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Renewal Energy Efficiency Assessment

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Abstract: Over the years the significance of energy has greatly increased due to the pressing need to tackle climate change and reduce our dependence on fuels. Solar power, wind energy and hydroelectric power are considered as alternatives that can meet our energy requirements. By incorporating these energy sources into our mix, we can reap benefits such as job creation and economic growth particularly in rural and remote areas. To evaluate the potential of energy production in 11 countries a study was conducted using Data Envelopment Analysis (DEA) EBM analysis. The study considered three factors; the number of patents related to renewable energy, the capacity of energy installations and the gross domestic product (GDP). The output that was analyzed focused on energy production. The countries included in this study were Australia, Brazil, China, France, Germany, Japan, Netherlands, South Korea, Spain United Kingdom, and United States. This study's findings provide policymakers and investors with a framework for assessing each country's capability to generate energy. This methodology offers insights that can guide policy decisions concerning energy production across different nations.

Keywords: Renewable energy, Energy efficiency assessment, Data envelopment analysis, EBM analysis, Energy production

Introduction

In years there has been a global movement towards renewable energy sources to address concerns about climate change and achieve sustainable development. This movement brings benefits for the environment, economy, and society. However, to fully unlock the potential of energy sources we need to do more than just accept them; we must continuously strive to improve their efficiency and effectiveness.

Evaluating the efficiency of energy systems is crucial in this endeavor. By examining their performance, we can identify areas for optimization. Ensure utilization of available resources. Over time various strategies have been developed to assess the effectiveness of energy technologies. These range from approaches to advanced statistical models. However, many of these methodologies have limitations, such as oversimplifying dynamics or lacking assessment criteria.

In our paper we introduce an approach called Slack based Measurement (SBM) that analyzes the efficiency of energy systems. SBM offers a framework that considers inputs and outputs for a thorough assessment of

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renewable energy generation, distribution and consumption. Unlike approaches that solely focus on energy production, SBM considers critical factors, like resource utilization, waste generation and environmental implications. SBM takes an approach to assessing the efficiency of renewable energy systems leaving no aspect untouched.

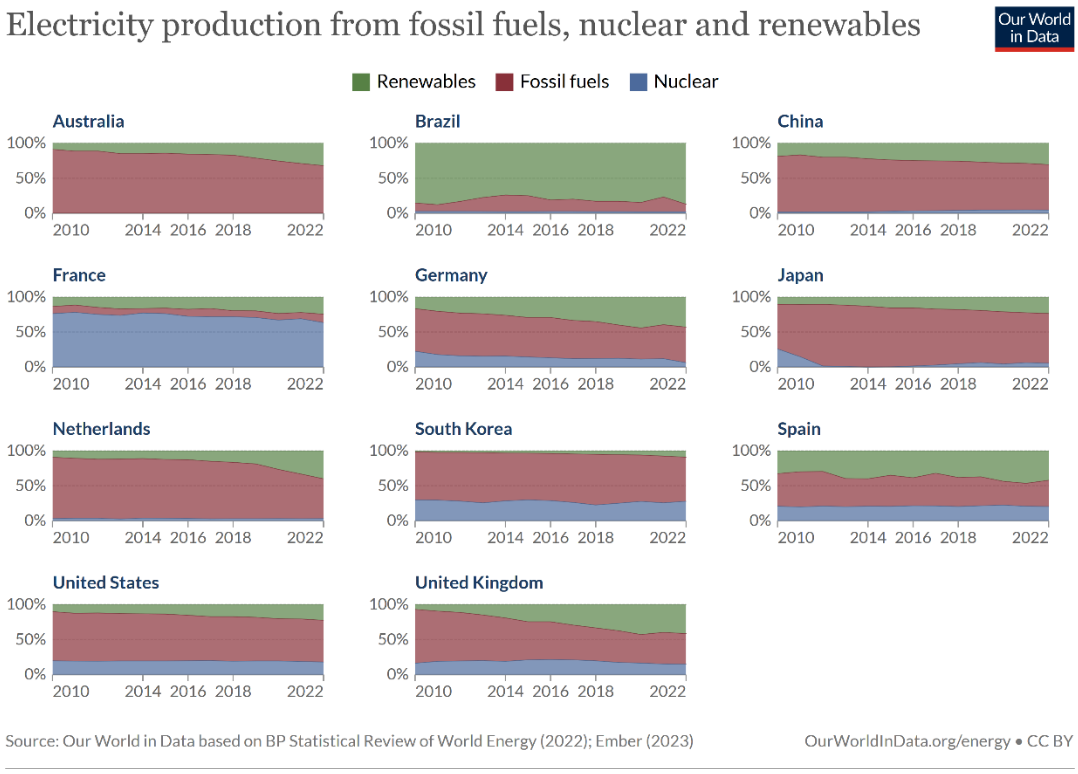

Figure 1. Comparison of electricity production from fuels, nuclear power, and renewables.

The main objective of this study is to use the SBM approach to evaluate and compare the efficiency of energy systems in ten countries. We have selected these nations based on their locations, energy landscapes and stages of development. Our aim is to gain insights into how their renewable energy systems perform and identify areas that can be improved by conducting a thorough examination using the SBM approach. This comparative research serves as a foundation for making decisions and shaping policies by identifying best practices factors contributing to success and areas that need more attention.

This research offers two contributions. Firstly, we present a framework for analyzing energy efficiency using the SBM technique, which addresses the limitations of existing methods and provides a comprehensive evaluation of renewable energy systems. This framework can enhance decision making processes, guide policy formulation and assist in creating long term energy strategies. Secondly, we provide an analysis of energy efficiency, across the selected countries. Our findings offer insights that can influence collaborations, information sharing, technology transfer ultimately leading to improved global renewable energy efficiency.

This research holds importance in the context of accelerating the global shift towards renewable energy sources. Policymakers, energy planners and other stakeholders can make informed decisions. Develop effective strategies to promote renewable energy technologies by identifying areas for improvement and emphasizing best practices. Moreover, the findings of this study can be utilized to enhance collaboration, facilitate information sharing and support technology transfer thus contributing to the pursuit of a sustainable and low carbon future.

In the sections of this paper, we will delve into the methodology employed, outline the framework devised, conduct an analysis, and provide a comprehensive explanation of our findings. The aim of this project is to offer insights into assessing energy efficiency while shedding light on its implications for policy making and practical implementation. Through these explorations we also establish a foundation for research on this subject matter.

Literature Review

Existing Approaches of DEA SBM

The proposed model known as DEA SBM presents an opportunity to examine how efficiently Municipal Solid Waste (MSW) recycling systems promote learning (Chang et. al., 2013) (Chang, Liu, & Yeh, 2013). The research community is particularly interested in identifying the activities that have contributed to advancing this field. In their study Liu et. Al. (2016) aimed to uncover these research activities, also known as research fronts within the domain of DEA (Liu, Lu, & Lu, 2016). Yang et. al. (2017) focused on assessing the efficiency of water and energy resource utilization across provinces, in China (Yang & Li, 2017). To address challenges Mousavi et al. proposed a framework based on efficiency DEA that is not constrained by specific orientations (Mousavi & Ouenniche, 2018). Hu et.al.(2019) employed a slack based DEA model called SBM DEA with five input variables and four output variables to evaluate the eco efficiency of 281 CWWTPs located in 126 level parks (NIPs) (Hu, Guo, Tian, Chen, & Recycling, 2019). Evaluating waste and total energy consumption serves as the focus when assessing Chinas regional sustainable innovation according to Xu et.al.(2019) (Xu, Bossink, & Chen, 2019). The authors of a study in 2020 investigated how Koreas local governments are investing in research and development (R&D) using a data analysis method called slack based model data analysis (SBM DEA) (Lee, Choi, Seo, & Change, 2020). They proposed an efficiency model called data envelopment analysis and slacks-based measure considering undesirable outputs (S DEA SBM UO) which builds upon the traditional DEA model, for unexpected output. Another research paper by Li et. al. (2021) examined the spatiotemporal evolution characteristics and influencing factors related to this topic (Li, Sarwar, & Jin, 2021). Lastly Wang et al.s (2022) main contribution is providing ideas for promoting quality agricultural development during Chinas transition period by studying green biased technical changes, in Chinese agriculture (Wang, Zuo, Qian, & Health, 2022).

Methodology

The Slack-based Measurement (SBM) Method

The non-negative data input is a compulsory requirement in the application of DEA models. Tone 2001 and Tone 2002 (Tone & Sahoo, 2004) developed the Slacks-based measure of efficiency (SBM) to evaluate the efficiency of the DMUk by Equation:

$$P\backslash\,(x_0, y_0) = \left\{(\bar{x}, \bar{y})\,|\, x \geq \sum_{j=1,\neq 0}^{n} \lambda_j x_j, \bar{y} \leq \sum_{j=1,\neq 0}^{n} \lambda_j y_j, \bar{y} \geq 0, \lambda \geq 0\right\}$$

Please keep in mind that the functions optimal value should be greater, than or equal to $\rho 2$, which in turn should be greater than or equal, to 1.

Selection of Ten Countries and Input-Output Variables

Table 1. List of 11 selected countries.

No	DMUs	**Countries**
1	Coun1	Australia
2	Coun2	Brazil
3	Coun3	China
4	Coun4	France
5	Coun5	Germany
6	Coun6	Japan
7	Coun7	Netherlands
8	Coun8	South Korea
9	Coun9	Spain
10	Coun10	United Kingdom
11	Coun11	United States

Table 1 illustrates the studies employing Data Envelopment Analysis (DEA) to assess the efficiency performance of Decision-Making Units (DMUs) spanning various sectors. Moreover, it displays the utilization of distinct variables. Emphasis is placed on the prioritization of commonly utilized variables found in previous studies. Specifically, this study focuses on eleven countries serving as DMUs, considering three inputs and one output. The performance efficiency evaluation for these eleven countries considers three variables: Total Number of Renewable Energy Innovation Patents (TNREIP), Total Renewable Energy Capacity (TREC), Gross Domestic Product (GDP), with Total Renewable Energy Production (TREP) being the designated output variable.

Results and Discussion

In this study, the focus lies on addressing the slack issues prevalent in conventional DEA models, such as CCR and BCC. To effectively tackle this challenge, we recognize the noteworthy merits of utilizing the SBM-I-C methodology in Data Envelopment Analysis (DEA). This choice is made with the intent of evaluating the efficiency units and rankings of individual countries under scrutiny(C. N. Wang, Yang, Vo, & Nguyen, 2022). By employing the SBM-I-C approach, we aim to overcome the limitations inherent in traditional DEA models and present a more comprehensive and accurate assessment of country efficiency. Table 2 shows the statistics on input and output data of 11 countries in 2020.

Table 2. Statistics on Input/Output Data for the Year 2020

2020	TNEIPs	TREC (MW)	GDP (Billion US)	TREP (GWH)
Max	128,933	899,625	21,060	2,149,534
Min	13	18,477	910	32,998
Average	13,989	165,052	5,144	403,528
SD	36,596	244,463	6,265	598,516

Table 3 displays the persuasive results of the Pearson correlation test performed on the inputs and outputs for the year 2020. The presence of significant positive connections validates the "homogeneity" and "isotonicity" statistics, so meeting two critical conditions for the successful application of the DEA model. Furthermore, the significant correlations identified among the variables provide major grounds for reasonable input and output selection. The extraordinary correlation coefficient of 0.9935 between TREC and TREP in relation to RE, for example, highlights the extraordinarily high level of reliability in the data collection method. This study shows that nations with a significant Total Renewable Energy Capacity (TREC) are more likely than their counterparts to attain a correspondingly larger Total Renewable Energy Production (TREP).

Table 3. Calculated Pearson correlation matrix of inputs and output

	TNEIPs	TREC (MW)	GDP (Bill. US)	TREP (GWH)
TNEIPs	1	0.9738	0.5776	0.9512
TREC (MW)	0.9738	1	0.6976	0.9935
GDP (Bill. US)	0.5776	0.6976	1	0.7243
TREP (GWH)	0.9512	0.9935	0.7243	1

Table 4 displays the Diversity Matrix, created using the DEA SBM I-C model to compare 11 nations' performance. The matrix shows how these countries differ in efficiency. The DEA SBM I-C model, which measures efficiency using input and output parameters, is a strong analytical framework. The diversity matrix reveals efficiency differences across the 11 countries. The diversity value in each matrix cell demonstrates how efficient two countries are. A smaller diversity number indicates similar efficiency levels, while a greater value indicates distinct ones.

Table 4. Diversity matrix

	TNEIPs	TREC (MW)	GDP (Bill. US)
TNEIPs	0	0.2650	0.2076
TREC (MW)	0.2650	0	0.2617
GDP (Bill. US)	0.2076	0.2617	0

Table 5 illustrates the DEA SBM I-C model's Affinity Matrix comparing 11 countries' efficiency. The Data Envelopment Analysis Slack-Based Measure Input-Oriented Slack Based model (DEA SBM I-C) is a powerful analytical tool that measures efficiency by considering input and output parameters(Kler et al., 2022). The affinity matrix links countries by efficiency. The affinity value between two countries reveals how efficient they are. Higher affinity values indicate greater similarity, whereas lower values indicate less.

Table 5. Affinity matrix

	TNEIPs	TREC (MW)	GDP (Bil US)
TNEIPs	1	0.4699	0.5849
TREC (MW)	0.4699	1	0.4767
GDP (Bil US)	0.5849	0.4767	1

In 2020 we can see the performance ranking of 11 countries, in Table 6. This ranking is based on the adjusted Slack Based Measure (SBM) model, which is derived from the CCR model. It shows us how efficient and effective each country is in using their resources to achieve their desired outcomes (Peng, Wang, Xuan, Nguyen, & Management, 2022). Policymakers and researchers can find this information valuable as it helps them identify which countries are performing well and where improvements can be made (C. N. Wang, Yang, Nguyen, & Vo, 2022).

Table 6. Performance ranking of 11 countries in 2020.

No.	DMU	Score	Rank
1	Australia	0.300436	11
2	Brazil	1	1
3	China	0.524808	4
4	France	0.482037	5
5	Germany	0.395533	8
6	Japan	0.373996	9
7	Netherlands	0.421178	7
8	South Korea	0.325747	10
9	Spain	0.438937	6
10	United Kingdom	0.574795	2
11	United States	0.559242	3

Figure 2 depicts the energy consumption rankings of 11 countries. Thanks to this visual representation, we can gain a feel of how different countries use renewable energy. The ranking assists us in identifying the countries that have successfully adopted and integrated renewable energy technologies. A rating is often presented from highest to lowest or lowest to highest.

Discussion of Findings

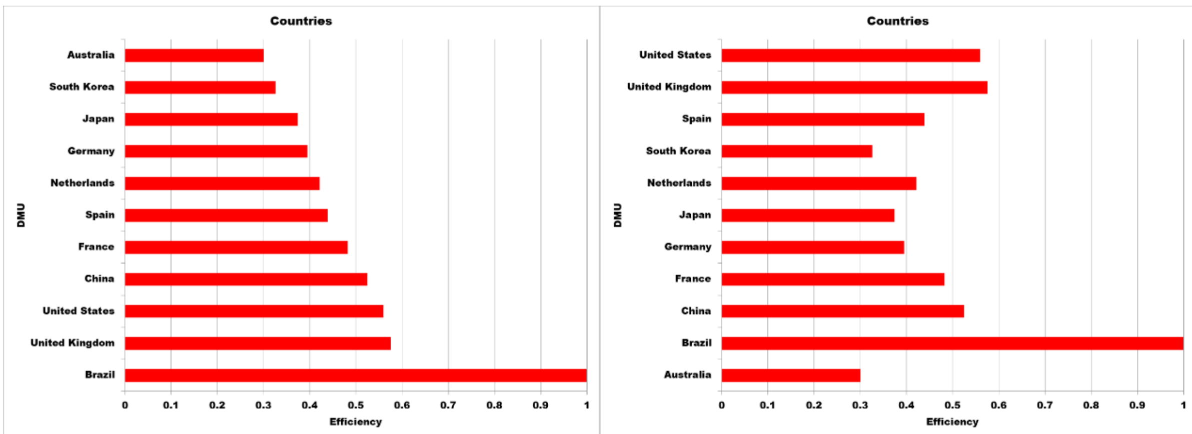

Figure 2. Ranking of 11 countries' renewable energy

Based on the data presented in Figure 2, which showcases the performance ranking of 11 countries in 2020 regarding renewable energy utilization, several noteworthy observations and insights can be gleaned. The findings offer a valuable basis for a comparative analysis of countries' renewable energy efficiency and highlight the varying levels of success in harnessing renewable energy sources.

The discussion of findings reveals Brazil as the top-ranked country, achieving the highest score of 1, signifying its exceptional performance in renewable energy utilization. Conversely, Australia secured the lowest rank with a score of 0.300436, indicating potential room for improvement in its renewable energy practices. Meanwhile, the United Kingdom and the United States secured the second and third positions, respectively, showcasing commendable efficiency in their renewable energy initiatives.

Insights into renewable energy efficiency can be derived from the rankings, enabling a better understanding of how each country optimally utilizes its renewable energy resources. Such insights can contribute to the identification of best practices and success factors adopted by top-performing countries. These exemplary practices can serve as models for other nations aspiring to enhance their renewable energy efforts. Conversely, countries with lower rankings can benefit from this assessment by identifying potential areas for improvement. Analyzing the strategies and policies employed by higher-ranked countries can provide valuable guidance for addressing challenges and optimizing renewable energy utilization.

The data also holds crucial policy implications and recommendations for governments and policymakers worldwide. Countries with higher rankings can reinforce their policies and initiatives to sustain their renewable energy leadership, while lower-ranked countries can develop tailored strategies to elevate their renewable energy performance. The performance ranking of 11 countries in renewable energy offers valuable insights for comparison and evaluation. By leveraging these findings, countries can work towards a sustainable and greener future, ensuring optimal utilization of renewable energy sources and contributing to global efforts in combating climate change.

The analysis of the performance ranking of 11 countries in renewable energy utilization provides significant insights and implications for policymakers, researchers, and energy analysts. The discussion of findings encompasses a comprehensive examination of various aspects, including:

The ranking of the 11 countries reveals distinct variations in renewable energy efficiency. Brazil stands out as the top-performing country, attaining a perfect score of 1, showcasing exemplary practices in renewable energy utilization. On the other hand, Australia lags, securing the lowest rank with a score of 0.300436, indicating potential areas for improvement. The rankings offer a clear comparison of countries' performance, providing a baseline for evaluating their renewable energy efforts.

The data-driven ranking sheds light on the level of success achieved by each country in harnessing renewable energy sources. Countries like China, France, Germany, and the United Kingdom demonstrate notable efficiency in their renewable energy initiatives, obtaining competitive scores within the top five rankings. These insights provide valuable benchmarks for understanding the varying degrees of renewable energy utilization across nations.

The high-ranking countries offer valuable insights into the best practices and success factors that contribute to their renewable energy efficiency. Analyzing the strategies and policies implemented by top-performing countries can provide valuable lessons for other nations seeking to optimize their renewable energy utilization. Sharing and adopting these best practices can lead to significant improvements and advancements in renewable energy deployment.

For countries ranking lower in the performance assessment, the findings illuminate potential areas for improvement in their renewable energy endeavors. Identifying specific weaknesses and challenges can guide policymakers in formulating targeted policies and strategies to enhance renewable energy adoption. Addressing these areas can contribute to overall national progress in transitioning towards sustainable energy sources.

The performance ranking data carries crucial policy implications and recommendations. High-ranking countries can build on their achievements by reinforcing existing policies and exploring further opportunities for renewable energy expansion. Meanwhile, lower-ranked countries can utilize the insights gained to develop tailored policies and initiatives aimed at boosting renewable energy utilization. Policymakers can collaborate and learn from each other to accelerate global renewable energy deployment and combat climate change effectively.

The discussion of findings stemming from the performance ranking of 11 countries in renewable energy presents a valuable resource for understanding the landscape of renewable energy utilization. The insights garnered can inform strategic decision-making, foster international collaboration, and drive a collective effort towards a sustainable and greener future.

Conclusion

Limitations and Future Research

The study's conclusion must acknowledge certain limitations that may impact the interpretation and generalizability of the findings. Methodological limitations, such as the specific assumptions and simplifications inherent in the Data Envelopment Analysis (DEA) approach, should be recognized. Additionally, data availability and quality can pose challenges, as incomplete or unreliable data may affect the accuracy of the analysis. Addressing these limitations in future research endeavors can enhance the robustness and reliability of performance assessments in the renewable energy domain.

Furthermore, potential enhancements to the framework used for renewable energy efficiency evaluation should be explored. Refining the DEA approach and incorporating advanced analytical techniques can yield more nuanced insights into countries' renewable energy performance. Integrating qualitative data and conducting case studies could provide a deeper understanding of the contextual factors influencing renewable energy adoption and identify best practices.

Summary of Findings

The findings of this study make substantial contributions to the field of renewable energy assessment. The performance ranking of 11 countries offers a valuable benchmark for comparing renewable energy efficiency across nations, enabling policymakers and researchers to identify high-performing countries and areas for improvement. The insights into renewable energy efficiency shed light on successful strategies and best practices employed by leading countries, offering valuable lessons for others to emulate.

Implications for policy and practice are evident from the ranking results. High-ranking countries can bolster their efforts by reinforcing successful policies and scaling up renewable energy initiatives. Conversely, lower-ranked countries can utilize the findings to devise targeted policies aimed at accelerating renewable energy deployment.

Future directions for research in the renewable energy domain should consider addressing the identified limitations and expanding the scope of investigation. Comparative studies encompassing a broader range of countries and renewable energy sources can provide a more comprehensive understanding of the global renewable energy landscape. Exploring the potential impact of external factors, such as economic, political, and environmental conditions, can further enrich the analysis.

The study's findings offer valuable insights into renewable energy efficiency across countries and present opportunities for fostering sustainability. By recognizing the limitations and refining the methodology, future research can contribute to an evidence-based approach in promoting renewable energy adoption and facilitating the transition to a more sustainable energy future. The study's implications for policy and practice serve as a call to action for policymakers and stakeholders to collaborate in advancing renewable energy agendas for the benefit of future generations and the planet.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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