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Assessing the Energy Efficiency of Saudi Arabia's Relatively Middle Eastern Countries in the Context of Sustainable Development Goal Seven (SDG7)

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ABSTRACT

This paper employs a non-parametric approach to assess and compare the energy efficiency of Saudi Arabia with that of other Middle Eastern countries in the context of SDG7. An approach for evaluating the performance of each unit that utilizes optimization and linear programming is data envelopment analysis (DEA). A reference set for an inefficient unit is created to facilitate the comparison of various units against the efficiency boundary and enhance the efficiency of each unit. The research employs data envelopment analysis, incorporating three input and two output variables. This approach enables Middle Eastern countries to identify ineffective measures and recall essential actions necessary for enhancement. This study's findings suggest recommendations for the effective utilization of resources. This analysis indicates that Saudi Arabia, along with certain Middle Eastern nations, exhibits greater energy efficiency than most countries in the region. When analyzing the Middle East, Saudi Arabia, United Arab Emirates, Bahrain, Cyprus, Qatar, and Turkiye are notable examples of sustainable practices requiring further investigation. Furthermore, Yemen, Lebanon, and Syria require additional scrutiny to enhance effectiveness. The proposed study presents noteworthy conclusions concerning energy efficiency. The findings are anticipated to aid government agencies in pinpointing the factors influencing sustainable development and facilitating policymaking in Middle Eastern countries.

Keywords: SDG7, Data Envelopment Analysis, Middle East Countries, Energy Efficiency, Gross Domestic Product
JEL Classifications: C32; O13; O47

1. INTRODUCTION

Energy is a dynamic contributor to the economy of a country. Many aspects of society are impacted by it, including employment, health, food preservation, agriculture, medical technology, and education. Middle East Energy has provided solutions to the energy community throughout the Middle East for over 45 years. Middle Eastern countries rely primarily on gas and oil, not coal. In 2023, 76% of power was generated by gas and 18% by other fossil fuels. Most Middle Eastern countries have yet to adopt clean power. Last year, the Middle East produced 5% of its energy from clean sources, behind the world average of 39% (Middle East, 2023). In Saudi Arabia, total petroleum production in 2023 is estimated at 11.113 million barrels per day, while refined petroleum consumption for 2022 is estimated at 3.649 million barrels per day. The projected natural gas output for 2022 is 121.87 billion cubic meters, which aligns precisely with the consumption level of 121.87 billion cubic meters (Saudi Arabia, Energy, 2023).

In recent years, it has been recognized that natural gas and crude oil are catalysts for rapid development and growth and the resultant transnational trade worldwide (Demirbas et al., 2017). The Middle East is believed to be home to over half of the world's proven reserves. If the oil from Venezuela and the tar sands from Canada hadn't been added to global reserves, it would be far higher than 60%. (World Proved Oil Reserves, Fact or Fiction, 2024). 14% of the world's energy demand comes from renewable energy (RE) sources. A significant portion of the world's electricity is generated by large-scale hydroelectric plants (Demirbas et al., 2017).

Specifically, Almasri and Narayan's study aimed to identify the extent of energy efficiency (EE) and the harnessing of solar, wind, and geothermal energy resources within the selected regions (Almasri and Narayan, 2021). A study conducted by Mohsin et al. (2021) involving data analysis on forty-eight countries around the world located in numerous regions revealed exciting findings. Based on the difference-in-difference method and Data Envelopment Analysis, it was determined that Bangladesh, Singapore, Nepal, and Uzbekistan failed to implement energy reforms. However, energy reforms and development in Sub-Saharan Africa have achieved desired outcomes (Mohsin et al., 2021).

In the study of Ma and Wang (2022), Analysis of geographical and policy factors affecting energy efficiency fluctuations was employed, as well as building high, medium, and low GDP growth scenarios and predicting energy efficiency forecasts using a long-short-term memory neural network model. Energy efficiency improved most significantly upstream. In contrast, energy efficiency decreased downstream and in the middle and lower streams. According to future development trends, 6.5% economic growth would be most favorable to energy efficiency.

This study's objective is to model and measure the Energy Efficiency of Middle East Countries using a non parametric approach to understand the situation. The following sections follow a logical order:

- In the section "Materials and Methods," the data and DEA approach used to estimate energy efficiency are illustrated.
- We present the results and interpretations of our energy efficiency investigation in the "Results" section.
- The "Conclusions" section summarizes and concludes the study.

2. LITERATURE REVIEW

This study, which employs DEA to model and assess energy efficiency in Middle Eastern countries, holds significant implications for the field of operations research. DEA, a non-parametric method, is used to estimate output frontiers and assess the practical efficiency of decision-making units.

Charnes et al. (1978) introduced novel methodologies for assessing the effectiveness of decision-making units within public programs. Ang (2006) indicates that studies conducted at both national and international levels during the 1970s and 1980s identified specific traditional indicators. The analysis undertaken by Yeh et al. (2010) revealed that the eastern provinces of China achieved superior energy efficiency compared to the western provinces. Additionally, Taiwan's energy consumption exceeded that of the eastern provinces during that period. Notably, the eastern and central provinces were found to adhere to China's highest energy efficiency utilization rankings. Camioto et al. (2022) employed a DEA-slack-based measurement model to analyze energy efficiency in BRICS countries. Ibrahim and Alola (2020) report a significant decrease in renewable energy nexus efficiency from 2006 to 2016.

The optimization of energy use is a significant worldwide concern that is crucial for attaining sustainable development. Although the use of clean energy is growing steadily, more than 80% of worldwide energy consumption is from fossil fuels, including oil and natural gas, and around half of power production relies on coal resources (Li et al., 2017). Consequently, the public, scholars, and governments are directing increasing focus on this issue. The assessment of energy efficiency in various locations and industries has great importance as it not only enables the identification of disparities in energy efficiency but also establishes a quantitative foundation for enhancing efficiency (Song et al., 2015). Based on our current understanding, the energy efficiency calculated using various criteria and indicators exhibits significant variation. Several researchers have conducted studies on measuring energy efficiency to achieve a more precise assessment of energy efficiency. Most notably, Hu and Wang (2006) introduced the notion of total factor energy efficiency (TFEE), which gained widespread recognition. TFEE posits that output production is impossible with solitary energy input, necessitating combining energy with other elements (such as labor and economic capital). As the TFEE framework describes, energy efficiency is the ratio of the desired energy input to the input needed at a particular output level. Initial techniques for assessing Total Factor Economic Efficiency (TFEE) assume that combining production elements, including labor, capital, and energy, would result in a single output, often represented as the gross domestic product (GDP). Given the prevailing use of fossil fuels in global energy consumption, the severity of environmental pollution is progressively escalating. Hence, a substantial body of research has progressively integrated ecological concerns into assessing energy efficiency (Zhang et al., 2018).

Furthermore, this implies that energy efficiency is a crucial concern associated with the synchronized development of the economy, energy, and the environment. There are parametric and non-parametric approaches to measuring energy efficiency. One of the prerequisites for Parametric Stochastic Frontier Analysis (SFA) is the assumption of a production function (Pulina et al., 2010). The Non-parametric DEA approach efficiently assesses the efficiency of decision-making units in complex scenarios with many inputs and outputs. It has been extensively used to evaluate time-frequency efficiency measures (TFEE). Zhu et al. (2015) highlighted that Data Envelopment Analysis (DEA) is a data-driven approach used to assess the effectiveness of a group of uniform Decision-Making Units (DMUs).

Despite research on energy efficiency analysis, a universally accepted standard for choosing input and output variables has yet to be established. From 1993 to 2003, Honma and Hu (2008) computed the energy efficiency of a specific area in Japan using the same conceptual framework. During manufacturing operations, the predominant energy consumption structure is still fossil fuels.

Consequently, the environment is significantly affected by substantial carbon emissions, wastewater, and waste gas produced by conventional energy sources. In this context, energy efficiency assessment includes unwanted outputs such as carbon emissions and waste gas (Wu et al., 2016). In their evaluations of energy efficiency in 30 provinces and cities in China, Li and Lin (2015), Zhang and Choi (2013), and Wang, et al. (2012) also included GDP and carbon emissions as output variables. Furthermore, Makridou et al. (2016) and Feng and Wang (2017) use the factors above to assess the effectiveness of high energy-consuming businesses in European Union nations and industrial sectors at the province level in China. The industry-based research (Boyd and Pang, 2000; Worrell et al., 2003; Wei, 2007; Azadeh et al., 2007; Mukherjee, 2008; Martínez, 2013; Martínez, 2015) agrees that energy intensity reduces efficiency.

Shi et al. (2010) examined the energy efficiency of 28 administrative regions in China from 2000 to 2006. They found that industries in the east had the highest average energy efficiency, followed by those in the central area. The high technological efficiency and extensive energy utilization in industrial production also contribute to significant energy waste.

Finally, Zhou et al. (2012) estimate economy-wide energy efficiency performance from a production perspective by measuring energy efficiency at the macro level and proposing a parametric frontier approach for 21 OECD countries. Ireland, Italy, and Norway have the highest efficiency scores, while Canada, New Zealand, and Belgium have the lowest. This study examined the energy efficiency of Middle Eastern countries globally within the framework of SDG7, employing specific variables for measurement and subsequently presenting the concluding outcomes.

3. MATERIALS AND METHODS

3.1. Data

The Secondary data used in this study covers Saudi Arabia's relatively Middle Eastern countries. The dataset for this study (Session 2010-2019) was obtained from the World Bank and Our World in Data Portals (World Bank Indicators, 2024 and Our World in Data Energy, 2024). This study included Middle East countries to analyze their energy efficiency efforts. DEA was used three inputs i.e. energy consumption, total labor force, population total and two output variables i.e. CO_2 emission and gross domestic product to measure energy efficiency. The data description for test is presented in the following Table 1 that clarifies more about inputs and outputs.

3.2. Proposed Mathematical Programming

There are two basic DEA models—CCR, developed by Charnes et al. (1978), and BCC, developed by Banker et al. (1984). The CCR models consider overall efficiency while assuming constant returns to scale. On the other hand, the BCC models provide more model-related details, considering pure technical efficiency and scaling variable returns.

Table 1: Data description

Type of variables	Variables descriptions
Input	Energy consumption (TWh)
	Total labor force
	population total
Output	CO_2 emissions (metric tons per capita)
	GDP (current US$)

In this paper, a proposed DEA model was used to assess the efficiency of each decision-making unit (DMU). Evaluation of DMUs was considered using the DEA model designated as DMUi, where i ranges from 1 to 15. The following proposed fractional programming problem was solved to obtain values for the input x_{ji} (j = 1, 2,3) and output y_{ki} (k = 1, 2) as variables. This study proses a standard formulation based on the model of Charnes et al. (1978) and the decision-making unit r (DMUr/θ_r) efficiency can be determined by solving the proposed DEA model as below.

$$max\ \ \theta_r = \sum_{k=1}^{2} \omega_k y_{kr}$$

st,

$$\sum_{j=1}^{3} \vartheta_j x_{jr} = 1$$

$$\sum_{k=1}^{2} \omega_k y_{ki} - \sum_{j=1}^{3} \vartheta_j x_{ji} \leq 0 \qquad \forall\ i,\ i = 1, 2, \ldots.., 15$$

$$\vartheta_k,\ \omega_j \geq 0 \qquad\qquad \forall\ j,\ k$$

Where;

xji = quantity of input j consumed by DMUi

yji = quantity of output 'k' formed by DMUi

ϑ_j = weight for input j

ω_k = weight for output k

From the above model, if θ_r equals 1, DMU_r is efficient compared to other units; else, the converse is true. Many DEA extensions, such as input or output-oriented models, are solved based on the control of the output or input parameters. Proposed model 4 has merit in that it uses a consistent set of four inputs and two outputs to compare the various efficiencies of the targeted nations, demonstrating that the middle east countries' efficiency efforts are comparable to those of the four developed countries. This study provides specific recommendations for Saudi Arabia's relatively Middle Eastern countries in the context of Sustainable Development Goals based on their ranking.

4. EMPIRICAL RESULTS

The energy efficiency was assessed using the three inputs and two outputs variables connected with the essential radial-model input orientated with constant returns to scale (CRS). The proposed DEA models will assist the Middle Eastern countries

Table 2: Energy efficiency of Saudi Arabia's relatively middle eastern countries using DEA

DMUs	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Saudi Arabia	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
United Arab Emirates	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Bahrain	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Cyprus	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Egypt, Arab Rep.	0.39	0.40	0.46	0.44	0.50	0.62	0.63	0.46	0.53	0.69	0.95	0.92
Iran, Islamic Rep.	0.73	0.81	0.78	0.60	0.56	0.56	0.62	0.64	0.43	0.40	0.39	0.44
Iraq	0.50	0.75	0.82	0.76	0.78	0.70	0.64	0.72	0.83	0.90	0.78	0.79
Jordan	0.40	0.46	0.48	0.49	0.53	0.61	0.61	0.64	0.69	0.75	0.77	0.77
Kuwait	0.84	0.88	0.96	0.94	0.89	0.84	0.86	0.88	0.89	0.92	0.80	0.84
Lebanon	0.64	0.71	0.74	0.74	0.75	0.84	0.87	0.88	0.96	0.92	0.59	0.42
Oman	0.64	0.66	0.73	0.68	0.72	0.79	0.77	0.71	0.69	0.71	0.66	0.60
Qatar	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Syrian Arab Republic	1.00	0.39	0.33	0.21	0.23	0.24	0.20	0.25	0.30	0.35	0.20	0.15
Turkiye	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Yemen, Rep.	0.38	0.56	0.71	0.55	0.64	1.00	1.00	1.00	0.80	0.68	0.72	0.61

Figure 1: Energy efficiency of Saudi Arabia's relatively Middle Eastern countries

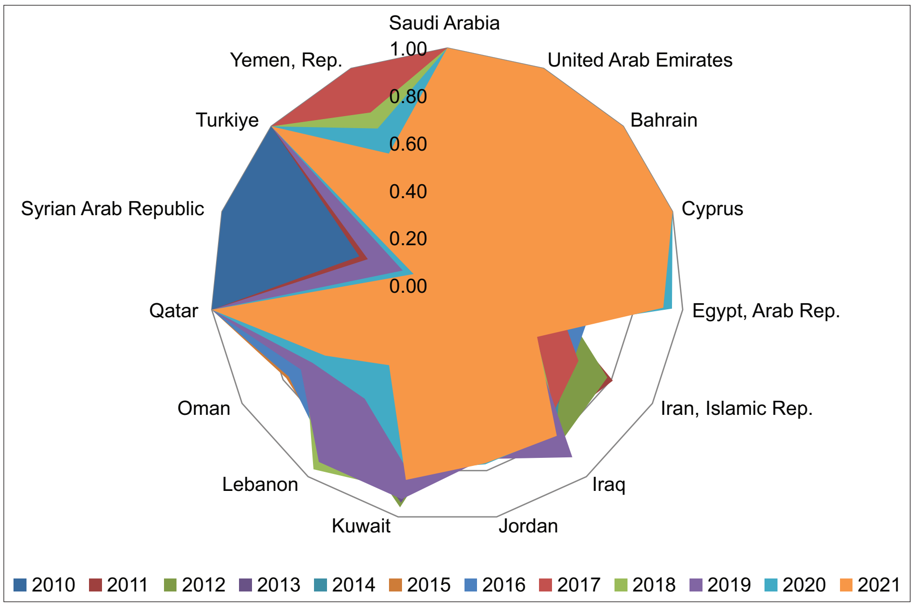


Figure 2: Gap analysis Energy efficiency

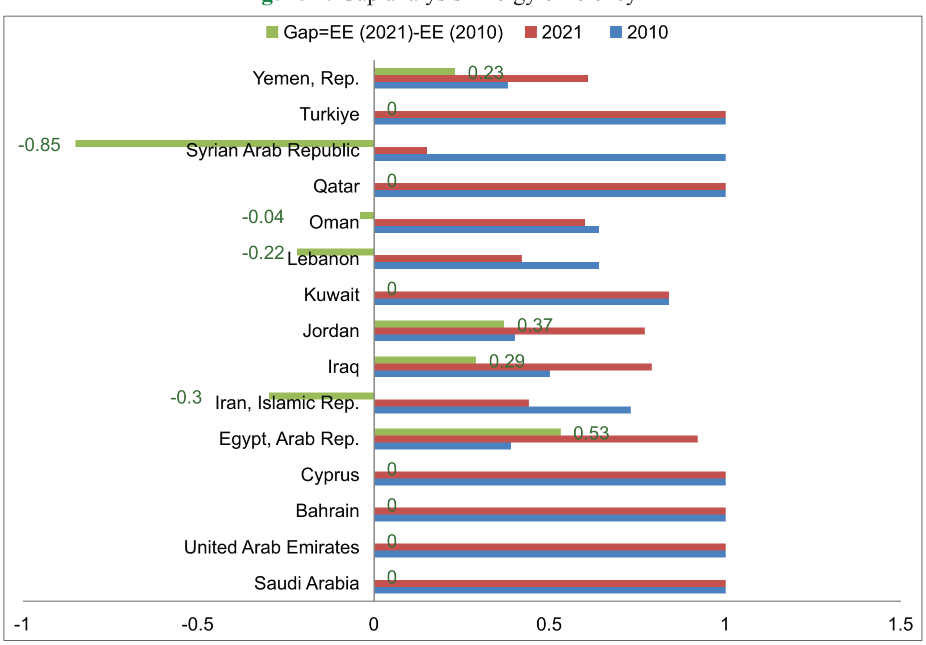


Table 3: Gap analysis energy efficiency

DMUs	2010	2021	Gap=EE (2021)-EE (2010)
Saudi Arabia	1.00	1.00	0
United Arab Emirates	1.00	1.00	0
Bahrain	1.00	1.00	0
Cyprus	1.00	1.00	0
Egypt, Arab Rep.	0.39	0.92	0.53
Iran, Islamic Rep.	0.73	0.44	-0.3
Iraq	0.50	0.79	0.29
Jordan	0.40	0.77	0.37
Kuwait	0.84	0.84	0
Lebanon	0.64	0.42	-0.22
Oman	0.64	0.60	-0.04
Qatar	1.00	1.00	0
Syrian Arab Republic	1.00	0.15	-0.85
Turkiye	1.00	1.00	0
Yemen, Rep.	0.38	0.61	0.23

in identifying ineffective measures and necessary actions for improvement.

4.1. Energy Efficiency using DEA

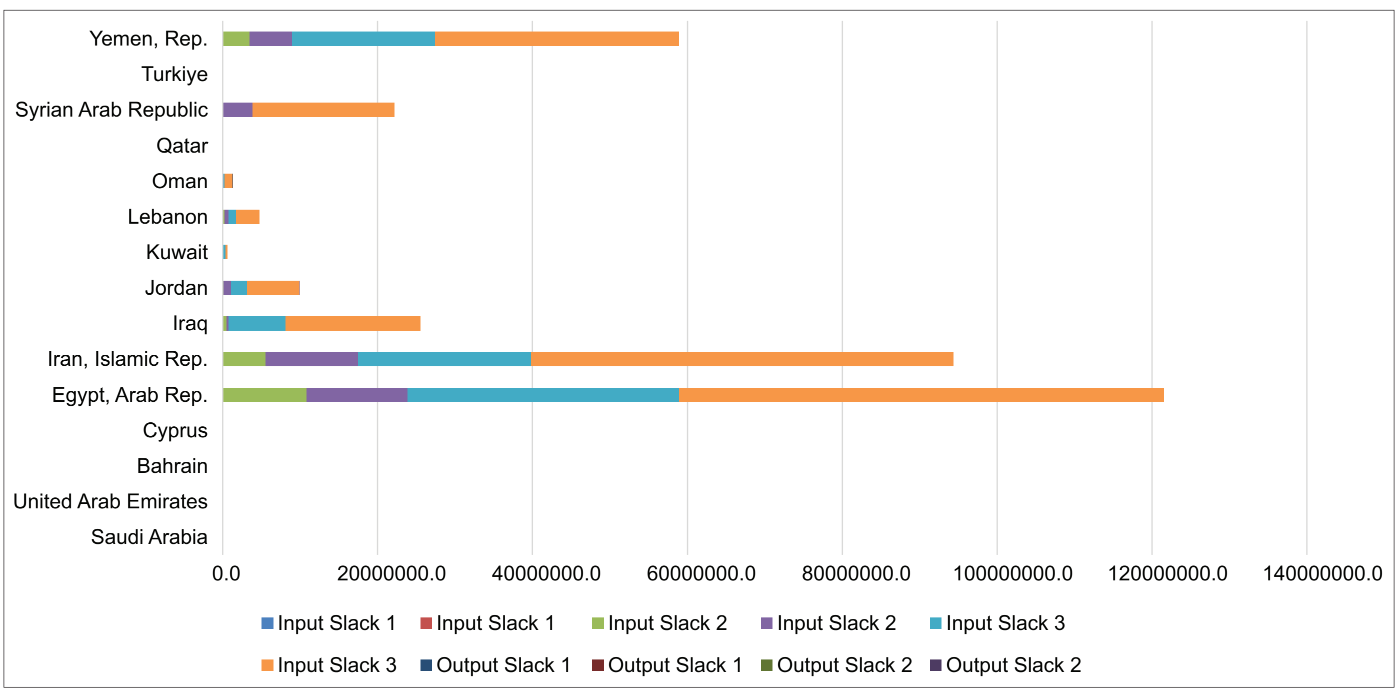
The level of energy efficiency is performed using the input-oriented DEA with CRS. The energy efficiency analysis results are shown in Table 2.

As shown in Table 2, Figures 1 and 2, Saudi Arabia, the United Arab Emirates, Bahrain, Cyprus, Qatar, and Turkiye have attained complete efficiency, as their energy efficiency score is 1. The Syrian population exhibited a commendable degree of energy efficiency in 2010 but decreased in efficiency thereafter.

Table 4: Input/output slacks for the years 2010 and 2021

DMUs	Time duration									
	Input Slack 1		Input Slack 2		Input Slack 3		Output Slack 1		Output Slack 2	
	2010	2021	2010	2021	2010	2021	2010	2021	2010	2021
1. Saudi Arabia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2. United Arab Emirates	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3. Bahrain	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4. Cyprus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5. Egypt, Arab Rep.	0.0	0.0	10846488.3	13002721.0	35078443.9	62534968.9	0.0	3.2	0.0	0.0
6. Iran, Islamic Rep.	626.8	571.6	5516367.2	11956207.3	22312080.3	54559428.8	0.0	0.0	0.0	0.0
7. Iraq	0.0	0.0	517248.9	296387.1	7299057.0	17420623.4	0.0	0.6	0.0	0.0
8. Jordan	0.0	0.0	135062.4	978156.0	2037572.5	6680763.8	0.0	3.2	0.0	0.0
9. Kuwait	0.0	0.0	0.0	0.0	347275.7	248366.1	4.0	4.0	0.0	0.0
10. Lebanon	0.0	0.0	220790.2	580368.4	917198.9	3018852.4	0.0	0.0	0.0	0.0
11. Oman	0.0	0.0	0.0	99323.0	184310.0	975604.5	0.7	0.0	0.0	0.0
12. Qatar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13. Syrian Arab Republic	0.0	0.0	0.0	3849166.1	0.0	18317704.1	0.0	0.0	0.0	0.0
14. Turkiye	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15. Yemen, Rep.	0.0	0.0	3458649.9	5566561.1	18385989.3	31478883.4	3.1	5.5	0.0	0.0

Figure 3: Input/output slacks for the years 2010 and 2021



While Egypt's energy efficiency is projected to reach 1 after 2019, Iran, Lebanon, and Yemen are experiencing a decline. On the other hand, Iraq, Jordan, and Oman consistently demonstrate above-average energy efficiency, with occasional scores approaching 1. This suggests that these countries have the potential to achieve complete energy efficiency in the near future. The data indicates that the majority of nations are efficient in resource utilization, with just a few deviations.

Moreover, the analysis of Saudi Arabia's energy efficiency relative to Middle Eastern nations reveals that the energy efficiency levels of Saudi Arabia and certain Middle Eastern countries are almost the same.

Based on the findings of the study (Table 3 and Figure 2), it is clear that the energy efficiency of Syria, Iran, Lebanon, and Oman is decreasing. As a result, these nations need to place a greater emphasis on their present situation analysis and take measures to reduce the existing deficit. On the other hand, Egypt, Jordan, Iraq, and Yemen are working to improve their energy efficiency and are making progress toward being completely efficient. Furthermore, the study reveals that Kuwait's energy efficiency is both constant and very good, but it is not efficient. In order to make it efficient, Kuwait has to concentrate on the present situation.

Table 4 and Figure 3 both provide an illustration of the slacks in input and output that are associated with each individual unit. According to these figures, Egypt, Iran, Yemen, Syria, Iraq, Jordan, Lebanon, and Oman all have a significant amount of potential for improvement in order to achieve efficiency.

5. CONCLUSION

These fifteen Middle Eastern nations were selected to fulfill the study's goal in the context of SDG7 to analyze Saudi Arabia's energy efficiency compared to that of other Middle Eastern countries. Concerning sustainable development goals, the study used the data envelopment analysis technique to compare Saudi Arabia's energy efficiency with that of other Middle Eastern countries. Energy sources that are both sustainable and economically efficient are essential to any country's social and economic growth.

According to the investigation's findings, several countries, such as Syria, Iran, Lebanon, and Oman, are seeing a decline in their energy efficiency. When energy consumption is frequently the primary driver of a nation's gross domestic product, these countries must adopt a more effective and efficient alternative energy strategy.

Egypt, Jordan, Iraq, and Yemen, on the other hand, are making efforts to enhance their energy efficiency and are making progress toward being entirely efficient. In addition, the analysis demonstrates that Kuwait's energy efficiency is consistent and highly excellent, yet inefficient. To make it effective, Kuwait needs to focus on the current circumstances.

Furthermore, Kuwait must develop the most effective energy techniques feasible to improve its economy. The report concluded that Saudi Arabia has made significant progress in terms of energy efficiency, as the country has consistently demonstrated higher levels of efficiency over an extended period. To further reduce the degree to which its economy depends on oil, Saudi Arabia should make a concerted effort to develop alternative energy strategies.

The investigation indicates that Saudi Arabia, United Arab Emirates, Bahrain, Cyprus, Qatar, and Turkiye demonstrate a commendable level of organization regarding energy efficiency, particularly compared to other African countries, and they are exemplary sustainable practices that authenticate further study. In addition, more Middle Eastern nations should be the subject of further research into their progress. These findings are subject to several restrictions. The Decision-Making Units conducting the research are required to maintain uniformity to comply with the terms of the DEA approach to evaluating the subject matter.

Based on the data analyzed in the study and taking into consideration other relevant criteria, the amount of energy consumed varies from country to country, and the production of energy also varies from country to country, making consistency difficult to achieve.

The data revealed challenges owing to its poor coverage of Middle Eastern nations, especially because additional information was required on the analyzed parameters. Hence, the research only applied to the study, encompassing fifteen nations. Despite this, the scholars will probably offer insightful perspectives regarding the subject matter. Therefore, additional research is essential to overcome this vulnerability.

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