ENERGY SECURITY AND ENVIRONMENTAL EFFICIENCY: EVIDENCE FROM OECD COUNTRIES

HUAPING SUN[*,§], MUHAMMAD IKRAM[†], MUHAMMAD MOHSIN[*]
and QAISER ABBAS[‡]

[*]*School of Finance and Economics*
Jiangsu University
Zhenjiang 212013, P. R. China

[†]*College of Economics and Management*
Nanjing University of Aeronautics and Astronautics
29 Jiangsu Avenue, Nanjing 211106, P. R. China

[‡]*Department of Economics*
Ghazi University Dera Ghazi Khan, Pakistan

Assessment of energy and environmental issues got a special focus due to global warming and climate vulnerabilities. Energy, environment, and economic development yielded a combined effect simultaneously, which is favorable for the economic point of view while unfavorable for environmental aspects. It is necessary to measure the energy, economic and environmental performance with appropriate methods. Therefore, this study measures the energy security and environmental efficiency. Data used in this study was collected from the official website of International Energy Agency (IEA), British Petroleum (BP) and World Bank. We employ a non-radial DEA technology for assessing energy and environmental efficiency for OECD countries. Results reveal that the values of energy intensity ranging from 0.93 to 0.30 while GHG emission per capita values ranging from 24.61 to 5.28. As for energy efficiency is concerned, the Iceland and Greece have the highest values 0.99 of energy efficiency whereas Ireland has the lowest value 0.34 of energy efficiency. Further analysis shows that the countries of Austria, Australia, Portugal, and Spain have the values between 0.70 and 0.80 for energy intensity whereas UK, Sweden, Germany and the USA, have the values of energy intensity between 0.40 and 0.50. The study proposes some valuable policy implications for policy and decision-makers to make the environment more sustainable.

Keywords: Assessment; DEA; environment; economy; energy; OECD.

1. Introduction

Climate change concerns have compelled the world to look for alternative energy options to reduce carbon emissions from traditional fossil fuels (Mohsin *et al.*, 2018). Even though renewable energy sources offer a sustainable source of energy, but unfortunately fossil

[§]Corresponding author.

fuels hold a majority of the world's power generation as a primary source (Bang *et al.*, 2018; Sun *et al.*, 2018, 2019a; Ikram *et al.*, 2019). As a result, electricity production is considered as a major and solitary carbon emitter worldwide, at the same time, energy demand is growing rapidly. Innovation and continuous switching, pattern from fossil fuel to renewable sources is an essential way forward for reducing carbon emissions because innovation has resulted in novel and better renewable energy technologies (Taghizadeh-Hesary *et al.*, 2013; Taghizadeh-Hesary and Yoshino, 2015, 2016a; Kolodko, 2018). Rapid international consciousness regarding climate change has forced the world to adopt several CO_2 reduction policies and set targets to reduce carbon emission (Benromdhane, 2015; Zhang *et al.*, 2018a). By this strong requirement, the adoption of carbon reduction policies targets and the improvement in technologies need to exploit renewable energy sources. It also requires the construction and development of methodologies in order to decide the optimal mixtures of renewable energy sources in the energy systems (Ouyang and Lin, 2014). This situation has developed various energy systems, and it should define the renewable energy sources targets and then analyze how to achieve those targets (Pérez *et al.*, 2013; Chen and Xu, 2018).

CO_2 emission has raised to 35.7 billion tons due to fossil fuel combustion, and industrial processes caused by 3% grew up of world economy, which represents the positive relationship between CO_2 emission and economic growth (Zhang *et al.*, 2015; Taghizadeh-Hesary *et al.*, 2016b; Zhang *et al.*, 2018b; Sun *et al.*, 2019b). The consumption of coal was seen low in 2014 by China, which ultimately enhanced the CO_2 emission only 0.9%, and was considered the lowest annual growth from the last decade due to population growth (Guo *et al.*, 2018; Sun *et al.*, 2014). Similarly, an increase of natural gas in power generation, the growth of CO_2 emission recorded 0.9% by the United States in the last two years (Jing *et al.*, 2018). The constant reduction rate of emissions in European countries was the outcome of lower demand for space heating and decreases in the consumption of fossil fuel for power production. Emissions in Australia, Japan, and Russia decreased by 2.1%, 2.6% and 1.5%, respectively while India, Brazil and Indonesia increased their emissions by 7.8%, 3.3% and 3.2% respectively (Nejat *et al.*, 2015; Mollahosseini *et al.*, 2017; Molinos-Senante *et al.*, 2015).

Currently, these emissions are considered as greatest threats to the sustainable environment. Empirical assessment, unfortunately, difficulty in achieving the low carbon society is lack of practical methodology to evaluate the pollution prevention and economic development and in a unified framework because the previous development usually addressed the merely various types of pollutions (Bujang *et al.*, 2016; Taghizadeh-Hesary *et al.*, 2016c; Vidadili *et al.*, 2017; Ikram *et al.*, 2019). Usually, economic development raises the level of numerous polluted entities without any green technology. To partially cope with the measuring difficulty, Data Envelopment Analysis (DEA) (Mohsin *et al.*, 2018) is considered as a practical methodology for evaluation of performance on several organizations in public and private sectors (Fleifle *et al.*, 2014). The economic activities are considered by desirable outputs (e.g., electricity) and inputs (e.g., the number of employees). They lack the practicality of traditional DEA and applications in energy and environmental assessment due to a lack of computational ability to handle the issue of undesirable bad outputs (e.g., CO_2) (Wang and Li, 2016).

Currently, various researchers are concerned with applications of DEA in energy and environment such as Sueyoshi and Wang (2018), Sueyoshi and Goto (2015), Sueyoshi and Yuan (2017), Taghizadeh-Hesary *et al.* (2018, 2019), Egilmez *et al.* (2013, 2016) and Rashidi and Farzipoor Saen (2015). In viewing the list of previous studies, the current study differentiated the analytical characteristics of DEA which can be separated into "radial" or "non-radial" classification. The study emphasizes on intermediate radial and non-radial approach and its associated mathematical application in energy and environment to increase the computability of DEA in energy and environmental assessment.

Previous studies used the basic description of environmental DEA technology through the fundamental assumption that production technology show the constant returns to scale (CRS). But, several actual cases show that the variant returns to scale and these situations cannot be deal with through the imposition of certain extra constraints in the similar pattern of traditional DEA models, since it might violate and disrupt the basic concept of environmental DEA technology. Färe and Grosskopf (1994) have briefly explained that how to deal with variant returns to scale for the application of environmental DEA technology nonetheless supporting work is needed on its application and characterization of environmental DEA technologies under their implementation and assessment of radial environmental performance.

In this study, we have proposed a framework to measure the environmental efficiency based on non-radial DEA technology. Further, we employ the detailed concept of the technology of energy and environmental DEA with the help of returns to scales (VRS) and non-increasing returns to scale (NIRS). The resulting radial DEA type models for assessing the performance of energy and environment under various situations have been then presented in this study. Moreover, we use an application study approach for assessing carbon emission performance against the energy consumption of OECD countries. For assessing nonlinear programming models, we also use linear equivalents models. Finally, this study proposes some valuable guidelines for policy and decision-makers to make the environment more sustainable.

The rest of the paper is set up as follows: Section 2 contains methodology, Section 3 explains results and discussion, Section 4 contains the conclusion and policy framework.

2. Methodology

Most pollution and contamination problems occur from the combined production of undesirable bad outputs during the production of desirable good outputs (Färe and Grosskopf, 2004). For example, the continuous emissions of nitrous oxide, carbon dioxide, and sulfur dioxide are unexpected when the electricity is produced from burning coal and thermal sources. We now regard a production process in which desirable good outputs and undesirable bad outputs are generated together. Let's assume the vector of undesirable outputs, desirable outputs, and inputs. $U \in R_+^J$, $Y \in R_+^M$ and $X \in R_+^N$. The production technology can be expressed as

$$T = \{(X, Y, U) : X \text{ can produce } (Y, U)\}. \tag{1}$$

In consideration of production theory, T is often regarded as bounded and a closed set, which is the assurance of the output closeness, and it means that limited number of inputs can merely generate the limited outputs (Zhou *et al.*, 2014; Zhou and Fan, 2010). Also, desirable outputs and inputs in T are considered to be freely disposable or robustly. Specifically, if $(X, Y, U) \in T$ and $X' \geq X$ or $Y' \leq Y$ then $(X', Y, U) \in T$ or $(X, Y', U) \in T$. To facilitate the suitable model, a production technology can generate the undesirable and desirable outputs, then the succeeding two assumptions proposed by Zhou *et al.* (2012) are imposed on T.

P.1. Outputs are weakly disposable, i.e., if $(X, Y, U) \in T$ and $0 \leq \theta \leq 1$, then $(X, \theta Y, \theta U) \in T$.
P.2. Undesirable bad outputs and desirable good outputs are null-joint, i.e., if $(X, Y, U) \in T$, and $\mathbf{Y} = \mathbf{0}$ then $\mathbf{U} = 0$.

Assumption P.1 indicates that the deterioration of undesirable bad outputs is not free, and the comparative decrease in undesirable bad outputs and desirable good outputs is possible. Assumption P.2 explains that a few undesirable bad outputs must also be generated during the production of desirable outputs. Specifically, the only way to eradicate undesirable bad outputs is to end the process of production of desirable outputs. Until now, the polluting technology also called the weak dispose-off capability reference technology conceptually modeled by Färe *et al.* (2005), for the concurrent generation of both undesirable and desirable outputs is explained by following output formula:

$$P(X) = \{(Y, U) \colon (X, Y, U) \in T\}. \tag{2}$$

$P(\mathbf{x})$ contains all feasible outputs which have the vector of $\mathbf{x}$ inputs and then it may be expressed as $(X, Y, U) \in T \Longleftrightarrow (Y, U) \in P(X)$ (Fare and Grosskopf, 2000). If $P(x)$ is a bounded and closed set and its equivalent production technology, while T represents an "environmental output set". Even though the production technology is conceptually well-defined, it cannot be used in the empirical application. Usually, first it requires to construct the equivalent relationships among the Shephard distance function, directional distance function, and T after that it can be generalized as a conventional single-output oriented production function (Charnes *et al.*, 1994). The distance functions can be used to assess on the base of parametric or nonparametric conditions. For measurement of nonparametric properties, Fare *et al.* (1989) presented the linear production technology, constant returns to scale (CRS) and Zhou *et al.* (2006) claimed that this type of production techniques can be used as environmental DEA technology because it is originated in DEA framework. Suppose that there are $k = 1, 2, \ldots, K$, DMUs, let our supposition is true for $\mathrm{DMU_k}$ the observed data on the vectors of inputs, undesirable bad outputs and desirable good outputs (Fare and Logan, 1983).

$$\boldsymbol{X}_k = (X_{1k}, X_{2k}, \ldots, X_{Nk}), \quad \boldsymbol{Y}_k = (Y_{1k}, Y_{2k}, \ldots, Y_{Mk}), \quad \text{and} \quad \boldsymbol{XU}_k = (U_{1k}, U_{2k}, \ldots, U_{Jk})$$

$$\sum_{j=1}^{J} U_{Jk} > 0 \quad \text{and} \quad \sum_{k=1}^{K} U_{Jk} > 0$$

$$F\colon (V_{k1}, \ldots, V_{kn}) \to (f_1(V_{k1})$$

$$T_{\mathrm{CSR}} = \left\{ (X, Y, U)\colon \sum_{k=1}^{K} Z_k X_{nk} \le X_n, n = 1, 2, \ldots, N \right\}$$

$$\sum_{k=1}^{K} Z_k Y_{mk} \ge Y_m, \quad m = 1, 2, \ldots, M \tag{3}$$

$$\sum_{k=1}^{K} Z_k U_{Jk} = U_{IJ}, \quad J = 1, 2, \ldots, J$$

$$Z_k \ge 0, \quad k = 1, 2, \ldots, K.$$

The construction of T_{CSR} provides a solid foundation for analysts and researchers in order to conduct an empirical estimation such as construction environmental performance index when Production technology shows the approximation of CRS. T_{CSR}, i.e., (3), follows the properties of the weak dispose-off capability of null jointness and outputs between undesirable outputs and desirable outputs (Mohsin *et al.*, 2018). CRS environmental DEA technology and $\mathrm{T_{CSR}}$ can be applied after the availability of suitable evidence of the consideration of production technology CRS. Various scholars have investigated the application and effectiveness of CRS environmental DEA technology in different schemes as well as in the assessment of productive efficiency and measurement of environmental performance having undesirable outputs (Charnes and Cooper, 1984; Zhou *et al.*, 2008). However, in practical cases the reference technology always does not show CRS while in other cases i.e., VRS might be observed in the actual situation (Fare and Lovell, 1978). Several researchers have proposed the studies with regard to the assessment of the returns to scale property e.g., Färe and Grosskopf (1997) and Rogge (2012). Consequently, it is logical to differentiate various environmental DEA technologies whereas the equivalent DEA-based models for measuring environmental performance. Zhou *et al.* (2012) concluded that the reference technology revealing CRS, and VRS or NRIS is particularly attractive in assessing studies. Hence, it is essential to demonstrate the environmental DEA technologies which validate NIRS and VRS. Like the conventional framework of DEA, NIRS environmental DEA technology (TNIRS) could be developed by imposing the restrictions on the variables of intensity on the CRS environmental DEA technology in order to reduce data uncertainty (Carstensen and Lindegarth, 2016).

$$T_{\mathrm{NIRS}} = \left\{ (X, Y, U)\colon \sum_{k=1}^{K} Z_k X_{nk} \le X_n, n = 1, 2, \ldots, N \right\},$$

$$\sum_{k=1}^{K} Z_k Y_{mk} \geq Y_m, \quad m = 1, 2, \ldots, \ M,$$

$$\sum_{k=1}^{K} Z_k U_{Jk} = U_{IJ}, \quad J = 1, 2, \ldots, J, \tag{4}$$

$$Z_k \geq 0, \quad k = 1, 2, \ldots, K.$$

In VRS DEA, unlike traditional DEA framework, the VRS environmental DEA technology (T_{NIRS}) could not remain structured via imposing the limitations due to yielded technology that might infringe environmental DEA technology. Therefore, it is essential to develop a differentiation between traditional DEA and the concept of environmental DEA technology. To endure it, we first make a slight modification on P.1 and P.2, whereby P.1 outputs are weakly disposable, i.e., if $(X, Y, U) \in T$ and $0 \leq \theta \leq 1$, then $(X, \theta Y, \theta U) \in T$, P.2 undesirable bad outputs and desirable good outputs and are null-joint, i.e., if $(X, Y, U) \in T$. Here P1 still shows the weak dispose-off capability reference technology for the concurrent generation of both undesirable and desirable outputs.

P.2 implies that the desirable good outputs necessarily exist as insignificant if undesirable bad outputs are insignificant. P3 is to some extent weaker than the previous one, and it can be considered as environmental DEA technology. VRS environmental DEA technology possibly is derived by multiplying the adjusting parameter not less than 1 with the right-hand side of the constraints of undesirable bad outputs. We follow the similar suggestion proposed by Faere *et al.* (1989) but multiply the right-hand side of desirable good outputs constraints with the same parameter. The resultant environmental output becomes:

$$T_{\text{VRS}} = \left\{ (X, Y, U) : \sum_{k=1}^{K} Z_k X_{nk} \leq X_n, n = 1, 2, \ldots, N \right\},$$

$$\sum_{k=1}^{K} Z_k Y_{mk} \geq \propto Y_m, \quad m = 1, 2, \ldots, M,$$

$$\sum_{k=1}^{K} Z_k U_{Jk} = \propto U_{IJ}, \quad J = 1, 2, \ldots, J, \tag{5}$$

$$\propto \geq 1, \quad Z_k \geq 0, \ \ k = 1, 2, \ldots, K.$$

The small difference between (5) and the model proposed by Scheel (2001) whereas model 5 is naturally more similar to DEA. T_{VRS} shows the VRS environmental DEA technology and it does not have an effect on its assessing property of environmental performance.

3. Results and Discussion

The overall world figures show better evaluations of the consumption of fossil fuel in this period even though the level of uncertainty may not be decreased. China's emission of CO_2

is twice as compared to the United States. But it is anticipated that in the next decade the emissions would have become equal. China's greater CO_2 emissions ranking is accredited to its emerging economy, huge population, and strongly reliant on the coal energy mix (Branger and Quirion, 2015). Similarly, the worldwide share contains Brazil 1.4%, South Korea is 1.7% whereas Mexico total share is 1.3% (Yin *et al.*, 2015). With a great jump of 5.2% in 2010, the world's total CO_2 emissions and the remaining states grow with 1.9% in 2012, 1.8% in 2013 and 2.2% in 2014. Whereas CO_2 emissions decreased in Mexico's by 1.6% and contrariwise enhanced by 3.3% in Brazil, Korea (0.2%), South Indonesia (3.2%) and Iran (2.6%) (Olivier *et al.*, 2016). The developing countries are expected to emphasize on reducing GHG emissions and save energy under the Paris agreement in order to ensure energy efficiency and environmental sustainability.

Table 1 reveals that the values of energy consumption (Koe capita) range from 14462.19 to 1841.08 including Israel 14462.19 highest value followed by Norway 8160.52, Sweden 6002.32, Germany 6568.5 and Australia has 5636.01 whereas Chile contains minimum energy consumption.

The values of the primary energy supply (million ton) range from 482.79 to 4.01, i.e., Luxembourg has the highest values 482.79 while Norway has a minimum value of 4.01. The consumption of renewable energy supply ranges from 77.03 to 2.71. Iceland has highest values of renewable energy consumption after that Norway 57.77, Sweden 53.25, Finland 43.24 and Chile 24.88 are the market leaders in terms of renewable energy while Korea and Israel have minimum values 2.71 and 3.71 respectively.

GHG emission per capita (kg/capita, 000) values range from 24.61 to 5.28 having Australia top 24.61 after that Netherland has lowermost GHG emission per capita 5.28 (Table 1).

Currently, it's mutually agreed that emission reduction means sacrifices in economic growth and development, furthermore, it exhibits externalities. Various countries contain economic growth among the value of 1 and 2. Usually, the countries consume higher energy for higher economic development contain an increasing tendency of GHG emission. According to the report (World Bank, 2015), during the period of 1960 to 1990, environmental indicators get more deterioration because of incessant temperature through the Greenhouse effect (GHG). Only carbon dioxide (CO_2) emission produced from fossil fuel is responsible for about 56.6%. Moreover, according to the report of International Energy Outlook, CO_2 emissions caused by the combustion of fossil fuels is worsening, which is damaging climate change (Mohsin *et al.*, 2019).

3.1. *Empirical results*

According to energy statistics 2014, we can see that the consumption of coal worldwide increased up to 0.4% comparatively to 2013 due to the highest share calculated 50.6% by China of total world coal consumption (Xie and Weng, 2016). Meanwhile, due to high domestic production, the consumption of coal increased to 11.1% in India which was a bit high in 2014 comparatively 7.3% in 2013. Moreover, a low coal consumption trend was seen at 5.3% in Germany, 20.3% in the United Kingdom, 3.7% in Italy, 2.5% in Australia, 1.6% in Japan and 0.3% in the United States (Vinci *et al.*, 2017; Hassan and Salim, 2015).

Table 1. Individual Indicators of OECD Countries

Country	EC (Koe Capita)	PES (Million Ton)	Renewable %	GHG (Kg/Capita, 000)	GHG Per Unit of EC	GDP Growth
Australia	5636.01	119.77	09.18	24.61	1395.22	3.29
Austria	3902.54	32.310	34.39	10.24	326.53	1.90
Belgium	5296.14	56.680	09.21	12.48	379.05	1.80
Canada	8033.36	267.19	22.03	21.79	1356.22	2.36
Chile	1841.08	25.940	24.88	5.360	630.28	5.20
Denmark	4183.86	43.850	33.17	13.54	503.53	1.48
Finland	3390.62	18.570	43.24	11.84	287.07	1.77
France	3979.19	5.3900	13.52	14.58	73.670	1.57
Germany	6568.50	34.870	14.21	13.44	162.98	1.44
Greece	4042.36	258.48	17.17	8.390	1930.62	1.01
Hungary	3999.74	267.24	15.56	11.84	3633.61	1.76
Iceland	2525.82	27.460	77.03	10.90	720.75	2.68
Ireland	2519.47	25.710	09.08	6.830	407.83	4.62
Israel	14462.19	21.280	03.71	14.04	4.51	5.16
Italy	3256.81	14.000	16.52	15.02	297.51	0.73
Japan	2903.28	4.6400	06.31	10.35	316.66	0.93
Korea	2928.13	170.41	02.71	8.760	2662.71	5.28
Luxembourg	3830.65	482.79	09.03	10.68	5331.77	3.68
Mexico	4677.42	234.70	09.22	12.34	1807.36	2.78
Netherlands	2022.87	4.4000	05.89	5.280	84.530	1.99
New Zealand	2548.52	8.2000	30.79	6.500	127.00	2.68
Norway	8160.52	4.0100	57.77	23.92	21.430	2.48
Poland	1553.64	177.35	11.91	5.820	4490.83	3.69
Portugal	4776.17	78.690	27.16	12.55	649.50	1.53
Spain	4255.64	18.220	16.25	18.82	281.24	2.04
Sweden	6002.32	28.640	53.25	11.46	136.76	2.04
Switzerland	2476.78	94.830	25.29	10.35	2395.62	1.55
Turkey	2295.33	24.030	13.37	7.190	492.60	4.01
UK	3287.75	17.720	08.71	8.820	216.79	2.08
US	3477.38	7.0500	08.72	9.650	84.330	2.56

Table 2 shows the values of energy intensity ranging from 0.30 to 0.93. New Zealand and Norway have 0.93 as the highest values, while Ireland and Luxembourg have a minimum value of energy intensity of 0.30.

As for energy efficiency is concerned, the Iceland and Greece have the highest values, 0.99 of energy efficiency whereas Ireland has the lowest value 0.34 of energy efficiency. Further it can be seen that the countries of Austria, Australia, Portugal, and Spain have the values between 0.70 and 0.80 for energy intensity whereas UK, Sweden, Germany and the USA, have the values of energy intensity between 0.40 and 0.50. Also, as for detailed results of efficiency, Australia, Austria, Mexico, and Switzerland contain the score between 0.70 and 0.80 whereas Germany, Sweden, UK and the USA have values between

Table 2. Energy Intensity, Energy Efficiency and Environmental Index

Country	Energy Intensity	Energy Efficiency	Environmental Index
Australia	0.72	0.74	0.65
Austria	0.74	0.74	0.65
Belgium	0.62	0.63	0.54
Canada	0.62	0.71	0.62
Chile	0.69	0.69	0.60
Denmark	0.50	0.50	0.41
Finland	0.58	0.56	0.47
France	0.51	0.48	0.39
Germany	0.46	0.49	0.62
Greece	0.84	0.99	0.93
Hungary	0.59	0.58	0.51
Iceland	0.89	0.99	0.97
Ireland	0.30	0.34	0.27
Israel	0.71	0.83	0.76
Italy	0.68	0.63	0.56
Japan	0.53	0.55	0.48
Korea	0.70	0.52	0.45
Luxembourg	0.30	0.37	0.30
Mexico	0.90	0.70	0.62
Netherlands	0.57	0.78	0.71
New Zealand	0.93	0.42	0.64
Norway	0.93	0.65	0.57
Poland	0.36	0.36	0.28
Portugal	0.84	0.95	0.87
Spain	0.89	0.41	0.62
Sweden	0.45	0.46	0.37
Switzerland	0.67	0.72	0.63
Turkey	0.69	0.91	0.82
UK	0.40	0.47	0.38
USA	0.40	0.43	0.34

0.40 and 0.50. Among all OECD countries, Italy's higher power prices result in Italy's most efficient towards energy efficiency, instead in Iceland, the improvement of energy consumption in power-intensive manufacturing comparatively makes Iceland's remarkable rising energy intensity level. During the last two decades, the decreasing energy intensity might be considered as a measure of energy efficiency improvement, including substantial environmental and economic benefits. Historically, energy intensity in transition economies was greater as compared to industrialized economies, but then again it has started to decrease sharply since the starting of the transition period. There should be a need to formulate strategies and policies of energy efficiency and technologies intended to solve the problems related to energy consumption to minimize greenhouse gas emissions.

Considerable differences have been noted during the shift of economic activities and the energy efficiency improvements. Especially 24 out of 30 OECD countries' average energy intensity from 2000 to 2015 decreased while this reduction was because of upgrading energy efficiency, industrial shifts, and economic activities. Energy efficiency structural shift in Germany, Ireland, Iceland, Netherlands, Canada, Japan, Luxembourg, UK, and the US caused a reduction in energy intensity. Enhanced energy intensity of Israel, Portugal and New Zealand was due to deteriorations in their energy efficiency structural reallocation, directing towards energy consumption. Spain failed to get a huge constructive shift in economic activity while Israel, Greece, Iceland, and Turkey got increased energy efficiency. GDP growth and GHG emissions show a coincidence i.e., increase in GDP growth caused enhanced GHG emissions, especially in Australia, Canada, Korea, and Poland. These countries' increasing GDP yielded a significant effect on GHG emissions whereas, in Israel, Netherland, New Zealand, Norway, and Denmark GDP growth and GHG emissions showed a bit weak relationship.

Table 3 shows OECD total GHG emissions value is 239719948.2, from 2000 to 2015, the maximum value is 104703444, mean value 6658887.45, and the minimum value is 65159.976. The scores vary for energy efficiency and energy intensity based on how energy is generated by renewable energy sources. Increasing renewable energy helps to reduce energy cost and GHG emission; for example, Japan doesn't have sufficient natural resources, i.e., crude oil and natural gas which is the smaller quantity among OECD countries. Japan's external dependent oil supplies might increase economic growth which surely can enhance its per capita GHG emission.

Currently, Germany is shifting the state energy demand to renewable energy supplies as well as the evolution support to promote renewable energy cross border trade. Energy efficiency can assess the CO_2 emission against energy consumption which is an important solution to decrease global warming and minimize climate vulnerabilities. Economic growth and development resulted in higher energy consumption, subsequently increasing the pressure exercised by energy consumption and production on the environment. Reducing energy intensity and improving energy efficiency are conducive to alleviating the inherent contradiction between economic development and environmental protection. In this regard, many countries such as Australia, Japan, Germany, and Sweden have done well, and they are promoting the decoupling of economic development from energy consumption.

Table 3. Summary Statistics of GHG Emission (Tons of CO_2 Equivalent Thousand)

Sum	239719948.2
Mean	6658887.45
Maximum	104703444
Minimum	65159.976

Generally, absolute decoupling is ready to reduce the environmental pressures after the consumption and production of fossil fuel (Wu *et al.*, 2018). Economic variable and energy efficiency shows that development in energy efficiency leads towards the alleviation of the cost of fuel through its environmental effects relying on the sources of energy. Moreover, it is still commonly agreed that the renewable energy is measured as more effectual as compared to fossil fuels because we argued that the consumption of renewable energy resulted in decreasing the level of CO_2 emission.

3.2. *Sensitivity analysis*

After solving several linear programming models, it may be affected via various uncertainty factors. First, the best practice frontier, created through the values of attainable entities, which is the estimate of the true frontier that might be subject to uncertainty happening in variation because of sampling of the attained frontier. Although the uncertainty can be reduced by using the solicitation of bootstrap methods in order to assess the differences in the values of sampling order in original data set, however, it is important to note that the best practice frontier concerning the constructing of environmental efficiency which is different from the construction of frontier in productivity analysis and efficiency assessment. One major practice for the development of environmental efficiency is to conduct a cross-sectional investigation to measure environmental performance through time. Such an implicational framework allows using the newly generated observations from all the comparable underlying entities at the different time frame to work out the frontier of best practice during the construction of environmental efficiency assessment.

Even though the variation and uncertainty in a sampling of the obtained frontier is not a basic objective of the current study, data accuracy during a new set of dataset generation is the most important reason for variation and uncertainty. Regarding CO_2 related data, as pointed out by Zhou *et al.* (2012), amount of variation and uncertainty in the accuracy of the data makes the development of the metrics of environmental efficiency assessment difficult, however in the methodology of proposed DEA's sensitivity concerning data agitation can be hypothetically checked. In this study we conducted the sensitivity analysis of measurement of environmental efficiency assessment via random way, which is exaggeratedly important to change in observations. Data exaggeration for all observations to generate a new data set has been supposed by within $\pm$ 10%. By producing the random numbers within the specific range of interlude [-10%, 10%], we produced 20 datasets for OECD states based on those 20 sets of the database, and the measurement of environmental efficiency can be attained.

By using the 20 new data sets of environmental efficiency, we first compute the average value of assessment of environmental efficiency furthermore to the equivalent standard derivations which have been examined to measure the exact variation in the newly developed data set. Results show that the effect of data uncertainty in the specific range of average values of measurement of environmental effects of each OECD country is reasonably weak. For the time being, the effect of data uncertainty and data variation reveals

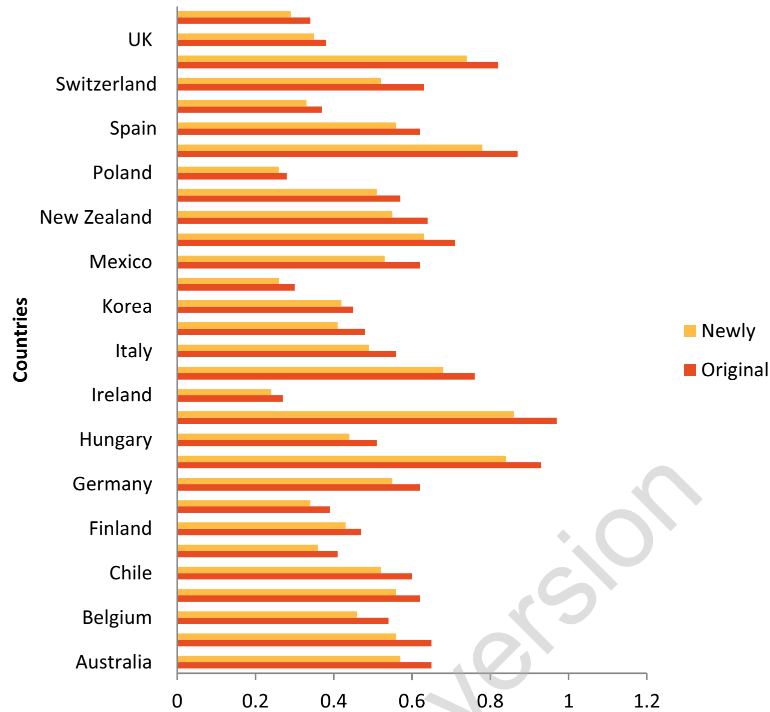

Figure 1. Original and Newly Simulated Values

that a small change on the standard derivation of the average values of measurement of environmental efficiency is presented in Figure 1, which may indicate that our results are strongly reliable and robust. It is suggested that in the precise range interval, the variation and uncertainty within data accuracy demonstrate that the average values of measurement of environmental efficiency are properly insensitive.

To assess the scattering of the values of environmental efficiency the values significantly fluctuated after the higher uncertainty in the data. While the data accuracy is considered as a major pillar and the comparison has been necessary between the values of measurement of environmental efficiency yielded by the original dataset and newly constructed dataset for the purpose of sensitivity assessment.

Few ostensible changes can be seen in Figure 1, especially in the median and ranges of measurement of environmental efficiency which shows the insensitivity of our model and the reliability of the accuracy assessment with the comparatively big sample size.

Significantly nominal changes in the values of measurement of environmental efficiency and lesser standard deviation with uncertainty in data accuracy reveal the lesser insensitivity, which ensures that they are performing under best practice frontier (in the case of uncertainty in data accuracy) which is surely the indication of the robustness of the best practice frontier. In essence, its main advantage of the proposed methodology is dealing with data irregularity problems, for example, a large number of zeros and it follows some desirable index number properties so the robustness of results verifies the above claim.

4. Conclusion and Policy Implications

We have discussed the VRS and NIRS environmental DEA technologies, wherein outputs are still weakly disposable essentially. This study developed framework based on non-radial DAE technique to assess the energy security and environmental efficiency. We have conducted the assessment of energy efficiency and constructed an environmental index. Results reveal that the values of energy consumption range from 14462.19 to 1841.08 including Israel 14462.19 highest value followed by Norway 8160.52, Sweden 6002.32, Germany 6568.5 and Australia has 5636.01, whereas Chile contains minimum energy consumption. The values of the primary energy supply range from 482.79 to 4.01 i.e., Luxembourg has the highest values 482.79 while Norway has a minimum value of 4.01 while the consumption of renewable energy supply ranges from 77.03 to 2.71. Iceland has highest values of renewable energy consumption after that Norway 57.77, Sweden 53.25, Finland 43.24 and Chile 24.88 are the market leader in terms of renewable energy while Korea and Israel have minimum values 2.71 and 3.71 respectively. GHG emission per capita values range from 24.61 to 5.28 having Australia top 24.61 after that Netherland has lowermost GHG emission per capita 5.28. As for energy efficiency is concerned, the Iceland and Greece have the highest values 0.99 of energy efficiency whereas Ireland has the lowest value 0.34 of energy efficiency. Further analysis shows that the countries of Austria, Australia, Portugal, and Spain have the values between 0.70 and 0.80 for energy intensity whereas UK, Sweden, Germany, and the USA, have the values of energy intensity between 0.40 and 0.50. Also as for detailed results of efficiency, Australia, Austria, Mexico, and Switzerland contain the score between 0.70 and 0.80 whereas Germany, Sweden, UK, and the USA have values between 0.40 and 0.50. Further, this study has some police implications for policymakers and the Government. The policy points are as follows:

(1) The Government should build an infrastructure for developing remotely located hydro projects, as mostly the hydropower projects are situated in isolated and hilly areas where infrastructure do not exist including easily getting roads, high voltage diffusion lines and efficient distribution system.
(2) It is necessary to break through the institutional constraint and inefficient operational utilities because there exist institutional barriers in OECD countries which obstruct the encouragement of regional energy exchange.
(3) There is a need to change the political mindset through delegation training programs because of historical trauma and narrow-minded nationalism have constrained regional cooperation on energy despite evidence of significant economic benefits in the region.
(4) The Government needs to facilitate conformity covering the energy sector, and the contract should be specified for policy-makers to ensure long term sustainability, transparency, and accountability.
(5) There should be a step taken by the government to construct regional energy security plan which focuses on the mechanism of joint development, having the aim that the investment would be maximized in the energy security plan, resource expansion, and other energy infrastructure.

(6) The public sector should encourage private sector participation in the energy sector to improve the economic performance of different departments based on federal government funds.
(7) Largest oil producers including Saudi Arabia, Canada, and huge oil consumer's countries should develop special economic corridors in order to reduce oil supply vulnerability which directly affects energy security.

Acknowledgments

We are also grateful for the financial support provided by the National Natural Science Foundation of China (Nos. 71774071, 71690241, 71810107001 and 71834003), and Young Academic Leader Project of Jiangsu University (5521380003).

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