most critical concerns. One of the fundamental reasons for the

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widespread depletion of the environment has been the worldwide production and utilization of oil (Tiep et al. 2021; Singh et al. 2018). Many countries have found ambitious energy usage and diversification planning to improve energy production to facilitate industrial economic development while reducing energy utilization (Zhang et al. 2018; Ahmad et al. 2020a; Petrović-Ranđelović et al. 2020).

It is believed that improving energy efficiency is a meaningful way to reduce energy consumption and minimize environmental emissions (Anser et al. 2020f; Anser et al. 2020e; Anser et al. 2020h; Anser et al. 2020c; Anser et al. 2020d). Consequently, the corresponding technical advancements in energy production and utilization must be encouraged (Asif et al. 2020; Sarker et al. 2020; Iram et al. 2020; Tehreem et al. 2020). The development of a fair and detailed climate policy framework for increasing energy efficiency is also important (Ouariachi et al. 2019). Many researchers and policymakers are consistently trying to improve the energy efficiency level with different optimal methodologies (Liu et al. 2020; Lin et al. 2020; Jun et al. 2020; Geng et al (2019). According to the International Energy Agency (IEA), the study explains that energy efficiency is aimed at controlling global energy consumption Sağlam (2017). The most efficient use of energy is to generate more sustainable development (Wasif Rasheed and Anser 2017; Xu et al. 2020; Ahmad et al. 2020b). The use of fossil fuel resources has been declining for the past few decades. Therefore, policymakers and researchers continuously look for novel sources for upgrading energy efficiency. The primary focus of previous studies was on the importance of clean and cheap electricity for sustainable development and the effective use of energy in specific areas to assess energy efficiency (Yousaf et al. 2020; Tehreem et al. 2020; Wasif Rasheed and Anser 2017; Xu et al. 2020).

The super-efficient model has become popular in recent years for assessing efficient and inefficient decision-making units (DMUs) because the super-efficient model measures the performance in both beneficial and harmful situations. The advantage of this new study is that it uses two data envelopment analysis (DEA) methods for measuring the energy efficiency of the Asia-Pacific regions (Mohsin et al. 2020b; Mohsin et al. 2018; Mohsin et al. 2021). However, DEA models have favorable theoretical properties, and so the environmental efficiency performance scores of many comparable entities are 1. Hence, it becomes challenging to make a meaningful comparison. According to the DEA, if a DMU obtains an efficiency score of 1, it is fully efficient and below 1 it is not efficient. Therefore, it is meaningful to include output shortfalls and input excesses in the DEA-based models while measuring energy efficiency performance (Yang et al. 2021; He et al. 2020; Mohsin et al. 2020a, b). Few studies have conducted energy efficiency analysis using a two-stage DEA model, particularly in Asia-Pacific countries.

Consequently, the purpose of this study is to fill the literature gap and to use advanced DEA methodology to calculate the optimum energy performance of the Asia-Pacific regions, which will be helpful for future sustainable development and policymaking (Hosseinzadeh Lotfi et al. 2011). Various research on energy performance, such as economic growth and environmental quality, have been performed; for example Bampatsou and Halkos (2019) explored the energy efficiency of energy-generating equipment, and Blum (2015) studied environmental efficiency in relation to economic growth. Song et al. (2018) assessed energy and CO2 emission efficiency, and Iftikhar et al. (2018) analyzed both economic and environmental efficiency (Mohsin et al. 2019; Mohsin et al. 2020a; Mohsin et al. 2021).

Even though numerous factors affect energy conservation implementation, the economic benefits are profound, according to the studies described above. Economic incentive policies, among other policies, were found to play a significant role in encouraging the adoption of energy-efficient goods, mostly when the goals and subsidy levels were acceptable (Sun et al. 2020b). As a consequence, GDP was introduced as an output element. The bulk of energy efficiency study is done at the national and regional levels, with no literature on Asia-Pacific economic energy efficiency (Sun et al. 2020c; Sun et al. 2020a; Sun et al. 2020b). On the other hand, the standard DEA model avoids input-output, resulting in errors in estimation performance. The super-performance DEA model, which essentially addresses the deviation issue created by the standard DEA model's exclusion of the slack component, is commonly utilized in energy efficiency measurement. The Asia-Pacific energy market did not reduce energy usage during this period. More significant measures are needed to fulfill the European Commission's energy efficiency targets. Consequently, a more in-depth analysis of the Latvian industrial sector is expected to recognize the potential for improved energy production and have specific recommendations for national policymakers.

Our contribution seeks to examine the energy efficiency mechanisms of the Asia-Pacific region by using DEA. Consequently, our primary aim is to determine the driving mechanism of maximization of energy efficiency without reducing economic growth and progress. The study uses DEA to assess the degree of interaction between energy use, environmental pollution, and economic development for this reason. Our paper also seeks to establish a series of indicators that present multiple facets of energy efficiency comparably and systematically. The aim is to go beyond reducing energy waste by raising energy production per unit of energy input to improve energy security. Unlike others, we measure energy efficiency using capital, labor, and energy consumption as input variables. GDP is utilized as a desirable output, while CO_2 emission is an undesirable result.

Consequently, a data envelopment method incorporating computer simulation is created to resolve energy efficiency and energy security and the study's target. The optimized approach will minimize the number of slacks (visualization of resources) through a simulation framework to determine the most effective point of energy efficiency. DEA is used to rate the applicable scenarios within the current range and find the best retrofit approach for enhancing energy efficiency.

The remainder of the paper is formulated as follows: The "Literature review" section defines the energy status of Asia-Pacific countries. The "Data and methodology" section presents the background of the selected model. The "Results and discussion" section elaborates on the results and discussion. The final section sums up the conclusion and policy suggestions.

Literature review

Energy initiatives and policies in Asia are needed to meet the world's infinite demand for energy, ensure energy stability, and reduce the impact of energy on the environment. Massive power plants are required. Hydroelectric power and coal electricity are no longer capable of serving developing nations' needs in energy generation. These countries are participating in the quest for alternative renewable energy sources. We note that collecting raw materials and underground facilities could be managed under a single roof if an agreement were reached between Asian countries (Alemzero et al. 2020b; Sun et al. 2020a; Alemzero et al. 2020a; Ríos and Olaya 2018; Iqbal et al. 2019; Al Asbahi et al. 2019; Sun et al. 2019); Chander (2017); Kamran (2018). Cooper's model is based on Farrell's method of mathematical programming, also called linear programming. Banker and Chang et al. (2006) later developed a DEA model with a variable return-to-scale (VRS) mechanism. Different DEA models have various advantages Ouenniche and Tone (2017). The SMB model with the ability to measure super-efficiency provides the best way to deal with undesirable outputs of CO2 emission. It can also compare the efficient DMUs, including country, city, and organization. CCR and BCC SEA models are two different DEA models in which efficient DMUs are given an efficiency score of 0 and an inefficient score below 1.

BCC and CCR models also recognize when DMUs are efficient and inefficient. The various techniques were developed as part of the DEA method. The super-efficiency process has both beneficial and harmful situations. It remains to be seen whether the super-efficiency model works better than both inefficient and effective DMUs. The super-efficiency strategy can also provide an essential method for decision-makers to explain the actual position of different forms of efficient DMUs.

The same level of inputs maximizes the outputs in the CCR-DEA model; however, as a by-product of valuable outputs, the manufacturing mechanism generates undesirable outputs, such as CO_2 pollution and contaminants. Environmental sustainability aims to create more good outcomes and fewer wrong outputs by utilizing the most periodic inputs (i.e., natural resources). In such instances, standard DEA models struggle to measure environmental efficiency because wrong outputs necessitate complicated dealings to achieve a more detailed estimate. Several DEA models have measured environmental performance by using low outputs in the conventional DEA system. This input-oriented model outperforms the DEA super-efficiency and SMB models, among others.

This imperative is compounded by the unequal allocation of resources in the Asia-Pacific region and the complexities of the global energy markets. This is expressed in the Committee on Energy's first-session report (E / ESCAP/73/30) and shows the relationship among the increasing demand for energy, dependency on fossil fuels, low energy usage, restricted use of renewable energy, lack of access to sustainable and clean energy, and the need to move to a low-carbon and environmentally sustainable energy future. While countries in the region accept the need for the transformation to a renewable energy infrastructure, the variety of circumstances they face suggests no concrete path or timetable for achieving this (Hanif et al. 2019). With large differences in geography and technological skills, Asia-Pacific countries have varying levels of development and uneven resources. There are several policy choices to calibrate each nation's response to driving progress towards a sustainable energy future. Many countries are well on the path to a sustainable future for energy, while some have just started. Regional collaboration for the utilization of capacity, expertise, technologies, investment, and local markets development is an integral component of the transition to renewable energy. However, the Asia-Pacific region needs to use available energy resources efficiently.

The ESCAP Member States invited the Secretariat to draw up this "Regional Renewable Energy Cooperation in Asia and the Pacific" theme study for 2017 in response to these opportunities and to add to the knowledge base and catalyze action. This publication takes note of the challenges and successes made in the region-wide transition to renewable energy. It outlines some of the strategies to be discussed by policymakers in the region to balance the economic, social, and environmental facets of life and provides a series of recommendations for implementing a regional partnership mechanism for renewable energy. The Asia-Pacific region's transition to renewable energy has also begun. Investment in renewables has overtaken investments in fossil energy region-wide. In several nations, more sophisticated energy efficiency plays a part in decoupling economic development from energy consumption. Cross-border communication connections for electricity are being built, and several others are proposed. Innovations of energy are proceeding quickly and are unleashing opportunities to challenge existing models of energy supply. At the household, district, and industrial levels, renewable energies, such as solar, generate low-cost energy. To change the power generation and transport markets, storage systems, smart grids, and hybrid cars are poised. Innovative strategies, system thinking, alternative financing sources, and advanced business models must respond to this new reality and leverage these developments to help the energy transition.

Energy security of Asia-Pacific countries

According to the IEA, the overall demand for power generation increased by 4.9% from 600 million kilotonnes of oil equivalent (ktoe) in Asia-Pacific countries to 18.7138 million ktoe. Asia-Pacific countries have achieved this significant increase. Global primary energy demand in the Pacific increased from 30.6% in 2000 to 39.1% in 2016, with the region comprising 71.8% of worldwide increases in primary energy demand (Zhang and Song 2021; Ma et al. 2019; Guo and Yuan 2020). All South Asian countries are projected to develop oil consumption by 6%. India has oil reserves of 187,138 million barrels (Table 1) of the most significant crude oil in Southeast Asia. Sri Lanka and Pakistan, in contrast, have 34,568 million and 4608 million, respectively. Unless India continues to consume its crude oil at the current pace, stocks will be depleted for 35 years (Yarovaya et al. 2021). As far as natural gas is concerned, India, with a combined capacity of 390,944 million cubic meters, followed by 116475 million cubic meters and 48,378 million cubic meters, respectively, for Japan and Indonesia. India, Pakistan, and Bangladesh only produce natural gas with a proportion of production reserves of 34, 20, and 17. For biomass, India has the highest share of 7479 million tonnes.

Table 1 shows that the per capita energy consumption in Pakistan and Sri Lanka ranges from 119.7 kWh in Bangladesh to more than 635 kWh. The overall regional electrification rate is 73%, meaning that about 418 million people live without sufficient electricity. This figure reflects over one-third of the 1.3 billion people worldwide without access to electricity. Therefore, the average non-solid fuel access in the area is 38%.

The electricity supply in South Asian countries (Fig. 1) shows that most countries depend on a single source for more than 50% of their power. The range of options to satisfy different energy needs is constrained by a single source, which raises energy security issues. In addition, despite large reserves of indigenous coal, Japan imported 28 million tons of coal in 2015, primarily due to low-level domestic coal and technical limits.

Table 1 The total energy supply of South Asian countries

Countries	Coal (Thousand Short Tons) ktoe	Natural gas (trillion cubic feet) ktoe	Nuclear (Million Kilowatthours) ktoe	Hydro (MJ/kg) ktoe	Wind, solar (watts) ktoe	Biofuels and waste (per kilogram) ktoe	Oil (million barrels) ktoe
Sri Lanka	12,024	1510	400	1290	346	44	4608
Nepal	13,487	791	812	12,000	398	1	9778
Hong Kong	11,846	734	5500	3400	635	2524	4354
New Zealand	20,702	1162	4246	3800	2165	5100	1259
Singapore	36,655	899	8931	3400	8575	15	707
Bangladesh	40,523	1984	23,071	10,000	90	16	9534
Philippines	58,126	16,827	3250	3457	826	9028	8546
Viet Nam	78,183	28,199	7811	2323	7651	28	14,646
Malaysia	84,786	20,741	32,210	2445	2285	28	600
Pakistan	104,460	10,750	26,036	2574	2401	247	34,568
Australia	127,033	43,908	31,314	8575	1379	2153	5381
Thailand	138,147	16,389	36,014	8575	819	496	26,301
Indonesia	244,066	48,378	38,901	8575	1602	21,953	57,546
Japan	432,032	116,475	100,895	8575	7124	7765	15,207
India	881,945	390,944	51,021	9991	12,193	7479	187,138

Source: IEA, World Energy Balances 2019

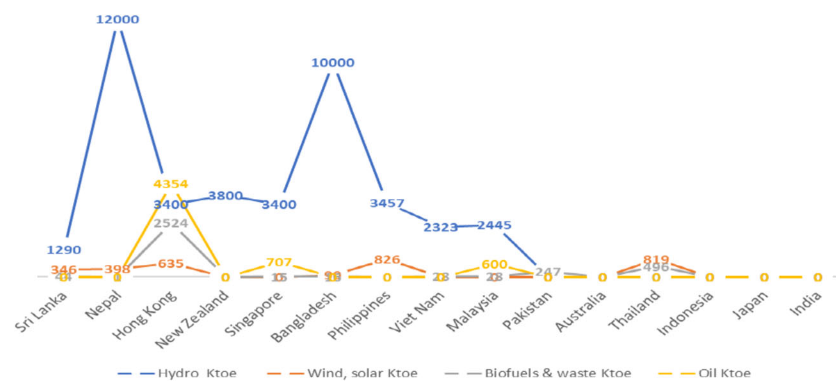


Fig. 1 The total energy supply of Asia-Pacific countries

Data and methodology

In this section, we discuss the proposed methodology. In this study, we use two DEA models, as suggested by Andersen and Petersen. One super slack-based measure model was created to examine the relative efficiency of Asia-Pacific countries using the constant returns scale (CRS). There are vital steps in place for different input and output DMUs. Using DEA model techniques, the principal objective is solved very easily for multi-complex problems, and multiple inputs and outputs also address unfamiliar issues. Cooper and his team proposed a DEA in 1979, called the Cooper–Carlos–Redous (CCR) method, using CRS techniques to calculate the technical efficiency (TE). Banker and his team subsequently introduced a new model called the BCC model. Efficiency results are found through the CCR model, and those DMUs have less input of the highest output levels evaluated efficiently. Unlike the CCR method, VRS techniques are used to measure efficiency (Conlon and McGee 2020). Furthermore, both models are further divided into two types: the first type is input-oriented, which is the main aim to minimize the inputs but simultaneously increase the output level, and the second is output-oriented, with a primary focus on increasing the output level without decreasing the input level.

The CCR model of DEA was introduced by Charnes et al. (1978) to measure decision package size and the technology's overall efficacy. The CCR model assumes that there are no decision packages and has m types of input indicators and t types of output indicators, resulting in the following performance measurement CCR model (Chege and Wang 2020; Blanchard 2019). In the DEA-CCR model, a DMU score of 1 indicates efficient, and below 1 indicates inefficient. There is no other logic tool to differentiate between efficient and inefficient DMUs (Emrouznejad and Liang 2018; Matsuyama 2019), their position or numerical rating of successful DMUs without influencing the rating non-efficiency DMUs, which is a drawback of the CCR-DEA model. A modern slacks-based measure of super-efficiency in DEA incorporates the super-efficiency model created by Liu et al. (2013). The key benefit of this model is the relative value of each productive DMU. Having a high DMU score indicates DMU super-efficiency, which is assigned a position or a rating of all the original efficient DMUs. Anderson and co-workers developed a new super-efficiency model based on a radial technique called the CCR-I input-oriented model to rank all efficient DMUs. This model data removes the DMUs to evaluate the solution set, an efficiency score, a super-efficiency model. The CCR-I model results in super-efficiency DMUS, and these values and consequences apply to rank the DMUs. To maximize radial environmental and energy efficiency, non-radial steps must be taken. Here are the model's optimal solutions: When DMU = 1, DMU applies a restriction to the CCR model with DEA performance. When the DEA data of a framework enables is efficient, both system and measure are efficient; when the DEA data of a decision package is efficient, both the system and scale will be efficient. Since the data envelope review can produce multiple effective decision packages that cannot be further correlated and synthesized, Fleishman and Anderson (1980) suggested the super-efficiency data model, which can evaluate the efficiency of different decision elements.

$$E\_1 = min\ \theta$$
$$s.t$$

$$\sum\text{\_}(j=1)^{n}\ \lambda\text{\_}j\ \ X\text{\_}ij + S\text{\_}i^{(x-)} = X\text{\_}ij0, \quad i = 1,\ldots,m, \quad (1)$$

$$\sum\text{\_}(j=1)^{n\lambda}\text{\_}j\ \ e\text{\_}lj + S\text{\_}l^{(e-)} = \theta\ e\text{\_}lj0, \quad l = 1,\ldots,L, \quad (2)$$

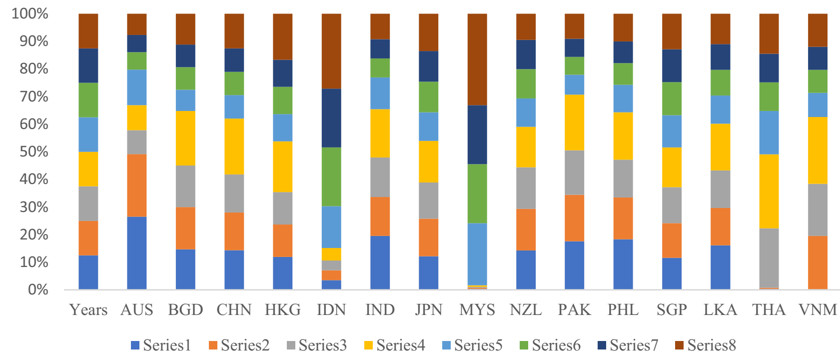
$$\sum\text{\_}(j=1)^{n\lambda}\text{\_}j\ \ y\text{\_}rj + S\text{\_}r^{(y+)} = y\text{\_}rj0, \quad r = 1,\ldots,S, \quad (3)$$

$$\sum\text{\_}(j=1)^{n}\ \lambda\text{\_}j\ \ b\text{\_}kj = \theta\ b\text{\_}kj0, \quad k = 1,\ldots,K, \quad (4)$$

$$\lambda\text{\_}j, S\text{\_}i^{(x-)}, S\text{\_}l^{(e-)}, S\text{\_}r^{(y+)} \geq 0, \quad \text{for all } j, I, l, \quad (5)$$

The CCR-DEA model is used for maximizing inputs through outputs. However, at the same time, the production process produces the worst outputs, including CO_2 emissions and pollutants, as spinoffs of valuable results (Fig. 2). With minimal inputs, environmental sustainability aims to produce more good outputs and fewer negative outputs. In such situations, conventional DEA models do not calculate

Fig. 2 Energy efficiency score



environmental performance because undesirable results require complex dealings to obtain a more detailed performance calculation. To date, numerous DEA models have been used to assess environmental efficiency by incorporating undesirable results into the traditional DEA framework. Among other models, this input-oriented model is the best in DEA super-efficiency and SMB models.

$$\mathrm{E\_2} = \min 1/2 \left(1/\mathrm{L}\sum\_(\mathrm{l}=1)^{\mathrm{L}\theta}\_\mathrm{l}^{\mathrm{e}} \quad + 1/\mathrm{K}\sum\_(\mathrm{k}=1)^{\mathrm{K}\theta}\_\mathrm{k}^{\mathrm{b}} \right) \text{ s.t}$$

$$\sum\_(\mathrm{j}=1)^{\mathrm{n}\lambda}\_\mathrm{j}\ \ \mathrm{X\_ij} + \mathrm{S\_i}^{(\mathrm{x}-)} = \mathrm{X\_ij0},\ \ \mathrm{i} = 1, \ldots, \mathrm{m} \tag{6}$$

$$\sum\_(j=1)^{n\lambda}\_j\ \ e\_lj + S\_l^{(e-)} = \theta\_l^{e}\ e\_lj0, \quad l = 1\ldots\ldots L, \tag{7}$$

$$\sum\_(j=1)^{n\lambda}\_j\ \ y\_rj – S\_r^{(y+)} = y\_rj0, \qquad r = 1, \ldots, S \tag{8}$$

$$\sum\_(\mathrm{j}=1)^{\mathrm{n}\lambda}\_\mathrm{j}\ \ \mathrm{b\_kj} = \theta\_\mathrm{k}^{\mathrm{b}}\ \mathrm{b\_kj0}, \qquad \mathrm{k} = 1\ldots\ldots\mathrm{K}, \tag{9}$$

$$\lambda\_\mathrm{j}, \mathrm{S\_i}^{(\mathrm{x}-)}, \mathrm{S\_l}^{(\mathrm{e}-)}, \mathrm{S\_r}^{(\mathrm{y}+)} \geq 0, \qquad \text{for all j, I, l,} \tag{10}$$

The non-parametric DEA method efficiently provides accurate effective new DMUs and achieves the best solution on the construction frontier. There are many inputs converted into outputs for DMUs. The DEA model can make intelligent the pure or overall technical, scale, and super-efficiency. There are two DEA models, the CCR model and the BCC DEA model; both are helpful benchmarking methods and handle multiple inputs and outputs. Additionally, Cooper et al. suggested selecting the best DMUs. Firstly, all DMUs use the inputs and outputs to allocate accurate data, and secondly, to evaluate the relative efficiency of all DMUs. In standard, the desired inputs and outputs are different measurement units, and the efficiency scores smaller input amounts and more significant amounts.

This study uses three inputs and one output: capital, labor force, and CO_2 emission. The result has only GDP (gross domestic product) with the input-oriented approach. In addition, measuring CO_2 emission with solid fuels and natural gas products and measuring GDP adds to a country's total gross capital. In this study, we use the input model analysis with the super-efficiency CRS-I model and SBM CRS method to assess energy efficiency and CO_2 emission using the DEA input-oriented method for Asia-Pacific countries in 2015-2018.

Meanwhile, the input model has infeasible results. This study did not recognize undesirable models, CO_2 emissions and select the input and output with the related energy efficiency analysis. Here we discuss the energy efficiency inputs and outputs of old studies. In this view, Suzuki Motors indicated that different inputs such as energy, primary energy consumption, non-energy consumption energy, and input such as population and output such as CO_2 and GDP are used to calculate the efficiency of Europe, APEC, and Asian countries. George et al. used labor and capital as input and GDP as output.

Results and discussion

Descriptive statistics

In this research work, we collected data for 15 Asia-Pacific regions for the period 2015–2018, using the World Bank and IEA as data sources. Unfortunately, data for some countries are missing, as data were not available for those countries. Four variables were used in the study: three input variables, i.e. labor force, capital, and CO_2 emissions, and one desirable output, gross domestic product (GDP). Table 1 highlights the input and output indicators.

Table 2 shows the descriptive statistics analysis of all four input and output variables. Table 3 shows the average input variable of the labor force reported as 119,956,207 thousand

Table 2 Input and output variables list

Input variables	Output variable
Capital	Gross domestic product (GDP)
Labor force	CO_2 emissions
Energy consumption	

Table 3 The input and output descriptive statistics results

Description	Max values	Min values	Standard deviation	Average
Labor force (% of total labor force)	787,399,317	2513,183	216,414,609	119,956,207
Capital (current US$)	4,794,552,264,789	26,590,573,979	1,162,016,048,774	549,629,222,900
CO2 emissions (kt)	94,29	18	2292	1009
GDP (current US$)	64,582	1248	21,307	18,671

from 2015 to 2018. China (CHN) has a maximum labor force in 2017 reported as 787,399,317 thousand, and New Zealand (NZL) has a minimum labor force reported as 2513,18 thousand. The capital average is about 549,629,222,900 (constant 2010 US$) persons from 2015 to 2018. The maximum capital country is China (CHN), with about 4,794,552,264,789 (constant 2010 US$) persons in the year 2017, while the minimum capital average reported for Sri Lanka (LKA) of about 26,590,573,979 in 2015. CO2 emissions input increased between 2015 to 2018 on average at 1009 K tons of carbon. The highest CO2 emission input is reported in China (CHN) at 94,29 K tons of carbon in 2018, while the lowest CO_2 emission reported about 18 K tons of carbon from Sri Lanka in the year 2015. To calculate the GDP average growth from 2015 to 2108 at current US dollars was reported about 18,671 billion. The maximum GDP was recorded in Singapore (SGP) at about 64,582 billion current US dollars in 2018, while Bangladesh (BGD) has minimum GDP average growth recorded about 1248 billion current US dollars in 2105.

Energy efficiency analysis

Generally, the DMU has an efficiency score that varies between 0 and 1. This paper uses the DEA model to overcome the following issues to solutions. We studied energy security and environmental sustainability and propose pathways to increase energy supply and mitigate climate change. There is no problem with a density between two or more DMU scores if it is 1 or more than 1, although Andersen, Petersen, and Tone established a super-efficiency model and SBM model used for efficient DMUs. DEA basic models do not correctly assess the DMU's efficiency score, but when a score >1 for each DMU is assigned, they can compare it with other DMUs. We used a super-efficiency score to make the liner programming formula given in Europe and the super SBM score used for the linear programming formula, which is shown in the equation. Table 4 represents the ranking of countries proposed in this study based on model results. The results of both models indicated that Singapore, China, New Zealand, Pakistan, Philippines, Japan, India, Indonesia, and Bangladesh are efficient DMUs during all the periods in both models. It was also found that variations in DMU efficiency scores result in rankings. In 2018, Hong Kong showed efficiency during that year, but results indicate inefficiency to the active region in succeeding years. Results further showed that Thailand and Vietnam are inefficient in 2015 and 2016 because they gained both DMUs and got the highest efficiency score, and they also improved their ranking. Pakistan was found to have an efficiency score and changed in ranking accordingly. In this background, both the optimal model measurement of DMUs and the relation with the super SBM model are more detailed and efficient for the rating and efficiency score. As discussed already, only successful DMUs achieve these rankings. There has been no improvement in results scores less than 1 (Ali and Erenstein 2017; Aghion et al. 2008; Abdullahi 2019).

Table 5 presents the efficient and inefficient DMU results of both models. During all studied years from 2015 to 2018, countries with efficiency scores of 1 or above were Bangladesh, Pakistan, China, Singapore, New Zealand, Philippines, Japan, India, and Indonesia, while Malaysia, Thailand, Vietnam, and Hong Kong had efficiency scores of 1 or above in a few years. However, Australia and Sri Lanka obtained a low average in all study years.

In this study, we selected 15 Asia-Pacific countries and further categorized them into four regions, namely: East Asia (China, Japan, Hong Kong), Southeast Asia (Thailand, Philippines, Vietnam, Malaysia, Singapore, Indonesia), South Asia (Pakistan, India, Bangladesh, Sri Lanka) Australasia (Australia, New Zealand). In Table 6, in both super and SMB models, regions that obtained low-efficiency scores included Australasia. East Asia and Southwest Asia received increasing efficiency scores between 2015 and 2018 (Figs. 2 and 3).

Figure 4 shows the super-efficiency score. In 2050, the United States, China, Canada, Japan, South Korea, and Russia are expected to lead building energy production, accounting for 80.04% of the overall demand of Asia-Pacific economies. Building demand in Asia-Pacific economies will grow from 1387.4 Mtoe in 2016 to 2456.8 Mtoe in 2050 over the projected era, owing mainly to increasing energy demand in emerging economies. Building demand could be held below 1770.46 Mtoe in 2035 to economic growth by 45% by 2035 relative to 2005, and then increase to no more than 2000 Mtoe in 2050. In this case, the construction sector's energy consumption by 2050 would be 1922.6 Mtoe, a 25% decrease

Table 4 DEA model results in efficiency scores and ranking for the study countries

DMU	Super-efficiency score (SES)				SBM score				Super rank	SBM rank
Years	2015	2016	2017	2018	2015	2016	2017	2018	2015-18	2015-18
AUS	0.76	0.65	0.25	0.26	0.37	0.180	0.180	0.22	4,4,4,4	4,4,4,4
BGD	2.80	2.90	2.88	3.75	1.47	1.56	1.56	2.12	12,12,12,12	12,11,11,12
CHN	1.91	1.81	1.83	2.69	1.13	1.12	1.12	1.67	15,15,15,15	15,14,14,14
HKG	0.75	0.74	0.74	1.16	0.62	0.62	0.62	1.05	3,3,3,3	3,3,3,3
IDN	1.03	1.05	1.04	1.33	4.46	6.26	6.26	7.96	13,13,13,13	13,13,13,13
IND	3.02	2.18	2.21	2.71	1.77	1.07	1.07	1.43	14,14,14,14	14,15,15,15
JPN	3.33	3.75	3.60	4.12	2.84	3.05	3.05	3.71	8,11,10,11	8,8,8,8
MYS	0.11	0.11	0.10	0.16	6.62	6.27	6.27	9.72	6,6,6,6	6,6,6,6
NZL	2.32	2.44	2.45	2.38	1.68	1.72	1.72	1.54	1,1,1,1	1,1,1,1
PAK	4.2	4.03	3.86	4.82	1.73	1.56	1.56	2.17	11,9,9,9	11,12,12,11
PHL	4.61	3.80	3.45	4.32	2.50	1.97	1.97	2.53	9,10,11,10	9,9,9,9,10
SGP	1.01	1.09	1.14	1.25	1.02	1.04	1.04	1.12	2,2,2,2	2,2,2,2
LKA	0.19	0.16	0.16	0.20	0.12	0.11	0.11	0.13	5,5,5,5	5,5,5,5
THA	0.12	0.11	6.79	8.44	4.97	3.26	3.26	4.57	7,7,7,7	7,7,7,7
VNM	0.04	4.14	4.04	5.20	1.87	1.79	1.79	2.56	10,8,8.8	10,10,10,9

BGD Bangladesh, *PAK* Pakistan, *CHN* China, *SGP* Singapore, *NZL* New Zealand, *LKA* Sri Lanka, *PHL* Philippines, *JPN* Japan, *IND* India, *IDN* India, *MYS* Malaysia, *THA* Thailand, *VNM* Vietnam, *HKG* Hong Kong, *AUS* Australia

from the existing energy security model. Sustainable resources accounted for just 22 Mtoe and 1.69% of overall building energy production in 2010. Thus, this proportion would barely change, while construction of zero-energy buildings will generate 11%, 27%, and 54% onsite by 2050, respectively.

Table 5 Efficient and inefficient sets of DMUs

	Super-efficiency				Super-efficiency SMB			
	2015	2016	2017	2018	2015	2016	2107	2018
Efficient DMUs are 1 or greater	BGD	BGD	BGD	BGD	BGD	BGD	BGD	BGD
	PAK	PAK	PAK	PAK	PAK	PAK	PAK	PAK
	CHN	CHN	CHN	CHN	CHN	CHN	CHN	CHN
	SGP	SGP	SGP	SGP	SGP	SGP	SGP	SGP
	NZL	NZL	NZL	NZL	NZL	NZL	NZL	NZL
	PHL	PHL	PHL	PHL	PHL	PHL	PHL	PHL
	JPN	JPN	JPN	JPN	JPN	JPN	JPN	JPN
	IND	IND	IND	IND	IND	IND	IND	IND
	IDN	IDN	IDN	IDN	IDN	IDN	IDN	IDN
		VNM	THA	HKG	MYS	MYS	MYS	HKG
			VNM	THA	THA	THA	THA	MYS
				VNM	VNM	VNM	VNM	VNM
								THA
Inefficient DMUs are less than 1	AUS	AUS	AUS	AUS	AUS	AUS	AUS	AUS
	HKG	HKG	HKG	MYS	HKG	HKG	HKG	LKA
	MYS	LKA	MYS	LKA	LKA	LKA	LKA	
	LKA	MYS	LKA					
	VNM	THA						
	THA							

Table 6 DMU efficiency average results based on DEA models

Categoric DMUs	Super-efficiency average score				Super SBM average score			
	2015	2016	2017	2018	2015	2016	2017	2018
East Asia	1.98	2.1	2.05	2.65	1.53	1.59	1.59	2.14
Southeast Asia	1.14	1.71	2.76	3.45	3.57	3.43	3.43	4.74
South Asia	2.54	2.31	2.27	2.87	1.27	1.07	1.07	1.46
Australasia	1.53	1.545	1.35	1.32	1.025	0.95	0.95	0.88

Robustness analysis

Table 7 shows sensitivity analysis of the influence of the efficiency score of each DMU with different DEA model efficiency results. We developed seven more cases to examine an impact on efficient and inefficient DMUs. We also found south Asia's efficiency scores (Sri Lanka) and Australasia (Australia). Fewer efficiency scores recorded for East Asia (Hong Kong) and Southeast Asia (Malaysia, Vietnam, Thailand), while East Asia countries (China, Japan), South Asia countries (Pakistan, India), South Asia (Singapore, Indonesia, Philippines) and Australasia (New Zealand) were found to be efficient for the whole period.

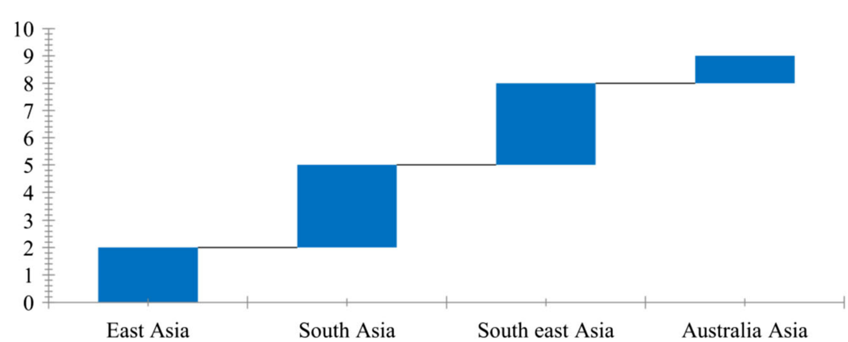
This study measures the fundamental concepts of the current DEA models. It examines the validity of this quantitative method quantitatively to the energy output of 15 countries in the Asia-Pacific region, further divided into four areas. Performance ratings for the DMUs are taken into account in the present research based on input-oriented super-efficiency analysis and input-oriented super SBM approaches. It also evaluated the ranking and efficiency score of all DMUs based on the available data. There are six vital points to shed light on obtained results and three recommendations about this context. For the years 2016 to 2020, China has set 10 million m2 of nearly zero-energy buildings. By 2025, all newly built buildings in Korea will be zero-energy buildings, according to the 2nd Energy Master Plan. In comparison to government priorities, pioneering non-governmental organizations (NGOs) have formulated mid-to-long-term objectives that are much more aggressive than government objectives. In the excess energy efficiency case, where building energy code standards are not upgraded, Asia-Pacific energy demand would begin to grow before it exceeds 2456.8 Mtoe in 2050, with no plateau before then.

Overcome energy use, supplement with higher-quality dryers, and put a premium on seeking a gas consumption alternative that is affordable and environmentally sustainable. Renewable technology has already played a vital part in low-carbon energy systems, both now and for the future. Many countries are transitioning to clean energy sources, including solar, wind, and hydro, to reduce their natural gas use (Alkire and Foster 2011). Consequently, governments have announced strong policies to tackle electricity scarcity to provide a safe atmosphere for their people. Solar PV, wind, and biogas are examples of non-fossil fuel energy sources that can offset fossil fuel energy. Many countries also use conservation energy in drying machines of milling factories, which has negative economic and environmental consequences; thus, energy-efficient tools need the rice milling factories (Afonso and Furceri 2010; Iqbal et al. 2020). This thesis proposes the model based on several previous prospect tests.

Energy security and energy efficiency

Energy imports control Asia-Pacific economies, and energy consumption continues to grow, accounting for roughly 60% of global energy demand. Asia-Pacific economy members decided in 2011 to reduce average energy intensity by 45% by 2035 relative to 2005 levels and rationalize and phase out unsustainable fossil fuel subsidies that promote excessive use while still delivering critical energy services. The Paris Agreement was drafted and accepted by consensus at the

Fig. 3 Super SBM average score



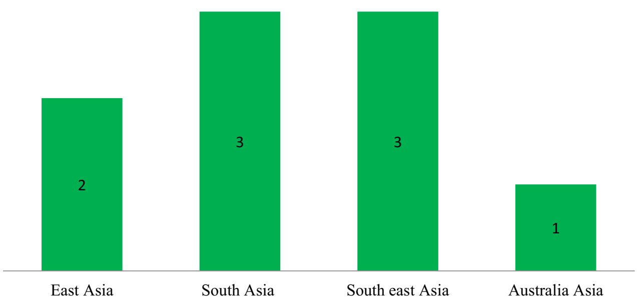


Fig. 4 Super-efficiency average score

2015 United Nations Climate Summit. The key aim is limiting the world surface temperature growth this century to below 2 °C and restricting global temperature rise to 1.5 °C over preindustrial levels. The planet must meet the building sector's greenhouse gas (GHG) emissions reduction capacity to limit global warming. According to reports, we need to reduce CO_2 emissions by 50–65% from today's levels by 2030 and entirely phase out fossil fuel CO_2 emissions by 2040 to have a 67% probability of reaching the 1.5 °C goals.

Figure 5 shows natural gas consumption (billion cubic meters). This research explores the fundamental principles and models of the super DEA methodology available. Energy security and environmental sustainability and propose pathways to increase energy supply and mitigate climate change. It empirically evaluates the applicability of this method of analysis to the energy efficiencies of 15 Asia-Pacific countries.

Figure 6 shows primary energy consumption (billion cubic meters). First of all, traditional efficiency analyses do not thoroughly equate to efficient DMUs, because in both super performance and super SBM analyses, we have identified multiple successful DMUs. We observed in both DEA models that no changes are reported in inefficient countries during all these years. However, we also realized that the DEA models provided precise results in DMU rankings and ratings. For example, Hong Kong was ranked as 5, 3, 3, 3, and 1 in the super-efficiency model for the years under examination.

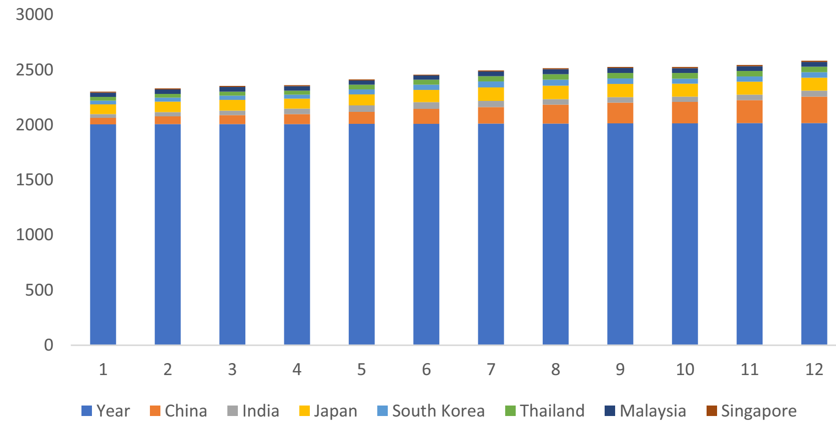
Figure 7 shows the unit price of natural gas imports (USD/cubic meters). Secondly, this is to evaluate and rank the fossil model based on 2015–2018 results. Bangladesh, Pakistan, China, and Singapore are all productive and above average countries, and Bangladesh, Pakistan, China, Singapore, New Zealand, Philippines, Japan, India, and Indonesia are below average. Both DEA models were performed for all the years. Thermoset found that the average efficiency scores for 10 regions of Asia-Pacific were higher than the scores for five regions of Asia-Pacific.

On the other hand, in the super SBM model, Bangladesh, Pakistan, and China have been included in fewer comparison sets than Hong Kong compared to the super-efficiency model. Lastly, relative to the remaining efficient nations, Bangladesh, Pakistan, which were lower in terms of efficiency score and rating, inefficient countries took Hong Kong more often as the reference country. This result may be because Hong Kong is far closer to the efficiency mark than other efficient countries.

Table 7 Different model results

Models	Categoric DMUs	Super-efficiency				Super SBM			
		2015	2016	2017	2018	2015	2016	2017	2018
Efficient DMUs were equal to or greater than 1	East Asia	2	2	2	3	2	2	2	3
	South Asia	3	4	4	4	4	4	4	4
	Southeast Asia	3	4	4	4	4	4	4	4
	Australia Asia	1	1	1	1	1	1	1	1
Inefficient DMUs were between 1 and above	East Asia	1	1	1	1	1	1	1	1
Average	South Asia	1	1	1	1	1	1	1	1
	Southeast Asia	3	2	1	1	1	1	1	1
	Australia Asia	1	1	1	1	1	1	1	1
Inefficient DMUs were below average	East Asia	1	1	1	0	1	1	1	0
	South Asia	1	1	1	1	1	1	1	1
	Southeast Asia	3	3	1	1	2	1	1	1
	Australia Asia	1	1	1	1	1	1	1	1

Fig. 5 Natural gas consumption



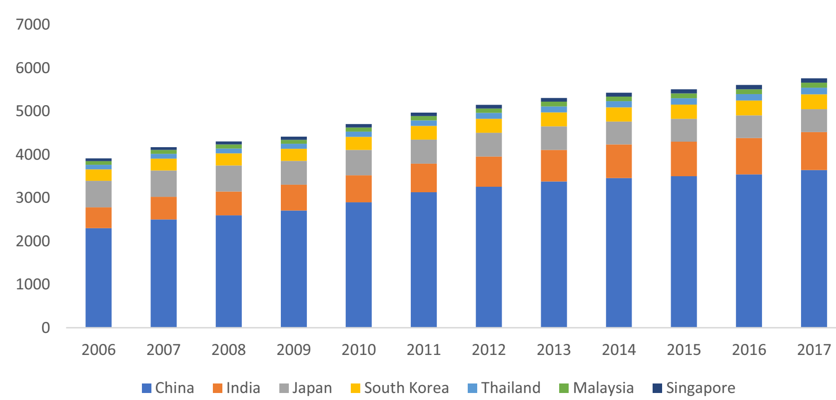
Conclusion and policy implications

In the first point, we compare the efficient DMUs using advanced efficiency analysis methodologies. Policies are needed that strengthen cross-border energy trade and increase trans-regional renewable energy investments for long-term energy security and environmental sustainability in the region. Meanwhile, we observed during the investigation that different DMUs are efficient in the results of both model during all study years, although we have to understand that the super-efficiency model and SMB have additional efficiency and ranking score. For instance, using the super-efficiency model during all years from 2015 to 2018, China recorded ranking scores 15, 15, 15, and 15, whereas the same country using SMB model results recorded different ranking scores as 15, 14, 14, and 14. Thus, the outcome depends on the distribution of scales, which is developing a super model compared to the SMB model, giving high efficient and accurate results.

In point two, after examining the DEA model ranking based on data from 2015 to 2018, we observe that New Zealand, Singapore, China, Pakistan, Philippines, Bangladesh, India, Japan, and Indonesia are efficient for above the average. Still, Sri Lanka, Malaysia, Vietnam, Thailand, Australia, and Hong Kong are under the average DEA models, and all studied. In point three, to assess the countries' efficiency scores and rank them, in both models for all the years, results show that Australasia and Southeast Asia have below-average efficiency scores. At the same time, East Asia and South Asia have total average efficiency near 1. These results show that South Asia and East Asia achieve their energy efficiency target, but Australia and Southeast Asia need to apply multiple strategies to reach their target result.

In comparison, there was a decrease in this ratio in the super SBM model. In the super SBM model, Singapore and New Zealand are taken more often than the super-efficiency model as a place point. In that regard, it is reasonable to assert that East Asia took a more frequent role in the super SBM model than South Asia, Australia, and Southeast Asia in all DEA models and all the years reviewed. In point five, we assumed that Asia-Pacific countries would become more efficient when they reduce the inputs. Asia-Pacific countries are worried about controlling these variables since GDP and GCF rely on multiple inputs and outputs in the economy. Paying for workers will create a decline in society's well-being and proceed to instability, and there would be no improvement in this feedback. As a result, Asia-Pacific countries suggest a practical and reasonable estimation of how to achieve a significant boundary under the defined targets of decreasing fossil fuels (solid fuels, natural gas, or total petroleum products). Observing the type of fuel used will be limited. Next,

Fig. 6 Primary energy consumption



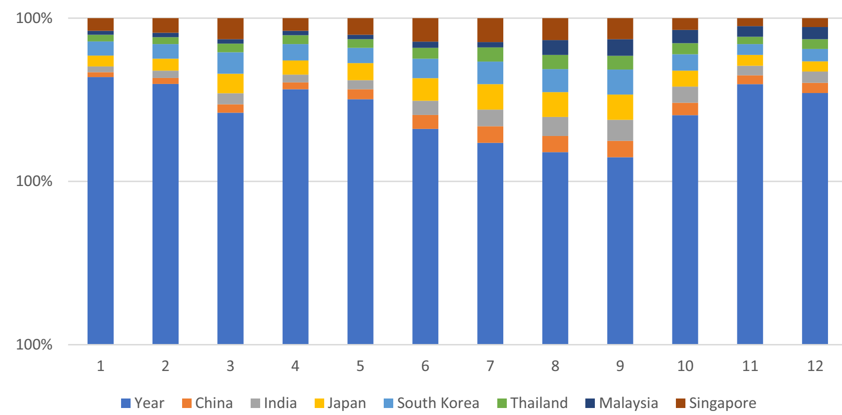


Fig. 7 Unit price of natural gas

initiatives aimed at growing energy conservation can emphasize helping a single province within a country, enhancing the total factor energy quality as a consequence of the province's policy assistance. The spillover impact of the entire factor energy performance of local region and also boost.

Second, lower energy quality means eliminating backward manufacturing potential and pursuing more renewable growth routes. There is a significant geographic disparity in Asia-Pacific energy efficiency. The strategy should concentrate on directing funds away from overcapacity sectors like steel, non-ferrous metals, chemicals, construction materials, and thermal power in low productivity areas.

Simultaneously, promoting the growth of emerging industries such as green environmental protection, high-tech, modern service industries, green agriculture, green ecology, green tourism, and rural economic revitalization in provinces with lower total energy efficiency values will increase planned production and boost energy quality by creating a green economy. To increase families' opportunities and income, access to electricity, piped water systems, and other facilities are fundamental. However, access to electricity is the first step in a household's usage of renewable electricity compared to biomass or kerosene for heating and lighting. Policymakers also need to establish suitable policies to ensure that households are connected as smoothly as possible to the energy grid. Although the construction of the power grid and distribution would remain slow due to investment trends, other initiatives would provide easy access to remote areas, such as rooftop solar photovoltaics, solar farms, and small stand-alone generators. To encourage investments in this area, policies to support these distributed energy systems are needed.

Author contributions Zulfiqar Ali Baloch: Conceptualization, Data curation, Methodology, Writing - original draft. Qingmei Tan: Data curation, Visualization. Yazeed Alfakhri: review & editing. Muhammad Zubair Khan: Writing - review & editing and software. Hassan Raza: Visualization, supervision, editing.

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Data availability The data that support the findings of this study are openly available on request.

Declarations

Ethical approval and consent to participate The authors confirm that they have no financial or personal conflicts of interest that could appear to affect the work reported in this article. We declare that we have no human participants, human data, or human tissues.

Consent for publication We do not have any person's data in any form.

Competing interests We declare that there is no conflict of interest.

References

Abdullahi S, Ismail AF, Samat S (2019) Determination of indoor doses and excess lifetime cancer risks caused by building materials containing natural radionuclides in Malaysia. Nucl Eng Technol 51 (1): 325–336

Afonso A, Furceri D (2010) Government size, composition, volatility and economic growth. Eur J Polit Econ. https://doi.org/10.1016/j.ejpoleco.2010.02.002

Aghion P, Burgess RR, Redding SJ, Zilibotti F (2008) The Unequal Effects of Liberalization: Evidence from Dismantling the License Raj in India. American Economic Review 98(4):1397–1412

Ahmad M, Khattak SI, Khan A, Rahman ZU (2020a) Innovation, foreign direct investment (FDI), and the energy–pollution–growth nexus in OECD region: a simultaneous equation modeling approach. Environ Ecol Stat 27:203–232. https://doi.org/10.1007/s10651-020-00442-8

Ahmad M, Li H, Anser MK et al (2020b) Are the intensity of energy use, land agglomeration, CO2 emissions, and economic progress dynamically interlinked across development levels? Energy Environ. https://doi.org/10.1177/0958305X20949471

Al Asbahi AAMH, Gang FZ, Iqbal W et al (2019) Novel approach of principal component analysis method to assess the national energy performance via energy trilemma index. Energy Rep. https://doi.org/10.1016/j.egyr.2019.06.009

Alemzero DA, Iqbal N, Iqbal S et al (2020a) Assessing the perceived impact of exploration and production of hydrocarbons on households perspective of environmental regulation in Ghana. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-020-10880-3

Alemzero DA, Sun H, Mohsin M et al (2020b) Assessing energy security in Africa based on multi-dimensional approach of principal composite analysis. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-020-10554-0

Ali A, Erenstein O (2017) Assessing farmer use of climate change adaptation practices and impacts on food security and poverty in Pakistan. Clim Risk Manag. https://doi.org/10.1016/j.crm.2016.12.001

Alkire S, Foster J (2011) Counting and multidimensional poverty measurement. J Public Econ. https://doi.org/10.1016/j.jpubeco.2010.11.006

Anser MK, Alharthi M, Aziz B, Wasim S (2020a) Impact of urbanization, economic growth, and population size on residential carbon emissions in the SAARC countries. Clean Techn Environ Policy. https://doi.org/10.1007/s10098-020-01833-y

Anser MK, Hanif I, Alharthi M, Chaudhry IS (2020b) Impact of fossil fuels, renewable energy consumption and industrial growth on carbon emissions in Latin American and Caribbean economies. Atmosfera. https://doi.org/10.20937/ATM.52732

Anser MK, Khan MA, Awan U et al (2020c) The role of technological innovation in a dynamic model of the environmental supply chain curve: evidence from a panel of 102 countries. Processes. https://doi.org/10.3390/pr8091033

Anser MK, Khan MA, Nassani AA et al (2020d) Relationship of environment with technological innovation, carbon pricing, renewable energy, and global food production. Econ Innov New Technol. https://doi.org/10.1080/10438599.2020.1792607

Anser MK, Yousaf Z, Hishan SS et al (2020e) Dynamic linkages between transportation, waste management, and carbon pricing: evidence from the Arab world. J Clean Prod. https://doi.org/10.1016/j.jclepro.2020.122151

Anser MK, Yousaf Z, Majid A, Yasir M (2020f) Does corporate social responsibility commitment and participation predict environmental and social performance? Corp Soc Responsib Environ Manag. https://doi.org/10.1002/csr.1977

Anser MK, Yousaf Z, Nassani AA et al (2020g) International tourism, social distribution, and environmental Kuznets curve: evidence from a panel of G-7 countries. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-019-07196-2

Anser MK, Yousaf Z, Nassani AA et al (2020h) Evaluating ecological footprints through inbound tourism, population density, and global trade. Pol J Environ Stud. https://doi.org/10.15244/pjoes/122445

Anser MK, Yousaf Z, Usman B et al (2020i) Management of water, energy, and food resources: go for green policies. J Clean Prod. https://doi.org/10.1016/j.jclepro.2019.119662

Anser MK, Yousaf Z, Zaman K et al (2020j) Determination of resource curse hypothesis in mediation of financial development and clean energy sources: go-for-green resource policies. Res Policy. https://doi.org/10.1016/j.resourpol.2020.101640

Asif M, Khan KB, Anser MK et al (2020) Dynamic interaction between financial development and natural resources: evaluating the 'resource curse' hypothesis. Res Policy. https://doi.org/10.1016/j.resourpol.2019.101566

Bampatsou C, Halkos GE (2019) Economic growth and environmental degradation: a conditional nonparametric frontier analysis. Environ Econ Policy Studies. 21(2):325–347

Banker RD, Chang H (2006) The super-efficiency procedure for outlier identification, not for ranking efficient units. Eur J Oper Res. 175 (2):1311–1320

Blanchard O (2019) Public Debt and Low Interest Rates. American Economic Review 109(4):1197–1229

Blum H (2015) The economic efficiency of energy-consuming equipment: a DEA approach. Energy Effic 8(2):281–298

Chander P (2017) Subgame-perfect cooperative agreements in a dynamic game of climate change. J Environ Econ Manag. https://doi.org/10.1016/j.jeem.2017.03.001

Charnes A, Cooper WW, Rhodes E (1978) Measuring the efficiency of decision making units. Eur J Oper Res 2:429–444. https://doi.org/10.1016/0377-2217(78)90138-8

Chege SM, Wang D (2020) The influence of technology innovation on SME performance through environmental sustainability practices in Kenya. Technol Soc. https://doi.org/10.1016/j.techsoc.2019.101210

Conlon T, McGee R (2020) Safe haven or risky hazard? Bitcoin during the Covid-19 bear market. Financ Res Lett. https://doi.org/10.1016/j.frl.2020.101607

Emrouznejad A, Liang YG (2018) A survey and analysis of the first 40 years of scholarly literature in DEA: 1978–2016. Socio Econ Plan Sci. https://doi.org/10.1016/j.seps.2017.01.008

Fleishman L, Anderson PW (1980) Interactions and the Anderson transition. Phys Rev B 21(6):2366–2377.

Geng Z, Zeng R, Han Y et al (2019) Energy efficiency evaluation and energy saving based on DEA integrated affinity propagation clustering: case study of complex petrochemical industries. Energy 179:863–875. https://doi.org/10.1016/j.energy.2019.05.042

Guo R, Yuan Y (2020) Different types of environmental regulations and heterogeneous influence on energy efficiency in the industrial sector: evidence from Chinese provincial data. Energy Policy. https://doi.org/10.1016/j.enpol.2020.111747

Hanif I, Muhammad S, Raza F, Gago-de-Santos P, Abbas Q (2019) Fossil fuels, foreign direct investment, and economic growth have triggered CO2 emissions in emerging Asian economies: Some empirical evidence. Energy 171:493–501

He W, Abbas Q, Alharthi M et al (2020) Integration of renewable hydrogen in light-duty vehicle: Nexus between energy security and low carbon emission resources. Int J Hydrog Energy. https://doi.org/10.1016/j.ijhydene.2020.06.177

Hosseinzadeh Lotfi F, Noora AA, Jahanshahloo GR, Reshadi M (2011) One DEA ranking method based on applying aggregate units. Expert Syst Appl. https://doi.org/10.1016/j.eswa.2011.02.145

Iftikhar Y, Wang Z, Zhang B, Wang B (2018) Energy and CO2 emissions efficiency of major economies: A network DEA approach. Energy 147:197–207

Iqbal W, Yumei H, Abbas Q et al (2019) Assessment of wind energy potential for the production of renewable hydrogen in Sindh Province of Pakistan. Processes. https://doi.org/10.3390/pr7040196

Iqbal W, Fatima A, Yumei H et al (2020) Oil supply risk and affecting parameters associated with oil supplementation and disruption. J Clean Prod 255. https://doi.org/10.1016/j.jclepro.2020.120187

Iram R, Anser MK, Awan RU et al (2020) Prioritization of renewable solar energy to prevent energy Insecurity: An Integrated Role. Singap Econ Rev. https://doi.org/10.1142/S021759082043002X

Jun W, Waheed J, Hussain H et al (2020) Working women and per capita household consumption expenditures; an untouched reality. Zb Rad Ekon Fak au Rijeci. https://doi.org/10.18045/zbefri.2020.1.35

Kamran M (2018) Current status and future success of renewable energy in Pakistan. Renew Sust Energ Rev 82:609–617

Lin K, Peng MYP, Anser MK et al (2020) Bright harmony of environmental management initiatives for achieving corporate social responsibility authenticity and legitimacy: glimpse of hotel and tourism industry. Corp Soc Responsib Environ Manag. https://doi.org/10.1002/csr.2076

Liu JS, Lu LYY, Lu WM, Lin BJY (2013) Data envelopment analysis 1978-2010: a citation-based literature survey. Omega (UK). https://doi.org/10.1016/j.omega.2010.12.006

Liu X, Peng MYP, Anser MK et al (2020) Key teacher attitudes for sustainable development of student employability by social cognitive career Theory: the mediating roles of self-efficacy and problem-based learning. Front Psychol. https://doi.org/10.3389/fpsyg.2020.01945

Ma D, Fei R, Yu Y (2019) How government regulation impacts on energy and CO2 emissions performance in China's mining industry. Res Policy. https://doi.org/10.1016/j.resourpol.2018.11.013

Matsuyama K (2019) Engel's law in the global economy: demand-induced patterns of structural change, innovation, and trade. Econometrica. https://doi.org/10.3982/ecta13765

Mohsin M, Zhou P, Iqbal N, Shah SAA (2018) Assessing oil supply security of South Asia. Energy 155:438–447. https://doi.org/10.1016/J.ENERGY.2018.04.116

Mohsin M, Rasheed AK, Sun H et al (2019) Developing low carbon economies: an aggregated composite index based on carbon emissions. Sustain Energy Technol Assess. https://doi.org/10.1016/j.seta.2019.08.003

Mohsin M, Nurunnabi M, Zhang J et al (2020a) The evaluation of efficiency and value addition of IFRS endorsement towards earnings timeliness disclosure. Int J Financ Econ. https://doi.org/10.1002/ijfe.1878

Mohsin M, Taghizadeh-Hesary F, Panthamit N et al (2020b) Developing low carbon finance index: evidence from developed and developing economies. Financ Res Lett. https://doi.org/10.1016/j.frl.2020.101520

Mohsin M, Hanif I, Taghizadeh-Hesary F et al (2021) Nexus between energy efficiency and electricity reforms: a DEA-based way forward for clean power development. Energy Policy. https://doi.org/10.1016/j.enpol.2020.112052

Ouariachi T, Olvera-Lobo MD, Gutiérrez-Pérez J, Maibach E (2019) A framework for climate change engagement through video games. Environ Educ Res. https://doi.org/10.1080/13504622.2018.1545156

Ouenniche J, Tone K (2017) An out-of-sample evaluation framework for DEA with application in bankruptcy prediction. Ann Oper Res. https://doi.org/10.1007/s10479-017-2431-5

Petrović-Ranđelović M, Mitić P, Zdravković A et al (2020) Economic growth and carbon emissions: evidence from CIVETS countries. Appl Econ 52:1806–1815. https://doi.org/10.1080/00036846.2019.1679343

Ríos JR, Olaya Y (2018) A dynamic analysis of strategies for increasing energy efficiency of refrigerators in Colombia. Energy Effic 11:733–754. https://doi.org/10.1007/s12053-017-9601-9

Sağlam Ü (2017) A two-stage data envelopment analysis model for efficiency assessments of 39 state's wind power in the United States. Energy Convers Manag. https://doi.org/10.1016/j.enconman.2017.05.023

Sarker SA, Wang S, Mehedi Adnan KM et al (2020) Economic viability and socio-environmental impacts of solar home systems for off-grid rural electrification in Bangladesh. Energies. https://doi.org/10.3390/en13030679

Singh A, Jamasb T, Nepal R, Toman M (2018) Electricity cooperation in South Asia: barriers to cross-border trade. Energy Policy. https://doi.org/10.1016/j.enpol.2017.12.048

Song M, Niu F, Mao N, Hu Y, Deng S (2018) Review on building energy performance improvement using phase change materials. Energy Build 158:776–793

Sun HP, Tariq G, Haris M, Mohsin M (2019) Evaluating the environmental effects of economic openness: evidence from SAARC countries. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-019-05750-6

Sun H, Pofoura AK, Adjei Mensah I et al (2020a) The role of environmental entrepreneurship for sustainable development: evidence from 35 countries in sub-Saharan Africa. Sci Total Environ. https://doi.org/10.1016/j.scitotenv.2020.140132

Sun L, Cao X, Alharthi M et al (2020b) Carbon emission transfer strategies in supply chain with lag time of emission reduction technologies and low-carbon preference of consumers. J Clean Prod. https://doi.org/10.1016/j.jclepro.2020.121664

Sun L, Qin L, Taghizadeh-Hesary F et al (2020c) Analyzing carbon emission transfer network structure among provinces in China: new evidence from social network analysis. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-020-08911-0

Tehreem HS, Anser MK, Nassani AA et al (2020) Impact of average temperature, energy demand, sectoral value added, and population growth on water resource quality and mortality rate: it is time to stop waiting around. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-020-09822-w

Tiep NC, Wang M, Mohsin M et al (2021) An assessment of power sector reforms and utility performance to strengthen consumer self-confidence towards private investment. Econ Anal Policy. https://doi.org/10.1016/j.eap.2021.01.005

Wasif Rasheed HM, Anser MK (2017) Effect on brand loyalty in Mobile phone purchasing (a case study in Bahawalpur, Pakistan). J Public Adm Gov. https://doi.org/10.5296/jpag.v7i1.11042

Xu Y, Chen Z, Peng MYP, Anser M.K. (2020) Enhancing consumer online purchase intention through gamification in China: perspective of cognitive evaluation theory. Front Psychol. https://doi.org/10.3389/fpsyg.2020.581200

Yang Z, Abbas Q, Hanif I et al (2021) Short- and long-run influence of energy utilization and economic growth on carbon discharge in emerging SREB economies. Renew Energy. https://doi.org/10.1016/j.renene.2020.10.141

Yarovaya L, Mirza N, Abaidi J, Hasnaoui A (2021) Human capital efficiency and equity funds' performance during the COVID-19 pandemic. Int Rev Econ Financ. https://doi.org/10.1016/j.iref.2020.09.017

Yousaf S, Anser MK, Tariq M et al (2020) Does technology orientation predict firm performance through firm innovativeness? World J Entrep Manag Sustain Dev. https://doi.org/10.1108/WJEMSD-11-2019-0091

Zhang Y, Song Y (2021) Environmental regulations, energy and environment efficiency of China's metal industries: a provincial panel data analysis. J Clean Prod. https://doi.org/10.1016/j.jclepro.2020.124437

Zhang Z, Jiaqiang E, Deng Y et al (2018) Effects of fatty acid methyl esters proportion on combustion and emission characteristics of a biodiesel fueled marine diesel engine. Energy Convers Manag. https://doi.org/10.1016/j.enconman.2017.12.098