Total-Factor Energy Efficiency in BRI Countries: An Estimation Based on Three-Stage DEA Model

Changhong Zhao [1], Haonan Zhang [1], Yurong Zeng [1], Fengyun Li [1], Yuanxin Liu [1], Chengju Qin [1] and Jiahai Yuan [1,2,*]

[1] School of Economics and Management, North China Electric Power University, Beijing 102206, China; zchh21@163.com (C.Z.); z442192820@163.com (H.Z.); hdddqccdz@163.com (Y.Z.); flash3wade@foxmail.com (F.L.); 50601149@ncepu.edu.cn (Y.L.); 50601427@ncepu.edu.cn (C.Q.)

[2] Beijing Key Laboratory of New Energy and Low-Carbon Development, North China Electric Power University, Beijing 102206, China

[*] Correspondence: 50601511@ncepu.edu.cn or yuanjh126@126.com; Tel.: +86-136-8310-7932

Abstract: The Belt and Road Initiative (BRI) is showing its great influence and leadership on the international energy cooperation. Based on the three-stage DEA model, total-factor energy efficiency (TFEE) in 35 BRI countries in 2015 was measured in this article. It shows that the three-stage DEA model could eliminate errors of environment variable and random, which made the result better than traditional DEA model. When environment variable errors and random errors were eliminated, the mean value of TFEE was declined. It demonstrated that TFEE of the whole sample group was overestimated because of external environment impacts and random errors. The TFEE indicators of high-income countries like South Korea, Singapore, Israel and Turkey are 1, which is in the efficiency frontier. The TFEE indicators of Russia, Saudi Arabia, Poland and China are over 0.8. And the indicators of Uzbekistan, Ukraine, South Africa and Bulgaria are in a low level. The potential of energy-saving and emissions reduction is great in countries with low TFEE indicators. Because of the gap in energy efficiency, it is necessary to distinguish different countries in the energy technology options, development planning and regulation in BRI countries.

1. Introduction

On 10 September 2013, Chinese President Xi Jinping successfully proposed the construction of two major initiatives during a visit to Central Asian and Southeast Asian nations: a "Silk Road Economic Belt" and a "21st Century Maritime Silk Road", which were collectively called the "Belt & Road initiative" (BRI). There are fruitful results in BRI energy cooperation, which played an important role in resource exploitation, oil & gas trade and electric power infrastructure development of countries along the lines. The "Vision and Action of Energy Cooperation on Jointly Building Silk Road Economic Belt and 21st-Century Maritime Silk Road" was published by National Energy Administration (NEA) in 12 May 2017 [1]. This policy document put forward that energy cooperation should insist six principles, including openness and inclusiveness, win-win and mutual benefit, market operation, safety development, green development and harmonious development. These principles show the firm determination of China to develop friendly cooperation with BRI countries and promote global energy development. As the Afroeurasian has gradually become the global energy hub, many countries also proposed some other influential initiatives around the economic cooperation, transportation and energy fields, such as the "Central Asia Regional Economic Cooperation" [2], the Russian "the Eurasian economic union" [3] and "European Strategy 2020" [4], etc. These international cooperations have achieved remarkable results. However, the initiatives also face very challenging barriers, including

lack of central coordination mechanism, potential clash of different political regimes and beliefs and financial viability of cross-border projects [5]. The "Belt & Road initiative" is centered on interregional cooperation, with energy cooperation as its focal point. Because most of the countries are developing or emerging economies, the low energy efficiency level and high carbon emissions intensity made the use of energy in these countries much higher than developed countries. And some also claimed that BRI would bring forth serious negative impact on local resources and environment [6].

It can be seen from Table 1, that the energy consumption and carbon intensity of some countries are declining. But the indicators of most of countries are stable or rising. It means that there is no improvement in the energy structure and utilization efficiency. This is one of the utmost problems for the development of most BRI countries. It is difficult for them to balance between the harmonious sustainable development of the environment and economic development.

Energy intensity and energy efficiency are the two well-known energy-efficiency indicators that are commonly used in macro-level policy analysis. Energy intensity is defined as the energy consumption divided by the economic output, and energy efficiency is the reciprocal of energy intensity. The unit GDP energy intensity and carbon intensity of the most BRI countries are higher than developed countries like the USA and Japan. It illustrates that there is huge potential in improving energy efficiency with advanced technique. It is feasible to change the mode of development by clean utilization of fossil energy, improving the level of electrification and developing renewable energy. What the Belt and Road Initiative appeals is that BRI countries will cooperate in the economy, energy, culture, transportation and so on and participate in global governance jointly. Ref. [7] considered that building energy saving targets represent a main concern if global energy shortage is to be avoided in the coming decades, especially considering the challenges of climate changes. Hence, for the BRI countries, enhancing energy efficiency should be at the top of the priority list.

Table 1. Gross Domestic Product (GDP) energy intensity and carbon intensity of different countries.

Countries	GDP Energy Intensity (kg Oil Equivalent/Dollar)					GDP Carbon Intensity (kg/Dollar)				
	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016
China	0.39	0.37	0.36	0.34	0.32	1.25	1.19	1.11	1.03	0.96
Russia	0.42	0.41	0.41	0.42	0.41	0.96	0.92	0.92	0.93	0.92
Korea	0.23	0.23	0.22	0.22	0.22	0.55	0.54	0.52	0.52	0.48
Indonesia	0.20	0.19	0.17	0.17	0.17	0.60	0.58	0.51	0.50	0.51
Thailand	0.31	0.31	0.31	0.31	0.30	0.74	0.73	0.74	0.73	0.72
Malaysia	0.29	0.30	0.29	0.28	0.29	0.77	0.77	0.76	0.75	0.77
Vietnam	0.41	0.40	0.41	0.41	0.39	1.01	0.99	1.04	1.08	1.02
Singapore	0.28	0.27	0.27	0.28	0.29	0.74	0.71	0.69	0.71	0.75
Philippines	0.14	0.14	0.14	0.14	0.15	0.38	0.39	0.39	0.40	0.42
New Zealand	0.13	0.13	0.13	0.13	0.12	0.23	0.22	0.22	0.21	0.20
India	0.71	0.70	0.71	0.69	0.70	2.20	2.15	2.21	2.18	2.19
Pakistan	0.38	0.36	0.36	0.36	0.36	0.86	0.82	0.82	0.82	0.84
Bangladesh	0.20	0.19	0.19	0.20	0.19	0.49	0.47	0.47	0.48	0.47
Saudi Arabia	0.38	0.38	0.39	0.39	0.39	0.89	0.88	0.90	0.90	0.90
UAE	0.30	0.28	0.28	0.30	0.30	0.76	0.73	0.72	0.75	0.76
Iran	0.53	0.56	0.56	0.58	0.59	1.24	1.34	1.34	1.35	1.38
Turkey	0.13	0.12	0.12	0.12	0.12	0.35	0.31	0.33	0.32	0.32
Israel	0.10	0.09	0.09	0.09	0.09	0.32	0.28	0.26	0.26	0.25
Egypt	0.38	0.37	0.36	0.34	0.35	0.92	0.89	0.87	0.85	0.85
Kuwait	0.28	0.29	0.29	0.30	0.30	0.80	0.76	0.72	0.78	0.77
Qatar	0.20	0.28	0.26	0.30	0.29	0.41	0.60	0.57	0.65	0.63
South Africa	0.80	0.79	0.77	0.72	0.71	2.84	2.80	2.73	2.54	2.46
Ukraine	0.85	0.80	0.75	0.69	0.70	2.06	1.96	1.80	1.57	1.67
Belarus	0.45	0.40	0.40	0.39	1.04	0.94	0.94	0.91	0.83	0.91
Poland	0.19	0.19	0.17	0.17	0.17	0.60	0.59	0.54	0.52	0.52

Table 1. *Cont.*

Countries	GDP Energy Intensity (kg Oil Equivalent/Dollar)					GDP Carbon Intensity (kg/Dollar)				
	2012	2013	2014	2015	2016	2012	2013	2014	2015	2016
Romania	0.20	0.18	0.18	0.17	0.17	0.47	0.39	0.38	0.36	0.35
Czech	0.20	0.20	0.19	0.18	0.17	0.51	0.50	0.46	0.46	0.46
Slovakia	0.17	0.18	0.16	0.16	0.15	0.33	0.34	0.31	0.30	0.29
Bulgaria	0.35	0.32	0.34	0.35	0.32	0.86	0.76	0.81	0.83	0.76
Hungary	0.17	0.15	0.15	0.15	0.15	0.32	0.30	0.30	0.31	0.31
Lithuania	0.14	0.13	0.12	0.12	0.12	0.28	0.25	0.26	0.25	0.25
Slovenia	0.34	0.36	0.32	0.32	0.32	0.32	0.31	0.27	0.26	0.24
Albania	0.36	0.38	0.41	0.42	0.41	0.28	0.29	0.32	0.31	0.29
Kazakhstan	0.36	0.34	0.36	0.34	0.33	1.22	1.27	1.08	1.11	1.10
Uzbekistan	1.07	0.98	0.94	0.89	0.84	2.33	1.93	2.10	1.99	1.87
Turkmenistan	1.03	0.85	0.84	0.89	0.84	2.59	2.13	2.12	2.22	2.10
America	0.14	0.14	0.14	0.14	0.13	0.35	0.35	0.35	0.33	0.32
Canada	0.19	0.19	0.19	0.18	0.18	0.32	0.32	0.31	0.30	0.29
EU	0.10	0.10	0.09	0.09	0.10	0.22	0.21	0.20	0.19	0.19
Japan	0.08	0.08	0.08	0.07	0.07	0.22	0.22	0.21	0.20	0.20

Source: BP World Energy Statistics [8].

In December 2015, Parties of the United Nations Framework Convention on Climate Change (UNFCCC) adopted the Paris Agreement to address climate change [9]. Parties agreed to keep the increase in global average temperature to well below 2 °C above pre-industrial levels, and to pursue efforts to stay below 1.5 °C. Many Parties also formulated and submitted Nationally Determined Contributions (NDCs) that outline the post-2020 climate action plans they intend to take under the Paris Agreement [10]. Paris Agreement has come into force in November of 2016. The main ways to reduce greenhouse gas emissions include improving energy efficiency, optimizing the energy structure, reducing fossil energy use and so on. According to rough statistics shown in Figure 1, the carbon emissions of BRI countries was around 10.9 Gt in 2014, accounting for 33.7% of global carbon emissions [8]. Ref. [11] applied the IMAGE integrated assessment model to estimate the annual abatement costs of achieving the NDC reduction targets and found that the ten major emitting economies, Brazil, Canada and the USA are projected to have the highest cots to implement the conditional NDCs, while the costs for Japan, China, Russia, and India are relatively low. If including China, the share of global carbon emissions by BRI countries will achieve 61.4% [8]. Hence, it is evident that BRI countries will be among the main forces to achieve carbon emissions reduction targets of Paris agreement in the future. In addition, the proportion of energy industry carbon emissions in BRI countries is around 80%, implying the important roles of energy industry in fighting against climate change. And energy industry will play an essential role in achieve NDC target. In the background of low carbon development, it is necessary to attach enough importance on efficient development to achieve coordinated and sustainable development in aspects including energy use, technology investment, labor and capital.

Data Envelopment Analysis (DEA) derives from multi-objective liner programming and Pareto optimal calculation. At present, DEA model created by Ref. [12] and extended by Ref. [13] has become the most frequent and basic methodology to evaluate the economic efficiency by comparing a decision unit with an efficient frontier using performance indicators. DEA is a popular approach and important analysis tool to evaluate efficiency in various sciences such as management science, operation research, system engineering, environmental sustainability, etc. [14–16]. In recent decades, several previous studies extended, proposed and applied DEA models for assessing of the efficiency in many fields of energy in various countries, economics and different areas. Ref. [17] reviewed and summarized the different models of DEA that had been applied around the world to development of various energy efficiency problems. Consequently, a review of 144 published scholarly papers appearing in

45 high-ranking journals between 2006 and 2015 have been obtained to achieve a comprehensive review of DEA application in energy efficiency. The large amount of DEA literature makes it difficult to use any traditional qualitative methodology to sort out the matter. Ref. [16] applied a network clustering method to group the literature through a citation network established from the DEA literature over the period 2000 to 2014. The four research fronts identified are "bootstrapping and two-stage analysis", "undesirable factors", "cross-efficiency and ranking" and "network DEA and dynamic DEA".
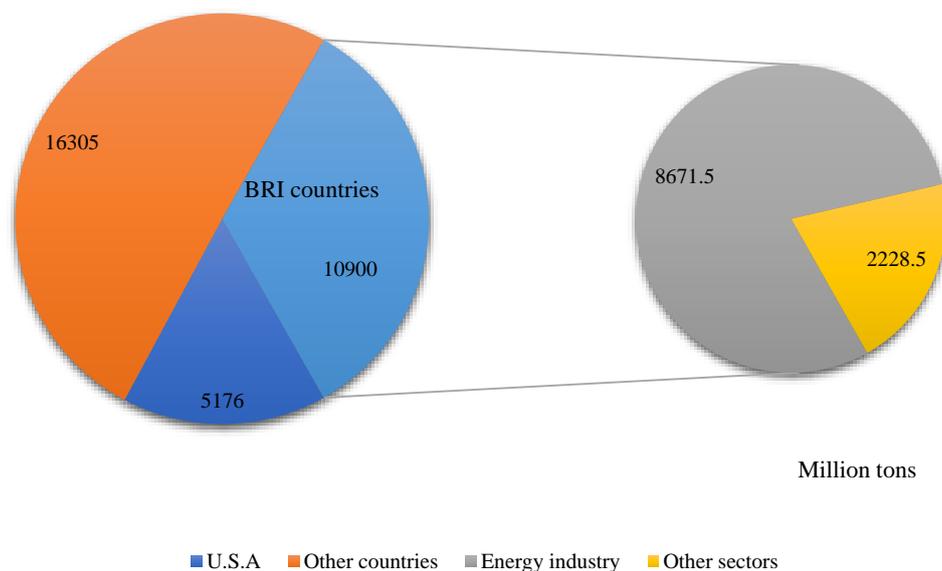

Figure 1. The carbon emissions situation of the Belt and Road Initiative (BRI) countries in 2014 [8].

Considering the amount of input variables, the analysis can be divided into two forms including single-factor and total-factor. The single-factor energy efficiency only can reflect the relationship between energy and economic output, neglecting the influence of other key inputs. And there may be some substitution effects among factors, which may lead to deviation of single factor method. If energy consumption is evaluated in terms of partial-factor energy efficiency, the result would be a misleading estimate [18,19]. Ref. [20] indicated that energy-efficiency improvement relies on total-factor productivity improvement. To overcome the disadvantage of partial-factor energy efficiency, an increasing number of researchers have devoted themselves to analyzing total-factor energy efficiency (TFEE) by using DEA approach. Total-factor DEA, based on production function, could reflect macro energy efficiency level of economy activity more comprehensively. Ref. [18] introduced the conception of TFEE which regarded energy, labor and capital as input variables firstly in 2006 and measured the energy efficiency level of China from 1995 to 2002 with DEA method. Ref. [21] measured the energy efficiency of provinces in China from 1995 to 2007. The result shows that the energy efficiency of most provinces pictures a reverse U-shape and the turning point came in about 2000, which there is no convergence between provinces and cities. Ref. [22] adopted DEA-Tobit method to make a comparative study on the total-factor energy efficiency of BRICS. The result indicated that the energy efficiency level of BRICS is not high and there is a significantly negative relationship between TFEE and industrial structure or energy consumption structure. Ref. [19] adopted DEA method to measure TFEE of Japan regionally and the changes of energy productivity of different regions. But there are some defects of traditional DEA method:

(1)   The method based on Ref. [23] is a radial and linear subsection measurement theory, and the effect of relaxation quantity is not considered. Hence, the deviation of efficiency evaluation may be produced;

(2) The influence of external environment and random error of decision-making units (DMUs) is not considered;

(3) The effect of environment and error could not be eliminated with two-stage Tobit regression model or least squares regression model analysis.

To solve this problem, Ref. [24] proposed the three-stage DEA approach consisting of a three-stage analysis: starting with a traditional BCC model, continuing with a Stochastic Frontier Analysis (SFA) to exclude the influence of environmental variables, statistical interference and management, and concluding with traditional BCC-DEA using adjusted data from the second stage to estimate the real efficiency. The three-stage DEA model is an excellent empirical approach with extensive application in range of industries and presents the advantage for efficiency evaluation by performing an efficient frontier. Ref. [25–29] have extended the application of three-stage DEA model on estimating the commerce and hotel performance in Taiwan, the cultural industries efficiency of China in 2004, agricultural production efficiency of China in 2008, ecological efficiency of China in 2008, and the true managerial efficiency of bank branches in Taiwan, respectively. Then, Ref. [30] analyzed the cultural industries efficiency among 31 provinces of China in 2008 by using three-stage and super-efficiency DEA model. Ref. [31] evaluated the effects of government measures on green productivity growth of China's manufacturing sector during the 11th Five-Year Period (2006–2010) by adopting three-stage DEA model. Ref. [32] found that regional industrial eco-efficiency in China is affected by the factors of the environmental regulation, technological innovation, level of economic development and industrial structure, and the national average industrial eco-efficiency declines by 30% after eliminating the impacts of external environment and statistical noise by adopting three-stage DEA approach. Ref. [33] evaluated the urbanization efficiency based on the three-stage DEA model, which takes the impact of exogenous factors on the urbanization rate into consideration. From the perspectives of governmental management and urban growth and scale, their study indicated the current urbanization mode and features in Chengdu based on land use data, socioeconomic and natural data in each district and county. It can be seen that the three-stage DEA method has matured and become an important branch of DEA model system. According to the characteristics of the efficiency research sciences, we can select the appropriate input and output variables and environment variables to make the results of the three-stage DEA model more flexible.

Ref. [34] used three-stage DEA model to measure total-factor energy efficiency (TFEE) and decomposition variables of 29 provinces of China in 2009. Ref. [35] adopted three-stage DEA model to measure energy efficiency level of China. Ref. [36] used three-stage DEA model and found that it is not low pure technical that restricts to enhance energy efficiency of mostly provinces in China. Therefore, the three-stage DEA model proposed by Ref. [24] is used in this article to measure and decompose TFEE in BRI countries in 2015. And the effects of environment variables to TFEE are also compared in this article.

2. Data Description and Econometric Methodology

2.1. Three-Stage DEA Model

Firstly, traditional DEA method is used in three-stage DEA model to analyze the energy efficiency. And then, Stochastic Frontier Analysis (SFA) method is used to correct the effect of environment variable and random error. Lastly, adjusted input data and raw output data are used to elevate DEA efficiency.

The 1st stage: traditional DEA method (BCC method). BCC method is used to handle validity problem of decision making unit under the assumption of variable returns to scale [12]. As for the returns to scale, it all depends on the amount of production that is attached to each isoquant. Input- and output-oriented models are two main approaches in DEA, which respectively measure the largest radial contraction of inputs and the largest radial expansion of outputs. Traditional classifier models

are oriented and hence the role of a flexible measure in an input-oriented model may differ from an output-oriented model [37]. The use of Deap 2.1 software to solve the question at hand is as follows:

$$min[\theta - \varepsilon(s^- + s^+)] \tag{1}$$

$$s.t.\begin{cases} \sum_{i=1}^{n} \alpha_i y_{ir} - s^+ = y_{0r} \\ \sum_{i=1}^{n} \alpha_i x_{ij} + s^- = \theta x_{0j} \\ \sum_{i=1}^{n} \alpha_i = 1, \alpha_i \geq 0, s^+ \geq 0, s^- \geq 0 \end{cases}$$

$i = 1, 2, \ldots, n; j = 1, 2, \ldots, m; r = 1, 2, \ldots, s; x_{ij}$ ($j = 1, 2, \ldots, m$) are input factors, y_{ij} ($r = 1, 2, \ldots, s$) is output factor and θ is efficiency value of decision making unit. The efficiency value calculated is the TFEE (CE), which can be decomposed into scale efficiency (SE) and pure technical efficiency (PTE). That is, CE = SE × PTE.TFEE TFEE is a comprehensive measurement and evaluation of the resource allocation ability and the resource efficiency in the case of variable returns to scale (VRS); pure technical efficiency is the production efficiency effected by management and system level and the measure of the gap of actual production point and the production possibility curve; scale efficiency is production efficiency effected by scale factors and reflects the gap between actual scale and optimal production scale. That is, the measurement of the difference between the actual production point and the F ray (starting from the origin, a ray passes through the maximum point of the slope tangent to the production possibility curve). The TFEE is 1, which means that the input and output is comprehensively effective. The bottom cause of failing to achieve TFEE is its invalid scale. So, the emphasis should be on the reform of how to exert scale benefit.

The 2nd stage SFA. Frontier4.1 software is used to solve this problem. The input and output slack variables got from the BCC model first stage may be affected by environment factors, random errors and internal management. SFA model is built in the second stage. Regression analysis was carried out to exclude significant errors, with the slack variables regarded as dependent variables, environmental variables and random errors regarded as explanatory variables. After eliminating the environmental variables and random errors, we could get input redundancy just for management inefficiency. Based on the result of first stage BCC model, we assumed that the number of observable management inefficiency is p. The input slack variables of DMUs were analyzed by SFA. The value of total adjustments, including slack and radial adjustments, was calculated by DEA. For the i-th DMU, the distance from an inefficient point where it is located to the projected point on the frontier by radial adjusting the level of inputs, $(1 - \theta) \times x_i$, is called "radial adjustment" [18]. The summation of slack and radial adjustments was the total value of "target" that could be decreased without reduction in output levels. With respect to energy input, the above summation was termed the energy saving target (EST) [38]. The radial approach is designed to maximize a level of unified inefficiency. The non-radial approach is designed to maximize the total amount of slacks, indicating the level of unified inefficiency in the objective function [39].

The regression model is constructed as follows:

$$s_{ik} = f^i(z_k; \beta^i) + v_{ik} + u_{ik} \tag{2}$$

$i = 1, 2, \ldots m; k = 1, 2, \ldots, n; s_{ik}$ represents that the i-th input slack variables come from k-th DMU; $z_k = (z_{1k}, z_{2k}, \ldots, z_{pk})$ represents the p observable environment variable. β^i is the parameter to be estimated for environmental variables; $f^i(z_k; \beta^i)$ is the effect of environment variable to input slack variables s_{ik}. This article selects $f^i(z_k; \beta^i) = z_k \times \beta^i \times v_{ik} + u_{ik}$ as mixed error term. u_{ik} represents inefficient management and we assume that it is normal distribution $u_{ik} \sim N(u^i, \sigma_{ui}^2)$ and $u_{ik} = (ce^i - 1) \times z_k \times \beta^i$. ce^i represents the cost efficiency of environmental variables; v_{ik} is random disturbance term and we make the assumptions that:

$v_{ik} \sim N(0,\ \sigma_{vi}^2)$, $v_{ik} = s_{ik} - z_k \times \beta^i - u_{ik}$; v_{ik} and u_{ik} are independent to each other. $\gamma = \sigma_{ui}^2 / \left(\sigma_{ui}^2 + \sigma_{vi}^2\right)$ is the proportion of technical inefficiency variance. Specially, when the value of γ becomes to 1, the influence of management factor is dominant; when the value of γ becomes to 0, the influence of random error is dominant.

We adjust the input items of DMUs using the regression result of SFA model. And the principle of is to adjust all the DMUs to the same objective conditions. Based on the most effective DMUs and the input amount, the adjustment of the input number of other samples is as follows:

T3 phase:

$$\hat{x}_{ik} = x_{ik} + [\max\left\{z_k\beta^i\right\} - z_k\beta^i] + [\max\{\hat{v}_{ik}\} - v_{ik}] \tag{3}$$

$i = 1, 2, \ldots, m; k = 1, 2, \ldots, n; x_{ik}$ represents the actual value of k-th DMU. $\hat{x}_{ik}$ is the its adjusted value; β^i is estimated value of parameter of environmental variables; $\hat{v}_{ik}$ is estimated value of random disturbance term.

The 3rd stage: input variables $\hat{x}_{ik}$ and raw output data y_{ik} are measured by BCC model. The efficiency values of DMUs is obtained by eliminating environmental variables and random errors.

2.2. Data and Index

Taking the degree of detail of the data into account, this article selects energy efficiency of 35 BRI countries in 2015. The input variables are Carbon emissions (C), Energy (E), Capital (K), Labor (L); the output variable is Gross Domestic Product (GDP) converted into 2010 dollars. The environmental emissions can be regarded either as inputs (costs) or as undesirable (negative) outputs in a DEA model, with each approach having inherent advantages and disadvantages [40]. We adopt the processing methods proposed by Ref. [41] and treat environmental emissions as input variables. In all research data, the data of carbon emissions and primary energy consumption are from Ref. [8] and the other data are from Ref. [42]. Input variables and output variables should contract tropism hypothesis in the model of DEA. So, this article adopts Pearson correlation test to examine it and the result is shown in Table 2. It can be seen that correlation coefficients of input variables and output variables are positive and can be checked by 1% significant level test, which indicates that the choose of input indicators and output indicators conforms to model requirements.

Table 2. The Pearson relevance of input variables and output variables of 35 BRI countries.

Variable	Carbon Emissions (C)	Energy (E)	Capital (K)	Labor (L)
GDP	0.983 ** (0.000)	0.875 ** (0.000)	0.949 ** (0.000)	0.746 ** (0.000)

** means it is significant at 1% significant level. The value of p is in the parentheses.

The choose of environment variables should affect TFEE and not affect by researchers. Therefore, the following factors are selected as environment variables in this article:

(1) Energy structure: it is represented by the proportion of fossil energy consumption in primary energy consumption;

(2) Degree of international trade: it is represented by the proportion of total import and export trade in GDP;

(3) Industrialization degree: it is represented by the proportion of industrial added value in GDP of countries.

3. Empirical Results

3.1. The DEA Result of the 1st Stage

Without considering the environmental variables and random errors, the average value of 35 BRI countries' national TFEE is 0.666, the average of pure technical efficiency is 0.879 and the average value of scale efficiency is 0.879. Shown in Table 3, the three efficiency values are 1 in Singapore, New Zealand,

Saudi Arabia, Turkey, Israel, Qatar, Poland, Hungary, Slovenia, and Kazakhstan. These countries are at forefront of energy efficiency; There is a big margin for improvement for the pure technical efficiency and scale efficiency of the other countries. The efficiency values of Uzbekistan and Ukraine are less than 0.2. What is more, the TFEE values of Central Asia and Commonwealth of Independent States are generally low. This maybe have something to do with geopolitics. But the result did not exclude the effects of environmental factors and random errors. The TFEE of each country could not be truly reflected, and the SFA needed to be measured.

Table 3. The national energy efficiency value of 35 BRI countries in 2015.

Country	Crste	Vrste	Scale	Returns to Scale	Country	Crste	Vrste	Scale	Returns to Scale
China	0.354	1.000	0.354	drs	Egypt	0.409	0.410	0.998	irs
Russia	0.511	1.000	0.511	drs	Kuwait	0.792	0.849	0.933	irs
Korea	0.647	1.000	0.647	drs	Qatar	1.000	1.000	1.000	-
Indonesia	0.696	0.718	0.969	drs	South Africa	0.232	0.240	0.968	irs
Thailand	0.383	0.387	0.990	drs	Ukraine	0.191	0.207	0.923	irs
Malaysia	0.526	0.537	0.979	irs	Belarus	0.364	0.628	0.579	irs
Vietnam	0.290	0.322	0.901	irs	Poland	1.000	1.000	1.000	-
Singapore	1.000	1.000	1.000	-	Romania	0.686	0.688	0.997	irs
Philippines	0.828	0.839	0.987	irs	Czech	0.879	0.905	0.971	irs
New Zealand	1.000	1.000	1.000	-	Slovakia	0.769	0.778	0.989	irs
India	0.493	1.000	0.493	drs	Bulgaria	0.392	0.661	0.593	irs
Pakistan	0.297	0.297	1.000	-	Hungary	1.000	1.000	1.000	-
Bangladesh	0.639	0.692	0.924	irs	Lithuania	0.958	1.000	0.958	irs
Saudi Arabia	1.000	1.000	1.000	-	Slovenia	1.000	1.000	1.000	-
The United Arab Emirates	0.713	0.825	0.865	drs	Albania	0.691	1.000	0.691	irs
Iran	0.426	0.430	0.990	drs	Kazakhstan	1.000	1.000	1.000	-
Turkey	1.000	1.000	1.000	-	Uzbekistan	0.150	0.262	0.572	irs
Israel	1.000	1.000	1.000	-					

Notes: Crste, Vrste, Scale represent TFEE, pure technical efficiency and scale efficiency; irs, drs and "-" mean increasing returns to scale, decreasing returns to scale and constant returns to scale, and it is same below.

3.2. SFA Regression Result

The input slack variables estimated in first stage is regarded as explained variables, including Carbon emissions, Energy, Capital, Labor. The Table 4 shows the result of SFA regression, in which the three environment variables are regarded as explanatory variable. It is necessary to notice that most of the slack variables values estimated in stage 1 are 0. Therefore, the variables should not be processed to logarithm and cost-dominant model should be chosen. It could be seen that LR test satisfied the 1% significant test in the SFA regression, which indicates that the external environment factors have influence on the input slack variables. The values of γ approach to 1 and the significant level of 1% is satisfied, which shows that the influence of managerial factors is critical and significant. In addition, most environmental variables pass the significance test for the coefficients of the input slack variables, indicating that input redundancy of countries is affected by external environmental factors.

Table 4. The regression results of the 2nd Stochastic Frontier Analysis (SFA) stage.

Inspection Quantity	Carbon Emissions	Energy Input	Capital Investment	Labor Input
Constant term	−10.108 ***	0.437 ***	261.619 ***	18.245 ***
	(−10.108)	(3.589)	(14.608)	(29.214)
energy resource structure	−6.177 ***	0.519 ***	−594.346 ***	−36.941 ***
	(−6.177)	(8.75)	(−38.417)	(−35.652)
Industrialization degree	30.75 ***	1.233 ***	455.598 ***	26.107 ***
	(30.75)	(−7.06)	(72.51)	(25.88)
Degree of international trade	−1.477	−0.084	−44.537 **	−2.605 ***
	(−1.477)	(0.685)	(−2.392)	(−19.3)
σ^2	258.061 ***	2.276 ***	127,531 ***	370.994 ***
	(258.061)	(4.373)	(127,530)	(371.857)
γ	0.999 ***	0	0.999 ***	0.999 ***
	(15,266)	.999 ***	(169,319)	(3,319,792)
		(5,126,025)		
Log Likelihood	−122.652	−40.375	−225	−125.184
One side LR test value	15.891 ***	41.006 ***	28.295 ***	23.545 ***

Notes: ** and *** donate significant at significance levels of 5% and 1%.

Generally, the negative coefficients of the environmental variables indicate that the increase of the environmental variables value decreases input slacks. Inversely, environmental variables with positive coefficients have unfavorable effects on eco-efficiency enhancement. Specifically, the impacts of each environmental variable are as follows:

(1) Energy resource structure: only the coefficient of the proportion of fossil energy consumption to energy investment is positive, while the other coefficients are negative. It shows that the increase of proportion of fossil energy consumption leads to the decrease of input redundancy in carbon emissions, energy input, capital investment and labor input. But it will increase the redundancy of energy input and aggravate the waste of energy. The reason of this result is likely to lie in the fact that the energy structure of most of BRI countries has reached a certain degree of saturation. The increase of the proportion of fossil energy will not greatly promote the growth of carbon emissions, energy input, capital investment and labor input. But the stagnancy of energy utilization technology level may aggravate the waste of fossil energy.

(2) Industrialization degree: the coefficients of the proportion of industrial additional value is positive to each input slack variables, which indicates that the improvement of industrialization will lead to the increase of input redundancy of factors like carbon emissions and energy input. The reason is likely to be that industrial development will inevitably lead to a large amount of energy consumption. There will be large amount of carbon emissions in the industry-oriented country. What' more, energy industry is a capital-intensive industry and needs a huge amount of capital and a small amount of labor input are needed.

(3) Degree of international trade: all coefficients of the proportion of total import and export trade in GDP are negative. But the effects of total import and export trade are not obvious, which shows that expanding the opening to the outside world is conducive to improving the TFEE of energy. Most of BRI countries are developing countries whose export products are mainly oil, gas, coal, wood and other raw materials to increase foreign exchange, and imported goods are mostly finished product. With the revolution of the global economic pattern, these countries have become emerging economies that popularly attract investment following a large amount of capital and labor input.

3.3. The Results of 3rd DEA Stage

Original input variables were adjusted according to Equation (3) to eliminate the effects of environmental variables and random errors. The real energy efficiency values were calculated by DEA again, and the results were shown in Table 5. Comparing the result of Tables 3 and 5, it could be seen that the TFEE average value of 35 countries in BRI decline to 0.537 from 0.666 after the environmental variables eliminated, which indicated that TFEE was overvalued because environmental variables and random errors with technical management level could not be really reflected. For individual countries, the TFEE values of New Zealand, Saudi Arabia, Qatar, Poland, Hungary, Slovenia and Kazakhstan reduce to less than 1. Contrarily, the TFEE value of South Korea increases to 1. The TFEE values of Singapore, Turkey and Israel keep to 1 still, which shows that there are little effects of energy structure, industrialization degree and opening degree to Singapore, Turkey and Israel. Conversely, the effects are obviously to the other countries. In the 35 countries of BRI, the countries with large growth in TFEE are China (143.2%), Russia (94.7%) and South Korean (54.6%) that are all east Asian countries. It indicates that environmental variables and random errors have a greater negative impact on their TFEE. After those factors are eliminated, the values have a greater ascension; countries with large reduction in TFEE are Slovenia (-69.9%), Kazakhstan (-66.2%) and Qatar (-61.3%), which shows that good environmental variables and random errors have a significant impact on the improvement of their TFEEs. From the point of regional distribution, the countries with high TFEEs concentrated in the East Asia and Eurasian border region where the country's economic development has reached a certain level and middle-income countries account for the majority. The countries with lower TFEEs mainly located in Southeast Asia, South Asia, Central Asia and Africa. These countries have a frail

economic foundation and their energy industries are in the initial stage of development. Consequently, there are great potential for energy saving and emissions reduction.

Table 5. The calculation result of the 3rd stage.

Country	Crste	Vrste	Scale	Returns to Scale	Country	Crste	Vrste	Scale	Returns to Scale
China	0.861	1.000	0.354	drs	Egypt	0.350	0.786	0.445	irs
Russia	0.995	1.000	0.995	drs	Kuwait	0.378	0.993	0.381	irs
Korea	1.000	1.000	1.000	-	Qatar	0.387	1.000	0.387	irs
Indonesia	0.733	0.733	1.000	-	South Africa	0.214	0.793	0.270	irs
Thailand	0.422	0.722	0.585	irs	Ukraine	0.185	0.762	0.243	irs
Malaysia	0.424	0.876	0.484	irs	Belarus	0.266	0.959	0.277	irs
Vietnam	0.273	0.655	0.417	irs	Poland	0.879	1.000	0.879	irs
Singapore	1.000	1.000	1.000	-	Romania	0.589	0.939	0.627	irs
Philippines	0.727	0.897	0.811	irs	Czech	0.595	0.986	0.603	irs
New Zealand	0.734	1.000	0.734	irs	Slovakia	0.516	0.980	0.526	irs
India	0.414	1.000	0.414	irs	Bulgaria	0.256	0.970	0.264	irs
Pakistan	0.346	0.588	0.589	irs	Hungary	0.598	1.000	0.598	irs
Bangladesh	0.497	0.876	0.568	irs	Lithuania	0.389	1.000	0.389	irs
Saudi Arabia	0.929	1.000	0.929	irs	Slovenia	0.301	1.000	0.301	irs
The United Arab Emirates	0.438	0.981	0.447	irs	Albania	0.694	1.000	0.691	irs
Iran	0.515	0.790	0.651	irs	Kazakhstan	0.338	1.000	0.338	irs
Turkey	1.000	1.000	1.000	-	Uzbekistan	0.140	0.856	0.164	irs
Israel	1.000	1.000	1.000	-					

In the 35 BRI countries, the average of TFEEs, pure technical efficiency and scale efficiency are 0.537, 0.918 and 0.579, respectively. The values of TFEE of South Korea, Singapore, Turkey and Israel are 1 at the forefront of efficiency. Among them, South Korea, Singapore and Israel are developed countries and in fields including social, economic, energy and environment they are matured ahead of the other developing BRI countries. The per capita GDP in Turkey is $13,825 (2010 dollars), higher ranking in developing countries. But its per capita GDP energy consumption is 0.32 kg oil equivalent/dollar, roughly same to Canada, Japan and other developed countries or even more than some European countries, which partly explains the source of Turkey's high energy efficiency. The four countries locating in different regions certainly perform positive impacts on the economic and social development of surrounding countries. Thereby, it will develop a favorable regional development mechanism by promoting the BRI cooperation.

Except the countries in the frontier, several countries including Russia, Saudi Arabia, Poland and China match with high TFEE (>0.8). There are a great many of similarities between these countries. For example, the industrial proportion is 30–40%; the GDP energy intensity is 0.3–0.4 kg oil equivalent per dollar; the proportion of fossil energy in primary energy use is more than 85% (the proportion of Saudi Arabia is over 99% as its abundant oil and gas reserves); those countries are all in the period of energy and economic transition and these countries have an active influence on the region and the world. Especially, China and Russia, as two superpowers of energy consumption and carbon emissions in BRI, have much higher energy efficiency than India. India's energy system is far behind the rapid growth of its population and economy, and in addition, its environmental indexes of regional water resources pressure, PM2.5 and carbon emissions intensity are extremely negative to the development. It is economic volume and emissions scale that determine the importance of China, Russia and India in the global energy and environmental governance. Relying on the dominant advantages of economic aggregate, territorial area and resource reserves, these countries with TFEE > 0.8 are in the period of rapid economic development or transition with active and stimulating performance for the regional development.

Countries with low TFEE (less than 0.3) are Uzbekistan, Ukraine, South Africa and Bulgaria. Expect Bulgaria, the other 3 countries have high GDP energy intensity of 0.89, 0.69 and 0.72 kg oil equivalent/dollar respectively, which are at the front ranks of the world. From the point view of geographical position and international situation, the main reason of low energy efficiency is geopolitical. Certainly, the reason may be that the level of energy utilization is not high. Central Asian countries locate in the inland with water resource shortage and few advantages to promote economy development, except the oil and gas trade with China. The international relationships between the

countries in Western Asia are complex and seriously affect the economy development due to perennial regional conflicts.

Ref. [18] analyzed energy efficiencies of 29 administrative regions in China for the period 1995–2002 with a newly introduced index of total-factor energy efficiency (TFEE). They found a U-shape relation between the area's TFEE and per capita income in the areas of China, which indicated the energy efficiency drops the most for an area in a developing stage but not in a developed stage. Considering most of BRI countries are emerging countries, out-of-date technologies and inappropriate production processes need to be upgraded while more output is still generated. The upgraded technologies and more advanced production processes should have been launched when an area or a region enters a developed stage and a better efficiency level is therefore expected. Ref. [43] employed DEA window analysis for measurement of TFEE of 23 developing countries based on their own frontier and thought that the energy-inefficient countries could take feasible improvement measures to reduce energy input without hindering economic output. Ref. [44] applied Bootstrap-DEA for comparing and analyzing the energy efficiency of BRICS, indicating that energy efficiency in BRICS is low, although, this rate is growing. In this article, the TFEE values of India and South Africa are in fairly low level. Ref. [45] used DEA for evaluate the energy efficiency of Organization for Economic Co-operation and Development (OECD) countries and indicated that countries based capital-intensive had energy efficient rather than labor-intensive countries. This is similar to the empirical results of this paper. The energy efficiency of Korea and Singapore based capital-intensive is higher than Thailand, Vietnam and South Africa.

As mentioned above, TFEE value is equal to the scale efficiency and pure technological efficiency. It could be seen from the Table 4 that the pure technological efficiency of BRI countries and the low scale efficiency value lead to low TFEE values. Therefore, we should improve the scale efficiency, and supplement technical input to improve the scale efficiency. China and Russia are in the stage of decreasing return to scale, and countries with TFEE of 1 are in the stage of constant return to scale. For the other countries in the stage of increasing return to scale, expanding the scale of input of energy, capital and other factors will obtain higher output ratio.

3.4. Projection Analysis

The projection principle of traditional DEA model is based on pure technical efficiency and slack variables. The value of pure technical efficiency is not 1 and the value of slack variables is not 0, which indicates that decision making unit is non-DEA efficiency [46]. Non-DEA efficiency of DMUs could be optimized by projecting on DEA efficient frontier to analyze the energy saving potential—the ratio of energy input to initial energy input. Projection correction value of DMU is the sum of radial modified value and modified value of slack variable. The radial modified value represents the value of various inputs proportional reduction or proportional increase. The positive number indicates the direction of change is increasing and the negative number represents reduction. The input-dominated BCC model is used in this paper to project and optimize the energy inputs and carbon emissions of 19 countries whose pure technique efficiency values are less than 1. As shown in Table 6, it can be found that Uzbekistan is the country with the greatest potential for energy conservation (54.6%) and then Ukraine (50.5%), Pakistan (47.4%) and South Africa (46.2%). In the future, improving energy management and utilization technology level should be focused on reducing energy waste. Consistent with energy saving potential, the four countries have the greatest emissions reduction potential. The main reason is that there is a high proportion of fossil energy in these countries will bring a large amount of carbon dioxide emissions because of poor energy utilization technology.

Table 6. Input projection optimization.

Country	Energy Projection Correction Value		Energy Input Projection (Mt Equivalent Oil)	Energy Saving Potential	Carbon Emissions Projection Correction Value		Carbon Emissions Projection	Emissions Reduction Potential
	Radial Modified Value	Slack Modified Value			Radial Modified Value	Slack Modified Value		
Indonesia	−46.38	0	173.9	26.7%	−132.1	−7.26	495.3	28.1%
Thailand	−36.4	−9.25	130.9	34.9%	−92.8	0	333.7	27.8%
Malaysia	−12.77	−3.34	102.9	15.7%	−34.5	0	278.1	12.4%
Vietnam	−25.14	−3.45	72.8	39.3%	−71.34	0	206.6	34.5%
Philippines	−4.83	0	46.9	10.3%	−14.92	−7.08	144.8	15.2%
Pakistan	−35.51	−5.39	86.2	47.4%	−91.9	0	223.1	41.2%
Bangladesh	−5.02	−1.19	40.4	15.4%	−14.63	0	117.7	12.4%
UAE	−2.19	0	117.7	1.9%	−5.95	−4.71	319.7	3.3%
Iran	−55.22	−28.48	262.8	31.8%	−139.2	−85.14	662.5	33.9%
Egypt	−20.44	0	95.3	21.4%	−54.82	−0.66	255.6	21.7%
Kuwait	−0.35	0	50.6	0.7%	−0.9	−1.4	132.1	1.7%
Qatar	−26.68	−33	129.2	46.2%	−89.06	−174.4	431.2	61.1%
South Africa	−22.17	−24.84	93	50.5%	−55.81	−61.13	234.1	50.0%
Ukraine	−1.34	−2.97	32.7	13.2%	−3.34	−10.54	81.7	17.0%
Belarus	−2.54	−0.53	41.7	7.4%	−7.02	0	115.1	6.1%
Poland	−0.67	0	49.3	1.4%	−1.82	−1.64	134.5	2.6%
Romania	−0.51	0	25	2.0%	−1.55	−4.37	76.1	7.8%
Czech	−0.85	−0.63	28.1	5.3%	−2.31	−11.05	76.2	17.5%
Slovakia	−8.77	−24.44	60.8	54.6%	−21.3	−60.76	147.6	55.6%

Although China's energy efficiency is very low compared with developed countries, China has been devoting to improve energy efficiency and has achieved a great success of energy consumption per unit of GDP declining by 21.2% from 2010 to 2016 [8]. Ref. [43] briefly reviewed the energy policies carried out by China and indicated that effective energy policies play a crucial role in improving energy efficiency. Furthermore, Ref. [47] used DEA method for evaluation of energy and emission efficiency in China, which showed that energy efficiency grows dramatic on CO_2 emissions and energy efficiency is 19% and 17%. Practice in China shows that effective energy policies play an important role in forcing all levels of government and energy-using units to take active measures to improving energy efficiency, such as, strengthening the energy efficiency responsibility and management system, improving energy efficiency standards in certain manufacturing sectors, promoting energy saving technology and products, accelerating the development of circular economy and so on. China's fresh experience on improving energy efficiency access is reproducible in BRI.

4. Conclusions and Policy Implications

With the three-stage DEA model, calculation results of total factor energy efficiency of 35 BRI countries are obtained with carbon emissions, energy consumption, capital and labor as input variables and GDP as output variable. After excluding the effects of environmental variables and random errors, the average value of TFEE decreases from 0.666 to 0.537. Therefore, it is necessary to exclude the effects of environmental variables and random errors when using the DEA model to calculate the actual energy efficiency. From the point of national differences in TFEEs, high-income countries including South Korea, Singapore, Israel and Turkey are in the efficiency frontier, and the energy efficiency of low-income counties including Uzbekistan, Ukraine and South Africa are in a low level. In those countries with high proportion of fossil energy, the problem of energy waste is serious, which means that there is high potential of energy conservation and emissions reduction in the future.

Energy cooperation in BRI is an important platform for promoting cooperation in other industries. Varying national development characters mean that the focus fields and pathways of energy cooperation should be determined on a country-by-country way. For countries with huge potential for energy conservation, cooperation in energy development and utilization technology can be carried out to help these countries out of the extensive use of energy. And it is also necessary to introduce clean and efficient electric power, renewable energy technologies and intelligent energy applications to these countries. The communication of experiences in energy allocation and scientific management from countries in the forefront of energy efficiency is essential for rational planning of energy utilization scale.

China and Russia are in the stage of decreasing return to scale, implying that business-as-usual expansion of energy investment will only lead to lower GDP growth. So, it is not recommended to increase energy consumption in exchange for GDP growth in the future in these two countries. Energy transition is a better choice to adjust economic structure by improving energy efficiency with a high-level production curve. Because the rest countries are in the stage of increasing return to scale, the expansion of energy input scale can effectively improve the growth rate of GDP. With the process of promoting the international cooperation, BRI countries should not only make progress in economic development but also have better opportunity in the coordinated development of society, energy and environment. For these countries, priority should be given to energy efficiency and various forms of renewable energy utilization to scientifically reduce pollutants and carbon emissions in the process of global energy and environmental governance.

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