Total Factor Efficiency of Energy and Carbon Emissions in 18 Asian Countries: An Empirical Assessment

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Abstract

Energy efficiency is crucial for reducing energy consumption and mitigating the negative impact of carbon dioxide emissions on the environment. The present study aims to evaluate the energy efficiency and emissions efficiency of 18 Asian countries using the undesirable slack-based data envelopment model and a total factor framework for the period 2001–2020. It has been observed that none of the countries had significantly improved energy efficiency. The total factor energy efficiency (TFEE) index shows that Asian countries have varying levels of energy efficiency, with some countries having high potential for improvement and others already performing well. Kazakhstan and Iran have the most room for improvement, while China and the UAE have seen fluctuations in their TFEE scores. The category with the highest number of countries includes Singapore, Hong Kong, Pakistan, India, Japan, Saudi Arabia, Israel, the Philippines, Bangladesh, and Indonesia, with some experiencing significant drops in TFEE scores over the years. Similar patterns can be seen in the total factor carbon emissions efficiency (TFCEE) Index, suggesting that no country is entirely efficient in reducing carbon emissions. Kazakhstan maintains its position at the bottom of the ranking for lowering carbon emissions, while Bangladesh has shown more success. Overall, there is a need for continued efforts to improve energy efficiency in these nations to reduce their carbon footprint and contribute to global sustainability goals.

Keywords: energy efficiency, carbon emissions efficiency, data envelopment analysis, undesirable slack-based model, total factor efficiency

1. Introduction

Access to and uses of energy are crucial for almost all major economic activities [1]. Because of this, energy is the engine that keeps the world going [2]. Energy usage has increased dramatically over the past century as societies have become more industrialized and reliant on energy sources like oil, coal, and natural gas [3]. This growth also contributes to environmental challenges like climate change, air pollution, species extinction, and the energy crisis [4]. In the "World Economic Outlook 2020" report, the International Energy Agency cites the energy crisis as the most pressing global issue [5]. Environmental issues like global warming, air pollution, and biodiversity loss have made it challenging to access reliable energy sources when energy demand is on the rise [6].

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Energy resources are fundamental to the expansion of the economy [7]. Earlier, Asian economies relied on input-driven growth, which has resulted in slow growth rates due to the law of diminishing returns and the use of energy-inefficient technology and equipment [8]. Improving energy efficiency is critical for sustaining Asia's economic growth [9]. Asia's energy demand has increased sharply because more people are living in cities, incomes are increasing, and the continent is becoming more industrialized [10–13]. The Asian Development Bank noted that developing Asia and the Pacific have seen rapid advancements in energy access, with an overall electrification rate of 96% in 2019–an increase of 16% since 2010 [14]. However, most energy is derived from non-renewable sources, making Asian economies significant CO2 emitters [15]. This has led to many environmental issues, such as air pollution and climate change. To mitigate these issues, Governments in Asia are investing in renewable energy sources and energy efficiency initiatives. In light of this, this paper aims to examine the energy efficiency and carbon emission efficiency of eighteen selected Asian economies.

Despite the widespread research on total factor energy efficiency [1,16,17], the Asian region and the effectiveness of carbon emissions have not received comparatively as much attention. Hou et al. [6] assessed the environmental efficiency of South Asia. Hu et al. [9] centered their attention on the total factor energy efficiency (TFEE) and emission efficiencies of the Association of South East Asian Nations (ASEAN) and non-ASEAN economies. Therefore, this paper will add to the body of knowledge by analyzing the total factor energy efficiency and total factor carbon emission efficiency (TFCEE) of selected Asian countries.

2. Theoretical Framework

The term "energy efficiency" describes a situation where more services are given while requiring fewer energy inputs [18]. In economists' eyes, energy efficiency is the proportion of monetary output to input energy [19]. It has become an increasingly important goal in modern society due to the growing need for energy and the environmental consequences of its production [20]. According to the International Energy Agency (IEA), energy intensity and energy efficiency are two well-known mechanisms to gauge how effectively energy is used. Energy intensity measures the amount of energy required to produce one unit of gross domestic product. In contrast, energy efficiency measures the amount of energy required to perform a particular activity or provide a service [21]. Energy efficiency is, in fact, the inverse of energy intensity. These conventional measures of energy efficiency focus solely on energy use as a contributor to economic output while overlooking the contributions of other crucial factors like capital and labor [22]. There is a substitution effect between energy and other inputs, and economic output requires a combination of energy use and other inputs (e.g., labor and capital stock) [23]. Estimates of energy consumption based on partial factors of energy efficiency are inaccurate because partial factor energy efficiency only accounts for a fraction of the factors contributing to energy consumption [24].

To counteract the disadvantage of partial factor energy efficiency, an increasing number of studies are focusing on total factor energy efficiency [9,25,26]. Hu and Wang [20] first proposed the term "total factor energy efficiency" (TFEE), which is defined as "the ratio of target energy input to the actual energy input." Similarly, total factor carbon emission efficiency (TFCEE) is determined by dividing the target CO2 emissions by the CO2 emissions that actually occurred [16]. TFCEE measures how efficiently a system or process produces its desired output while minimizing carbon emissions [27,28]. It can be used to evaluate the environmental impact of different technologies or industries. The TFEE and TFCEE can be calculated using parametric and non-parametric models. The present study employs the non-parametric undesirable slack-based data envelopment model, detail of which has been provided in Section 4.

3. Empirical Review of Literature

3.1. Inter-country studies

Many studies have been conducted for inter-country analyses. For example, Zhang et al. [23] used data envelopment analysis (DEA) to investigate total factor energy efficiency in 23 developing countries from 1980 to 2005. According to the findings, China grew the fastest among the developing countries examined. In practice, effective energy policies are critical for improving energy efficiency in China. Furthermore, Tobit regression analysis reveals a U-shaped relationship between total factor energy efficiency and per capita income. To get rid of random error from the model, Zhao et al. [29] used a three-stage DEA model to measure TFEE in thirty-five BRI (Belt and Road Initiative) countries in 2015. This led to a decreasing mean value of TFEE. It showed that the TFEE of the whole sample group was overestimated because of random errors and outside factors. High-income nations such as South Korea, Singapore, Israel, and Turkey had TFEE indicators of one, which places them on the efficiency frontier. In comparison, countries like Russia, Saudi Arabia, Poland, and China had TFEE values above 0.8. In addition, the indicators for Uzbekistan, Ukraine, South Africa, and Bulgaria were found to be weak. Countries with low TFEE indicators have considerable energy savings and emissions reduction potential. Due to the disparity in energy efficiency, it is necessary to differentiate between BRI countries regarding energy technology options, development planning, and regulation. Also, Ohene-asare [30] evaluated the energy efficiency of African nations between 1980 and 2011 using the undesirable slack-based DEA model. The average TFEE score for African nations was discovered to be 65%, which suggests that the continent used more energy to generate less GDP while producing more CO2. In order to promote sustainable development, the authors recommended that African nations invest in energy-efficient technologies and regulations.

Further, Nikbakht et al. [19] examined the environmental and energy efficiency performance of the countries of the Persian Gulf from 2000 to 2014. According to the results of the first phase of the data envelopment analysis study on energy efficiency, Saudi Arabia and the United Arab Emirates were the most energy-efficient countries, while Oman and Iran were the least. In the second stage of Tobit regression analysis, it was found that energy efficiency was positively related to GDP per capita, oil prices, industrialization level, and population size but negatively to FDIs. On the other hand, using a nonparametric Malmquist index, Woo et al. [31] examined the environmental efficacy of renewable energy from both a static and dynamic perspective in 31 OECD ("The Organization for Economic Cooperation and Development") countries between 2004 and 2011. The study suggests that OECD America is leading in terms of environmental efficiency, while OECD Europe is lagging. Additionally, the global financial crisis negatively impacted the dynamic efficiency of renewable energy in the studied countries.

3.2. Inter-regional studies

Shao et al. [32] used panel data and a parametric method to study how China's energy intensity constraint policy (EICP) affected total factor energy efficiency growth (TFEEG) in the country's industrial sector from 2001 to 2014. Following the implementation of EICP, the industrial sector in China experienced a decline of 4.31%. It has been suggested that the Chinese government should speed up the transition of the industrial sector to green development by adding market-oriented policies to the energy-saving policies they already have in place.

3.3. Asian studies

The studies on the Asian economies include Hou et al. [6], which evaluated South Asia's energy efficiency and environmental performance from 2001 to 2015 using DEA. In order to develop an energy efficiency and environmental performance index, the study compiled a comprehensive list of indicators. Bhutan and Pakistan demonstrated a declining trend as more secure nations, whereas Sri Lanka and India performed satisfactorily. Afghanistan, Bangladesh, and Nepal exhibited a remarkable decreasing trend. This study proposes a policy that expands the international trade of renewable energy to improve energy efficiency and environmental performance over the long term. Hu et al. [9] used the slack-based measure data envelopment analysis to calculate the energy and emission efficiencies of the ASEAN and other Asian economies from 2001 to 2017. It then uses the Malmquist productivity index to find the primary source of efficiency score changes due to technical changes and panel Tobit regressions to find the factors that explain the inefficiencies. After the Global Financial Crisis, the energy efficiency scores of ASEAN economies caught up to those of other Asian economies. However, the emission efficiency scores of different ASEAN economies fell behind those of other Asian economies during the same period. The primary source of efficiency score changes over time is efficiency changes, not technical changes. Reducing the proportion of secondary industry ratio in the entire industry and using fossil fuels to generate net electricity improve energy and emission efficiency.

4. The Undesirable Slack-Based Models

There are two major types of DEA models: radial and non-radial. To reduce all inputs (input efficiency) or increase all outputs (output efficiency) proportionally, given the output or input levels, is the focus of radial models [33]. When considering unwanted outputs, the radial input (output) oriented models only care about maximizing input (output) efficiencies, which means they ignore non-radial slacks in their estimation [34]. The Slack-Based Model (SBM), a subset of the DEA model, is non-radial in estimating efficiency. As a result, SBM is more discriminatory than the radial model because it considers input excesses and output shortfalls. Additionally, it is unit invariant, monotone decrease concerning input excesses and output shortfalls, and is unaffected by the statistics of the entire data set [35]. As a result, the non-radial and non-oriented models are the most effective at capturing all efficiency measures within the context of undesirable outputs [34]. The non-radial, non-oriented model with undesirable outputs seeks to increase sound output while decreasing inputs and undesirable outputs.

This study followed Tone [36] to formulate the SBM for the technology set T, which includes n DMUs $(j : 1, ..., n)$, assuming that the DMUs employ m $(i : 1, ..., m)$ common inputs in order to generate s_1 desirable outputs $(r : 1, ..., s_1)$ and s_2 undesirable outputs $(r : 1, ..., s_2)$. The formulation of the non-oriented SBM model in the existence of undesirable outputs is as follows:

$$p^* = min[\frac{1 - \frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{X_{io}}}{1 + \frac{1}{s_1+s_2}(\sum_{r=1}^{s_1}\frac{s_r^g}{y_{r_0}^g} + \sum_{r=1}^{s_2}\frac{s_r^b}{y_{r_0}^b})}] \tag{1}$$

Subject to:

$$\sum_{j=1}^{n}\lambda_j x_{ij} + s_i^- = x_{io}; \quad i = 1, 2, \ldots, m \tag{2}$$

$$\sum_{j=1}^{n}\lambda_j y_{rj}^g - s_r^g = y_{io}; \quad r = 1, 2, \ldots, s_1 \tag{3}$$

$$\sum_{j=1}^{n} \lambda_j y_{rj}^{b} + s_r^{b} = y_{io}; \quad r = 1, 2, \ldots, s_2 \tag{4}$$

$$\lambda_j \geq 0, (\forall j); s_i^{-} \geq 0, (\forall i); s_r^{g} \geq 0, (\forall r); j = 1, 2, \ldots, n \tag{5}$$

Where s_i^- and s_r^b symbolize surpluses in inputs and undesirable outputs, respectively. s_r^g indicates deficiencies in desirable outputs, and λ_j are intensity variables that are generated by the optimal linear programming solution. The objective function, Eq. (4), is a constant decreasing function for all s_i^-, s_r^g and s_r^b, and p^* meets $0 \leq p^* \leq 1$. It is worth noting that the optimal solution overwhelms λ^*, s_i^{-*}, $s_r^{g^*}$, $s_r^{b^*}$ in such a way that a DMU would only be efficient if $p^* = 1$, in which case, all the input and output slacks are equivalent to zero.

According to Charnes & Cooper [37], equation (1) can be converted into the linear programming problem in a following manner:

$$\tau^* = \min(t - \frac{1}{m} \sum_{i=1}^{m} \frac{s_i^-}{x_{io}}) \tag{6}$$

Subject to:

$$t + \frac{1}{s_1 + s_2} (\sum_{r=1}^{s_1} \frac{s_r^g}{y_{r_0}^g} + \sum_{r=1}^{s_2} \frac{s_r^b}{y_{r_0}^b}) = 1 \tag{7}$$

$$\sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = x_{io} t; \quad i = 1, 2, \ldots, m \tag{8}$$

$$\sum_{j=1}^{n} \lambda_j y_{rj}^{g} - s_r^{g} = y_{ro} t; \quad r = 1, 2, \ldots, s_1 \tag{9}$$

$$\sum_{j=1}^{n} \lambda_j y_{rj}^{b} + s_r^{b} = y_{ro} t; \quad r = 1, 2, \ldots, s_2 \tag{10}$$

$$\lambda_j \geq 0, (\forall j); s_i^{-} \geq 0, (\forall i); s_r^{g} \geq 0, (\forall r); j = 1, 2, \ldots, n \tag{11}$$

Further, following Banker et al. [38], the convexity constraint ($e\lambda = 1$) was added as the variable returns to scale (VRS).

It is worth noting that τ^* is an indicator of technical efficiency, which seeks to minimize inputs to produce both desirable and undesirable outputs. However, energy efficiency evaluation concentrates on the energy inputs and carbon emission efficiency focuses on the carbon dioxide (CO2) emissions. As a result, the target energy input, i.e. $e_0 - s_i^{-^*}$, and the target CO2, i.e. $c_0 - s_{uo}^{-^*}$, for a particular DMU can be determined using the optimal parameters obtained from the model's solution in equation (1) and (6). The $s_i^{-^*}$ is the ideal input excess, which corresponds to the constraints for the energy input e, and is one of the m inputs previously defined. Moreover, $s_{uo}^{-^*}$ is the optimal excess in undesirable output, which corresponds to the constraints for the undesirable output, i.e. CO2.

From this the TFEE and TFCEE is formulated as:

$$TFEE = \frac{Target\ Energy\ Input_{(i,t)}}{Actual\ Energy\ Input_{(i,t)}} \tag{12}$$

$$TFCEE = \frac{Target\,Undesirable\,Output\,CO2_{(r,t)}}{Actual\,Undesirable\,Output\,CO2_{(r,t)}} \tag{13}$$

The target energy input is less than or equal to the actual energy input and the target CO2 emissions is less than the actual CO2 emissions. According to equations 12 and 13, $0 \leq TFEE \leq 1$ and $0 \leq TFCEE \leq 1$. The TFEE and TFCEE score ranges between 0 and 1, where DMU is efficient at the score of unity.

5. Data and Variables

The study used information on 18 Asian nations, including Bangladesh, China, Hong Kong, India, Indonesia, Iran, Iraq, Israel, Japan, Kazakhstan, Malaysia, Pakistan, the Philippines, Saudi Arabia, Singapore, Thailand, the United Arab Emirates, and Vietnam. The study used two outputs, namely GDP and CO2, with the former being a desirable output and the latter being viewed as an undesirable output. It also used three inputs: labor, capital stock, and energy. No database could provide capital stock information from 2001 to 2020. As a result, the capital stock was determined using the perpetual inventory method following Chien & Hu [39] and J. Hu & Kao [40].

$$k_t = I_t + (1 - \delta)k_{t-1} \tag{14}$$

Where k_t symbolizes the gross capital stock for the current year; $k_(t-1)$ represents the gross capital stock for the preceding year; δ denotes the capital stock's depreciation rate; and I_t is taken as gross fixed capital formation for the current year. Following Y. Wu [41] and X. P. Zhang et al. [23], the depreciation rate is taken as 6% on the capital stock.

The data for the total labor force, gross fixed capital formation (constant 2015 US$) and GDP (constant 2015 US$) were obtained from the World Development Indicators. The capital stock information was extracted from Penn World Table 10.0. Data for Energy (quadrillion bitumen) and CO2 (million metric tons) was gathered from the US Energy Information Administration. For the present analysis, CO2 has been converted into quadrillion bitumen.

6. Empirical Results

6.1. Total-factor energy efficiency (TFEE)

TFEE scores were calculated using the undesirable SBM and the VRS assumption. For generalization, Table 1 presents the yearly TFEE and average saving potential for Asian nations. Due to the high possibility of excessive variation in efficiency scores in cross-sectional examinations for each year, the TFEE was estimated on a pooled frontier rather than a year-specific frontier [42]. Countries with a TFEE of unity form the efficiency frontier of energy consumption among 18 countries in the same year, implying that energy is used at its most efficient in these countries [23]. Moreover, these countries can be seen as leaders in the effort towards sustainability and energy efficiency. In 2001, this efficiency frontier for energy consumption consisted of six countries, namely, Bangladesh, Iraq, Israel, Saudi Arabia, Singapore, and the United Arab Emirates; by 2020, this number increased to ten countries, including China, Hong Kong, India, Indonesia, Israel, Japan, Pakistan, Philippines, and Singapore. The average scores over the years show, however, that no country was entirely energy efficient throughout the duration of the study. None of the countries have made significant progress toward improving energy efficiency, and they all still need to make substantial changes to reduce their energy consumption.

The average total factor energy efficiency score, shown in Table 1, varies between 0.327 (Kazakhstan) and 0.976 (Indonesia). This means that during the study period of 2000–2020, Indonesia was one of the most efficient of the 18 countries chosen, while Kazakhstan was the least efficient. Also, this shows that Kazakhstan has much room to save energy, i.e., 67.31 percent per annum, while Indonesia needs to cut its energy use at a rate of 2.40 percent per year.

The following ranges show the total-factor energy efficiency frontier of the 18 Asian countries:

First, (0 - 0.4): The calculated results for TFEE for 18 nations highlight that two countries fall under this category, i.e., Kazakhstan (0.327) and Iran (0.390). Since these nations are among the least efficient in the world, they have a high potential to improve their energy efficiency. As was previously mentioned, Kazakhstan needs to reduce its annual energy use by 67.31 percent, while Iran has an average energy savings potential of 61 percent.

Second, (0.4-0.8): This category includes six countries: Malaysia, China, the UAE, Thailand, Vietnam, and Iraq, with TFEE scores of 0.566, 0.611, 0.612, 0.680, 0.758, and 0.792, respectively. TFEE in China is on the rise, while in the UAE, it dropped significantly between 2006 and 2011. Iraq's fortunes declined steadily from 2001 to 2017 and fluctuated after that. Meanwhile, Malaysia and Thailand have seen relatively steady growth since the 2000s, while Vietnam saw a slight decline between 2003 and 2011 before recovering.

Third, (0.8–1.00): This category consisted of the maximum number of countries, as ten chosen Asian countries have made the TFEE index in this category, for instance, Singapore (0.839), Hong Kong (0.844), Pakistan (0.862), India (0.872), Japan (0.898), Saudi Arabia (0.922), Israel (0.931), the Philippines (0.938), Bangladesh (0.970), and Indonesia (0.976). Among these nations, Singapore and Saudi Arabia have faced a sizeable fluctuating trend, as Singapore's TFEE declined from 1.00 in 2003 to 0.610 in 2010. Similarly, the TFEE of Saudi Arabia has declined from 1.00 in 2007 to 0.684 in 2010.

Table 1: *Total factor energy efficiency (TFEE)*

Year	Bangladesh	China	Hong Kong	India	Indonesia	Iran	Iraq	Israel	Japan	Kazakhstan	Malaysia	Pakistan	Philippines	Saudi Arabia	Singapore	Thailand	UAE	Vietnam
2001	1.000	0.371	0.940	0.771	0.902	0.390	1.000	1.000	0.749	0.468	0.478	0.737	0.899	1.000	1.000	0.648	1.000	0.912
2002	1.000	0.386	0.947	0.764	0.929	0.405	1.000	0.963	0.755	0.441	0.450	0.807	0.831	0.885	1.000	0.627	0.920	0.894
2003	0.975	0.371	0.906	0.806	0.959	0.428	1.000	1.000	0.762	0.450	0.460	0.823	0.834	1.000	1.000	0.628	0.962	0.896
2004	0.991	0.336	0.809	0.808	0.977	0.436	1.000	0.994	0.754	0.391	0.493	0.829	0.818	1.000	0.957	0.628	1.000	0.767
2005	0.985	0.331	0.840	0.830	0.924	0.396	0.931	0.973	0.778	0.317	0.480	0.809	0.907	1.000	0.854	0.642	0.994	0.741
2006	0.989	0.334	0.811	0.827	0.962	0.398	0.949	0.952	0.784	0.310	0.480	0.767	0.927	0.955	0.803	0.668	1.000	0.730
2007	0.977	0.350	0.776	0.843	0.956	0.422	1.000	0.952	0.797	0.269	0.494	0.785	0.917	1.000	0.744	0.689	0.578	0.707
2008	0.984	0.407	0.831	0.818	0.987	0.416	0.928	0.979	0.821	0.238	0.517	0.805	0.904	0.959	0.654	0.698	0.352	0.676
2009	1.000	0.459	0.714	0.813	1.000	0.377	0.773	0.937	0.927	0.294	0.495	0.822	0.998	0.816	0.610	0.666	0.316	0.656
2010	0.948	0.504	0.683	0.841	1.000	0.406	0.745	0.898	1.000	0.281	0.520	0.810	0.962	0.684	0.660	0.669	0.312	0.635
2011	0.958	0.644	0.738	0.851	1.000	0.410	0.718	0.962	0.978	0.263	0.541	1.000	1.000	0.822	0.687	0.659	0.312	0.733
2012	0.950	0.662	0.787	0.851	1.000	0.376	0.611	0.847	0.987	0.270	0.570	0.852	0.976	0.917	0.717	0.673	0.338	0.737
2013	0.960	0.703	0.781	0.878	1.000	0.362	0.518	0.932	0.950	0.274	0.572	0.906	0.974	0.907	0.775	0.656	0.482	0.804
2014	0.959	0.755	0.815	0.879	1.000	0.361	0.538	0.893	0.935	0.295	0.592	0.924	1.000	0.992	0.808	0.660	0.379	0.769
2015	0.940	0.823	0.754	0.927	1.000	0.351	0.633	0.863	0.982	0.298	0.650	0.888	0.940	1.000	0.815	0.681	0.399	0.758
2016	0.921	0.846	0.798	0.964	0.966	0.403	0.684	0.858	1.000	0.298	0.685	0.868	0.965	1.000	0.824	0.690	0.486	0.741
2017	0.930	0.936	0.953	0.984	0.959	0.404	0.498	0.838	1.000	0.322	0.697	0.860	0.930	0.927	0.881	0.706	0.533	0.751
2018	0.969	1.000	1.000	0.982	1.000	0.373	1.000	0.866	1.000	0.338	0.677	0.945	0.983	1.000	1.000	0.747	0.759	0.754
2019	0.955	1.000	1.000	1.000	1.000	0.338	0.395	0.914	1.000	0.365	0.710	0.996	0.994	0.794	1.000	0.805	0.612	0.742
2020	1.000	1.000	1.000	1.000	1.000	0.352	0.912	1.000	1.000	0.355	0.753	1.000	1.000	0.786	1.000	0.759	0.499	0.758
Average	0.970	0.611	0.844	0.872	0.976	0.390	0.792	0.931	0.898	0.327	0.566	0.862	0.938	0.922	0.839	0.680	0.612	0.758
Energy saving potential (%)	3.05	38.90	15.59	12.82	2.40	61.00	20.83	6.90	10.20	67.31	43.44	13.83	6.20	7.79	16.06	32.01	38.84	24.19

6.2. Total-factor carbon emissions efficiency (TFCEE)

Using slack based undesirable DEA model proposed by Tone [36], the TFCEE scores have been calculated and reported in Table 2. Moreover, Figure 1 illustrates each nation's potential carbon emissions reduction. It has been observed that Kazakhstan and Iran ranked among the least efficient countries in terms of carbon efficiency, with poor performances in reducing their carbon emissions and protecting the environment. It is supported by the fact that Kazakhstan and Iran have the lowest total factor carbon emission efficiency, i.e., 0.288 and 0.418, respectively. Moreover, the statistics shown in Figure 1 depict that these countries need to reduce carbon emissions by 71.16 percent per year and 58.19 percent per year, respectively. Therefore, Kazakhstan and Iran must take significant steps toward reducing their carbon emissions and protecting the environment. The above statistics indicate the urgent need for these countries to adopt more sustainable and environmentally-friendly practices to improve their carbon efficiency. It is essential for their well-being and the global community's efforts to combat climate change.

Also, Bangladesh has the highest TFCEE score. This means that out of the 18 Asian countries, Bangladesh uses the least amount of coal and other fossil fuels. Moreover, the country has implemented various policies, such as promoting renewable energy sources, setting energy efficiency standards for appliances, and investing in public transportation [43]. Despite having the highest TFCEE score, Bangladesh still needs to cut its carbon emissions by 0.51 percent annually. A similar trend is observed in the study of Hou et al [6].

A significant improvement concerning reducing carbon emissions has been observed in China as it follows the upward trend in TFCEE. However, China has a long way to go in protecting the environment because it needs to cut its carbon emissions by 44.57 percent per year. In practice, effective energy policies are critical for improving China's energy efficiency. The Chinese government has recognized the importance of carbon efficiency and has implemented various policies and measures to promote it. For instance, the government has implemented a nationwide carbon trading system that incentivizes companies to reduce carbon emissions. Additionally, they have set energy efficiency targets for industries and provide financial incentives for buildings that meet energy efficiency standards [44]. However, there have been instances where local officials have yet to consider or enforce these energy policies. For example, in Shaanxi province, coal mines were often allowed to surpass their allocated energy quotas due to corruption and lack of enforcement. This resulted in excessive energy consumption and environmental pollution, counteracting the government's efforts to promote energy efficiency [45].

Similarly, other countries like Malaysia, the UAE, Thailand, India, and Vietnam need to reduce their carbon emissions levels annually by 42.90 percent, 36.69 percent, 28.57 percent, 24.49 percent, and 23.08 percent, respectively. Many Asian countries need to take significant action to reduce their carbon emissions levels to mitigate climate change's effects. These targets set by various countries demonstrate the urgency and importance of reducing the carbon footprint to ensure a sustainable future for future generations. Individuals and governments must take responsibility and make conscious efforts to reduce their environmental impact.

Table 2: *Total factor carbon emissions efficiency (TFCEE)*

Year	Bangladesh	China	Hong Kong	India	Indonesia	Iran	Iraq	Israel	Japan	Kazakhstan	Malaysia	Pakistan	Philippines	Saudi Arabia	Singapore	Thailand	UAE	Vietnam
2001	1.000	0.271	1.000	0.620	0.812	0.428	1.000	1.000	0.797	0.438	0.535	0.820	0.998	1.000	0.992	0.676	1.000	1.000
2002	0.987	0.285	0.942	0.616	0.813	0.432	1.000	0.952	0.793	0.414	0.497	0.896	0.921	0.946	1.000	0.662	0.933	1.000
2003	1.000	0.285	0.880	0.658	0.842	0.447	1.000	1.000	0.781	0.410	0.504	0.899	0.928	1.000	1.000	0.652	0.970	1.000
2004	1.000	0.269	0.786	0.650	0.876	0.454	1.000	0.992	0.791	0.355	0.518	0.926	0.888	1.000	0.984	0.642	1.000	0.779
2005	1.000	0.272	0.770	0.677	0.892	0.423	0.945	0.945	0.808	0.286	0.503	0.906	0.920	1.000	0.864	0.626	0.995	0.778
2006	1.000	0.286	0.785	0.683	0.922	0.429	0.986	0.931	0.828	0.276	0.505	0.862	0.964	0.991	0.836	0.677	1.000	0.750
2007	1.000	0.321	0.752	0.685	0.951	0.467	1.000	0.917	0.833	0.248	0.502	0.843	1.000	1.000	0.832	0.740	0.629	0.734
2008	1.000	0.367	0.800	0.661	0.964	0.439	0.809	0.950	0.851	0.219	0.526	0.855	1.000	1.000	0.690	0.685	0.388	0.718
2009	1.000	0.407	0.707	0.649	0.966	0.399	0.752	0.934	0.946	0.256	0.515	0.869	1.000	0.900	0.526	0.649	0.354	0.727
2010	1.000	0.451	0.656	0.670	0.930	0.423	0.838	0.904	1.000	0.244	0.523	0.872	1.000	0.826	0.614	0.709	0.349	0.658
2011	1.000	0.554	0.691	0.698	0.943	0.417	0.799	0.948	0.941	0.225	0.544	1.000	1.000	0.912	0.649	0.698	0.345	0.730
2012	1.000	0.577	0.736	0.704	0.965	0.384	0.667	0.832	0.889	0.228	0.566	0.917	1.000	0.930	0.688	0.711	0.369	0.762
2013	1.000	0.610	0.722	0.748	0.981	0.377	0.540	0.948	0.879	0.229	0.565	0.966	1.000	0.946	0.753	0.707	0.500	0.842
2014	1.000	0.671	0.747	0.762	0.983	0.378	0.556	0.941	0.878	0.247	0.587	0.965	1.000	0.940	0.795	0.707	0.406	0.781
2015	1.000	0.745	0.706	0.826	0.994	0.382	0.655	0.911	0.944	0.256	0.632	0.923	1.000	1.000	0.804	0.728	0.427	0.702
2016	0.982	0.799	0.741	0.894	1.000	0.448	0.652	0.929	1.000	0.258	0.661	0.875	1.000	1.000	0.813	0.760	0.508	0.681
2017	0.972	0.916	0.876	0.938	1.000	0.447	0.557	0.926	1.000	0.279	0.675	0.842	0.948	0.976	0.890	0.778	0.556	0.736
2018	0.987	1.000	1.000	0.962	0.999	0.415	1.000	0.945	1.000	0.286	0.655	0.957	0.986	1.000	1.000	0.822	0.774	0.705
2019	0.969	1.000	1.000	1.000	0.983	0.389	0.474	1.000	1.000	0.310	0.692	0.986	1.000	0.897	1.000	0.846	0.627	0.638
2020	1.000	1.000	1.000	1.000	1.000	0.384	0.939	1.000	1.000	0.304	0.714	1.000	1.000	0.730	1.000	0.813	0.533	0.662
Average	0.995	0.554	0.815	0.755	0.941	0.418	0.808	0.945	0.898	0.288	0.571	0.909	0.978	0.950	0.837	0.714	0.633	0.769
Potential reduction in CO2 emissions (%)	0.51	44.57	18.51	24.49	5.92	58.19	19.16	5.49	10.20	71.16	42.90	9.10	2.24	5.03	16.35	28.57	36.69	23.08

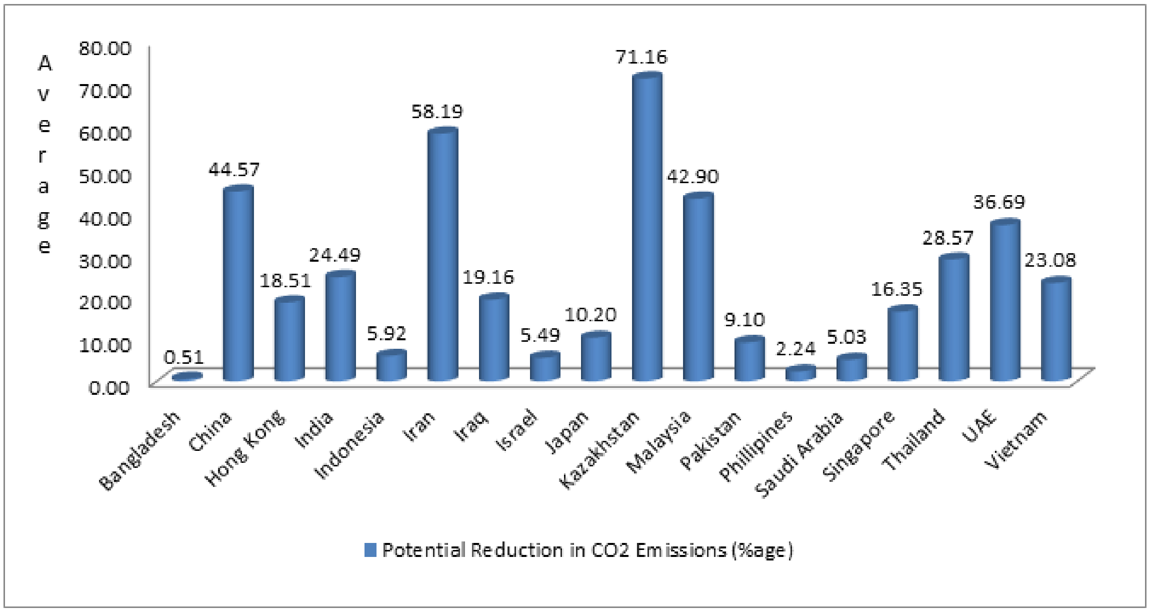

Figure 1: *Average potential reduction in CO2 emissions (2001-2020)*

7. Conclusion

It has been observed that the 18 Asian countries have yet to make significant progress toward improving energy efficiency. Similar patterns can be seen in the TFCEE index, suggesting that no country is entirely efficient in reducing carbon emissions. Many countries in the Asian region have recognized the importance of transitioning to more sustainable energy sources and reducing their carbon footprint. This has led to the implementation of various policies and initiatives aimed at promoting renewable energy, increasing energy efficiency, and reducing greenhouse gas emissions. However, challenges still need to be addressed, such as the high reliance on fossil fuels and the need for more significant investment in renewable energy infrastructure. Despite these challenges, Asian countries have shown great potential for achieving their energy and climate goals. For instance, China has become the world's largest producer of renewable energy and has set ambitious targets to reduce its carbon intensity by 60–65% by 2030 [46]. India has also made significant progress in expanding its renewable energy capacity and has set a target of achieving 40% of its total energy capacity from non-fossil fuel sources by 2030 [47]. Other countries, such as Japan and Vietnam, have also set ambitious targets to reduce their carbon emissions and promote renewable energy. Overall, the trend towards greater sustainability in the region is promising, but continued efforts and investments are needed to achieve long-term goals and mitigate the impacts of climate change. However, some countries in the region may face economic and political challenges in transitioning towards sustainable energy sources, which could hinder their progress and slow down the overall trend toward sustainability [48]. In order to reduce carbon emissions, economists must consider various factors, such as energy consumption, the ratio of openness to trade, and the emergence of new technologies [49].

Furthermore, there is also a need for greater international cooperation and collaboration to address the global challenge of climate change. This includes sharing knowledge and expertise and providing financial and technological support to developing countries. A step in the right direction towards achieving this goal is the Paris Agreement, which 195 nations signed in 2015. However, there is still a long way to go to achieve the target of limiting global temperature rise to below 2°C above pre-industrial levels. In conclusion, while the trend toward greater sustainability in Asia is promising, it requires continued efforts and investments from governments, businesses, and individuals to achieve long-term goals and mitigate the impacts of climate change.

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