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DEA Window Analysis on Renewable Energy Efficiency in OIC Countries

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Abstract

This study aims to investigate the efficiency of the member countries of the Organization of Islamic Cooperation (OIC) in the transition to renewable energy. Using the Data Envelopment Analysis (DEA) method with a window-based approach, this study analyzes 45 OIC countries during the 2015–2021 period. The Window DEA analysis results show that the level of efficiency stability varied considerably and fluctuated in each window. Based on country groups, it was concluded that the OIC-Africa group is the group of countries with the most stable efficiency levels, followed by the OIC-Asia group, which is in a fairly stable position despite the imbalance in efficiency stability among member countries. The OIC-Arab group is the most unstable group, with highly fluctuating levels of efficiency stability among member countries. Finally, the potential improvement analysis concluded that the largest source of inefficiency came from the output variables, namely solar energy and renewable energy share.

Keywords: efficiency stability; renewable energy; organization of islamic cooperation (OIC); window data envelopment analysis (DEA); GHG emissions

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Introduction

At present, the world is experiencing extreme global warming. Ref. [1] explains that global warming refers to the rise in Earth's average temperature caused by the greenhouse effect, in which gases such as carbon dioxide (CO2), methane (CH4), nitrous oxide, and other compounds trap infrared energy and warm the lower and surface atmosphere. Since the Industrial Revolution, the burning of fossil fuels for energy, transportation, and industrial processes has been the largest source of CO2 emissions, while deforestation and land use change exacerbate the accumulation of greenhouse gases by reducing the Earth's capacity to absorb CO2 [1,2]. Methane is emitted primarily from agriculture, livestock, oil and gas production, and landfills. Although less abundant, it is significantly more potent than CO2 at trapping heat, thus contributing greatly to warming [2].The apparent increase in global average temperature of about 1°C since the late 19th century (with the last decade including the hottest years on record) has been coupled with rising sea levels, melting ice sheets, and more frequent extreme weather events such as storms, floods, and droughts [1,2]. This indicates that global warming also contributes to extreme global climate change.

These phenomena have profound and interrelated impacts, particularly in the economic and social spheres. Economically, climate change is projected to cause a substantial decline in global income; recent empirical analysis shows that the world economy is expected to experience a 19% loss in income over the next 26 years, largely due to rising temperatures and increased frequency of extreme events [3]. Low-income regions in low latitudes bear these losses disproportionately, exacerbating global inequality [4]. Sectors critical to livelihoods—such as agriculture, energy, and tourism—are particularly vulnerable, with the potential for a global GDP decline of up to 18% by 2050 without effective mitigation measures [5]. Socially, climate change exacerbates health risks,

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strains public health systems, and worsens food and water insecurity, often leading to greater migration and social instability, particularly in already vulnerable communities [6,7]. Uncertainty about climate impacts also causes anxiety, reduces well-being, and can erode social cohesion as populations grapple with resource scarcity and displacement [8].

Organization of Islamic Cooperation (OIC) countries also face global warming and environmental degradation, marked by rising greenhouse gas (GHG) emissions, severe water stress, deforestation, and significant vulnerability to climate change impacts. Although OIC countries as a whole have lower GHG emissions per capita than the global average, their total emissions have increased by 91% between 1990 and 2019, reaching 18.1% of global emissions. These emissions are driven by population growth, increased income, and stagnant carbon intensity [9]. This increase exacerbates the impacts of climate change, including extreme heatwaves, floods, droughts, and increased food insecurity, which disproportionately affect OIC members. Water scarcity is already critical, with 30 OIC countries experiencing water stress and 19 countries in critical condition, particularly in arid regions such as the Middle East and North Africa, where water reserves have declined sharply by approximately 2.7 million hectares between 2005 and 2018 [9]. These are compounded by rapid growth in waste generation (i.e., municipal solid waste), which has reached 2.01 billion tons annually, posing yet another escalating sustainability challenge for the OIC countries [10].

Furthermore, despite a modest decline in global deforestation rates in recent years, deforestation within OIC countries has accelerated, rising from 0.27% to 0.44% per year, contributing to biodiversity loss and ecosystem degradation [9]. Many OIC countries face high vulnerability to climate risks due to inadequate adaptation capacity, weak social infrastructure, and limited technological and financial resources, with more than half of them less prepared than the global average to manage climate impacts [10,11]. The health sector is particularly vulnerable, facing increased mortality from climate-related diseases. Although some OIC countries have advanced renewable energy and climate policies (e.g., Morocco's solar energy initiative)[1], excessive dependence on fossil fuels and inadequate environmental governance hinder broader progress toward climate targets [11].

In response to these escalating challenges, OIC countries have implemented various policies to tackle environmental degradation and climate change, with a focus on mitigation, warming, with the goal of achieving net-zero emissions by the second half of the 21st century. These countries are transitioning from fossil fuels, the largest source of carbon emissions, to low-carbon energy systems, emphasizing the cessation of new fossil fuel investments and promoting renewable energy and energy efficiency.

Nevertheless, the transition to renewable energy in OIC countries faces significant challenges. Many OIC countries are heavily dependent on fossil fuel revenues, which creates resistance from established industries and hinders rapid transition efforts. This dependence also complicates the shift of investment to renewable energy, especially given the large initial capital requirements in renewable energy projects, which burden the finances of many developing OIC countries [13].

The variability and intermittency of renewable energy resources also pose operational challenges for integration into existing electricity grids, which in many OIC countries are still underdeveloped or unprepared for such integration [14]. Furthermore, many OIC countries experience uneven access to electricity and infrastructure deficits, particularly in Sub-Saharan Africa and parts of Asia. This complicates the widespread delivery of renewable energy benefits [13,14]. Beyond these technical and economic barriers, attracting private capital is hampered by high investment risk perceptions and regulatory uncertainty. Addressing this requires new regulatory frameworks, policy support, and international cooperation [13,15].

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[1] The foundation of Morocco's renewable energy ambitions was laid in 2009 with the launch of its National Energy Strategy. This strategy set a bold vision for the country's energy future, aiming to achieve 25 GW (GW) of installed renewable energy capacity by 2030, with renewables contributing 52 % of the total electricity demand [12].

This study aims to evaluate the efficiency of OIC countries in transitioning to renewable energy using the Window DEA method. Assessing the efficiency of the transition to renewable energy is crucial to ensure that the use of renewable energy effectively delivers the expected environmental, economic, and social benefits. This evaluation enables stakeholders to determine the competitiveness and viability of renewable energy sources, ensuring that resources are allocated to the most profitable technologies. In addition, assessing efficiency under various market and regulatory conditions can detect areas where policy adjustments, subsidies, or incentives such as green certificates can accelerate the development of renewable energy [16].Thus, comprehensive efficiency assessments guide decision-making to balance economic viability, energy security, and climate impact, thereby promoting a sustainable and resilient energy transition in the OIC and other countries [17].

Literature Review

At the 28th Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC)—the outcome of the first global stocktake; the UAE consensus called for all parties to triple renewable energy capacity and double the rate of energy efficiency improvement by 2030, as part of a just, orderely and equitable transition away from fossil fuels in energy systems.[18]a. This has set in motion the pathway for the energy transition that aligns with the goal of the Paris Agreement for limiting the global average temperature increase to 1.5◦C above pre-industrial levels by the end of the century. It emphasizes the use of readily available technological solutions, particularly low-cost renewables combined with energy efficiency measures, which when scaled up rapidly can help achieve the 1.5 ◦C target. It has been estimated that the world would require three times more renewable energy capacity by 2030 or at least 11,000 GW, and must double the global average annual rate of energy efficiency improvements from around 2 percent to over 4 percent every year till 2030 [19].

Although renewable energy capacity is expected to reach 2.6 times its 2022 level by 2030**,** global primary energy intensity has improved by only 1.3% annually since 2019**,** compared to around 2% during 2010–2019**.** This remains well below the 4% annual improvement required**,** indicating the world is not on track to meet the 2030 target [20].

Prominent institutions such as the Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA) have recognized energy efficiency as a critical priority for reducing energy demand and enhancing energy savings. For instance, the European Union has placed energy efficiency at the core of its decarbonization strategy, as outlined in the Energy Roadmap 2050 and the European Green Deal, which aim to achieve a 50% reduction in final energy consumption compared to 2005 levels. A substantial share of this reduction is expected to be realized within the building sector, particularly in residential buildings [21].

Technological applications positively influence the productivity of renewable energy sources and energy efficiency. Specific technologies are enablers for both energy efficiency and renewable energy, offering important RE/EE synergies in both the power and end-use sectors. On the demand side, for example, the electrification of energy services (i.e., passenger transport or cooking heat) results in higher efficiency whilst enabling the deployment of renewable power. On the supply side, most renewable energy technologies in the power sector result in lower primary energy demand. This is affected by power generation from many types of renewable energy sources, which account for 100% efficiency vis-à-vis fossil power plants that achieve a 25–85% efficiency [22].

Furthermore, recent advances in the photovoltaic (PV) system have produced solar panels with better efficiencies, leading to smaller costs for solar power. Similarly, improvements in the design and construction of wind turbines (i.e., increased size and efficiency) have significantly increased wind energy production. Innovation in grid technology (e.g., smart grids) has enabled the greater integration of variable renewables for optimization, reduced energy loss, and efficient grid monitoring. This in conjunction with battery storage technologies (i.e., long-duration energy storage) provides a means for storing energy for hours, days, weeks or even seasons when renewable energy generation is abundant relative to load, and for releasing it when demand is greater than generation

[23]. Evidence suggests that the annual intensity improvements worldwide from today to 2030 average 2.3% in the stated policies scenario (STEPS) and 3% in the annual pledges scenario (APS). It is only in the net zero emissions (NZE) scenario that energy efficiency improvement exceeds 4% to achieve the doubling from the 2022 baseline of 2% by 2030. This is in line with the pledges of the Paris Agreement to limit global warming to 1.5°C. The benefits of doubling energy efficiency include reducing energy bills, alleviating poverty, and creating almost five million jobs globally, thus contributing to half of the emission reductions needed in the net zero emissions (NZE) scenario by 2030 and creating heathier living environments [24].

Renewable energy and energy efficiency can potentiate the effects of economic growth and environmental quality. For example, combining energy efficiency measures with the growing usage of renewable energy can help tackle environmental issues like climate change, air pollution, and resource depletion. Renewable energy and energy efficiency can play a significant role in declining CO2 emissions, thus improving environmental quality and boosting economic growth. A number of empirical studies have investigated the influence of renewable energy and energy efficiency as crucial elements in mitigating CO2 emissions and enhancing environmental quality whilst promoting economic growth. The results of these studies are often mixed. For example, ref. [25] investigated the effects of energy efficiency, renewable energy, and other factors on the carbon emissions of Mexico, Indonesia, Nigeria, and Turkey (MINT) countries from 1990 to 2014 using nonlinear autoregressive distribution lag methodology. The study's findings suggest that there is an asymmetric relationship between renewable energy and carbon emissions with the MINT countries. The outcomes show that a 1% change in energy efficiency (positive components) reduces carbon emissions by 0.23%, while a 1% volatility in the positive sum of renewable energy reduces carbon emissions by 0.8%. Additionally, economic growth has been found to increase CO2 emissions in the MINT countries. Ref. [26] investigated the long-term nexus between CO2 emissions and renewable energy, energy efficiency, fossil fuels, GDP, and property rights from 1995 to 2019 in nine developed countries. The results confirmed that renewable energy and energy efficiency are negatively correlated to CO2 emissions. Ref. [27] used a panel autoregressive distributed lag model on countries from South Asia to investigate the effects of renewable energy and energy efficiency on CO2 emissions for 1990–2014. The results revealed a long-run equilibrium relationship among carbon emissions, energy efficiency, and renewable energy, especially after controlling the effects of economic growth and trade openness. To elaborate, in the long-run, carbon emissions decline with a rise in renewable energy, but emissions increase with an improvement in energy efficiency. The study confirmed that renewable energy use in the long-run is an effective strategy to reduce CO2 emissions in South Asian countries. Ref. [28] examined whether energy efficiency, renewable energy, or natural gas is the most effective option for mitigating environmental degradation.The study used linear and non-linear panel models using panel data from 60 countries. The results showed that improving energy efficiency and increasing the consumption of natural gas and renewable energy are conducive to inhibiting environmental degradation. Additionally, energy efficiency is the most effective option to prevent environmental degradation. There are a number of empirical studies that focus on the influences of energy efficiency and renewable energy on economic growth. For example, Ref. [29] investigated the effects of energy efficiency and renewable energy on economic growth in emerging economies over 1992–2014. Using Westerlund's [30] cointegration test as well as causality test, the study found that energy efficiency positively influences economic growth in the long term, but renewable energy has no significant effects on economic growth. Ref. [31] investigated the effect of energy efficiency on economic growth. Using the RALS-EG cointegration test and the QARDL model, the study confirmed that renewable energy and energy efficiency have a significant positive effect on gross domestic product. The study advocates the use of renewable energy for promoting economic growth and reducing CO2 emissions. Ref. [32] investigated the effect of energy efficiency on economic growth. Using the RALS-EG cointegration test and the QARDL model, the study confirmed that renewable energy and energy efficiency have a significant positive effect on gross domestic product. The study advocates the use of renewable energy for promoting economic growth and reducing CO2

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emissions. Ref. [33] examined the effects of green technology development, green consumption, energy efficiency, FDI, economic growth, and trade on GHG emissions in South Asia (1981–2018) using the Breusch–Pagan LM, bias-corrected scaled LM, and Pesaran CD tests. The findings show that economic growth, trade, and exports significantly increase GHG emissions, while green technology development, green energy consumption, energy efficiency, and imports significantly reduce emissions. The study advocates promoting environmentally friendly and energy-efficient technologies to mitigate climate change. Ref.[34] investigated the potential effects of innovative solar energy technologies on CO2 emissions in China. The findings indicated that international collaboration in green technology development enabled China to jointly develop a new green technology that not only improves the efficiency of energy technologies but also contributes to CO2 emission mitigation. Ref. [35] investigated how economic complexity affects renewable energy and energy efficiency in the MENA region. They used econometric techniques like Panel-Corrected Standard Errors, Driscoll and Kraay's Spatial Correlation Consistent (SCC) method, and Generalized Least Squares using data from the MENA countries between 1990–2017. The results showed that economic complexity increases energy intensity, which contributes to environmental degradation by decreasing energy efficiency in the MENA countries. Further, the results reveal that negative effects of economic complexity and growth are larger than their positive effects, highlighting the necessity of restructuring economic activities and sectors. The study advocated that policymakers should encourage the use of more energy-efficient technologies in economic activities and production while promoting renewable energy consumption to enhance energy security in the MENA region. Ref. [36] investigated the effect of energy security, energy mix, technological advancement, trade openness, and political stability in 13 Arab countries from 2001 to 2019. At the first stage, the study used the DEA Super-SBM model with multiple input-outputs to gauge the energy efficiency in 13 Arab countries. This showed the variation in energy efficiency level over the study period and separated efficient resource utilization countries from inefficient ones. Next, the study used the Malmquist-Luenberger Index to investigate the impact of several critical contextual factors (i.e., energy security, energy mix, technological advancement, and trade openness) on energy efficiency in Arab countries by employing FGLS. The results confirmed that energy security negatively impacts energy efficiency in oil-producing countries, as higher energy security is linked to lowering energy efficiency, especially in Arab countries that produce oil. The share of renewable energy favorably impacts Arab countries that do not have significant oil reserves. The study advocates that Arab countries should prioritize and enhance energy efficiency by performing energy audits, adopting energy-efficient technologies, building codes and standards, and conducting public awareness campaigns. Ref. [37] investigated how entrepreneurial energy efficiency as a posture-based entrepreneurial strategic orientation can help small-and-medium-sized enterprises (SMEs) overcome barriers to green practices and improve their carbon footprint reduction through identification of green barrier, green planning, green networking and green innovation. The results indicate that by identifying green barriers and actively engaging in green networking, SMEs can undertake carbon footprint reduction initiatives as an effective strategy to enhance operational efficiency, reduce costs, and ultimately lower GHG emission.

Policy frameworks and regulatory mechanisms play a significant role in enhancing productivity for renewable energy and efficiency in energy use. In this vein, several international policies have been implemented to encourage renewable and efficient energy utilization. For example, there are subsidies, tax exemptions, feed-in tariffs, and targets. However, it has been argued that rapidly growing subsidies to the private sector for renewable energy have raised concerns about the effectiveness of such policies.

In this regard, the clean development mechanism (CDM)—an initiative of the UN framework convention on climate change—has become the primary conduit to subsidize renewable energy projects globally. Similarly, a number of countries have implemented energy-efficiency laws, which represents a new approach to reinforce the institutional setting for energy efficiency, as most of these laws have been implemented in the last 10 years. These laws provide a legal framework for the

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adoption of other regulations, such as labelling, minimum efficiency energy performance standards (MEPS), obligations for large consumers (i.e., Turkey and India), and energy-savings obligation for utilities (i.e., France). Energy-efficiency laws also provide a legal framework for setting up an energy-efficiency fund (i.e., Thailand and Uruguay). Recently, many major economies have adopted additional legislative and policy measures that are set to deliver further efficiency gains over the coming years. These include the inflation reduction act in the United States, the energy efficiency directive in the European Union, the revised act on rationalizing energy use in Japan, and the most recent cycle of the perform, achieve, and trade scheme in India. Annual investment in energy efficiency has exceeded US$ 390 billion in 2023, up from US$ 300 billion in 2020 [38].

Economic factors play a key role in expanding renewable energy technologies and promoting energy efficiency in renewable energy initiatives. There has been a steady reduction in renewable energy cost, especially solar and wind energy, making them as cheap as conventional energy sources like fossil fuels. Technological improvements, higher capital investment, and the extraordinary scale of the numeration of consumers have made renewable energy cheaper [39]. However, one consideration is the cost of capital required to finance renewable energy projects. Evaluating this cost and its relation to the productivity of renewable energy and energy efficiency is critical for assessing the feasibility and performance of projects to be funded. Empirical evidence suggests that sourcing external financing is more difficult in the case of new and rather immature technologies. For example, improved light emitting diode (LED) lighting, efficient heating, ventilation, and air conditioning (HVAC) systems, and smart grid technologies are enduring and cost-effective, but the perceived risks, especially at the initial stages of using such technologies, are high [40]. This leads to higher financing costs for such technologies till they are accepted in the market [41]. Banks, venture capitalists, and other institutional investors play a significant role in defining the cost of capital for energy efficiency projects [39]. Green finance and sustainable investment instruments have become the key concepts in finding efficient solutions for lowering the cost of capital for energy efficiency projects. In that respect, green bonds, green loans, and several other instruments and structures, such as public private partnership and international funding programs, are critical for the large-scale implementation of renewable energy projects.

Method

This study is a descriptive quantitative study using the Data Envelopment Analysis (DEA) method with a window-based approach. It covers a dataset of 45 OIC member countries to examine the efficiency and stability of zakat institutions[2] from 2015 to 2021. The data used is secondary data from reports issued by Statistical, Economic and Social Research and Training Center for Islamic Countries (SESRIC). Furthermore, the input variables used are Labor Force, GDP per capita, and Exports to Imports. Meanwhile, the output variables are Installed Renewable Electricity per capita (Solar, in Watts) and Renewable Energy Share in the Total Final Energy Consumption.

DEA was initially developed by Charnes et al. [43] and advanced by Banker et al. [44] to measure the productivity and efficiency of business units. This allows for multiple (weighted) outputs and multiple (weighted) inputs in measuring productivity or efficiency, commonly referred to as the weighted output level produced from the given input. In DEA, two basic models can be used, namely the Charnes-Cooper-Rhodes (CCR) model and the Banker, Charnes and Rhodes (BCR) model. The CCR model is used with the assumption that changes in DMU output value will be proportional to the increase in that specific output. This is in line with the Constant Return to Scale (CRS) assumption that the production function is fixed. Meanwhile, the BCR model assumes that changes in the DMU output value differ for each proportion of a certain input value change. This is in line with Variable Return to Scale (VRS), which states that each input does not necessarily produce

[2] A zakat institution is an organization that collects, manages, and distributes zakat (obligatory Islamic charity) to eligible beneficiaries (*asnaf*) in accordance with Islamic law (Shariah). It ensures transparent, efficient, and fair redistribution of wealth to reduce poverty and promote social welfare [42].

the same output. The VRS model assumes that the ratio between input and output increase is different, which means that an increase in input by 1 does not necessarily cause output to increase by 1; it could be smaller or larger.

This study was conducted in two stages of analysis. The first analysis used standard efficiency measurement using the VRS approach, and the second stage was a window analysis. The mathematical equation commonly used to measure efficiency using the DEA window method is as follows:

$$M_I = \frac{\sum_{t=1}^{M-K+1} \sum_{j=1}^{i+K-1} . E_{i,j}}{\mathrm{K\ x\ (M - K + 1)}}$$

where M = average efficiency level and K = window length.

According to Cooper et al. [45] window analysis measures relative efficiency and analyzes the stability of each DMU's efficiency using statistics such as Standard Deviation (SD). This is used to measure the difference in the average efficiency level of DMUs in each window; the smaller the standard deviation value, the more stable the efficiency value achieved by each DMU. Long Distance per Window (LDW) shows the largest difference in efficiency figures within a window; the smaller the LDW value of an OIC country, the more stable its efficiency, and vice versa. Long Distance per Period (LDP) describes the largest difference in efficiency figures across all observation periods. A smaller LDP value indicates higher efficiency stability, and vice versa. Long Distance per Year (LDY) shows the largest difference in efficiency scores in a year. A smaller LDY value indicates a better level of stability in the efficiency achieved by each DMU, and vice versa.

DEA window analysis has a number of features. For example, efficiency performance calculations assess whether efficiency scores are consistent over time. This approach not only compares data for each year from all periods, but also compares them using window grouping with a five-year window. Therefore, the use of windows serves to divide the research period into multiple groups of years to determine whether the efficiency scores achieved by each OIC country have changed significantly or remained stable. In addition, the performance of a unit in a particular DEA window period is compared to its performance in other periods.

This increases the number of data points included in the analysis, which may be useful when working with limited sample sizes, as mentioned earlier. In this case, varying the window width (the number of time periods included in the analysis) means covering the spectrum from contemporary analysis, which only includes observations from one time period, to intertemporal analysis, which includes observations from the entire period [46]. Four windows were used in this study, with each window lasting four years. Therefore, observations are evaluated solely in the context of previous observations made during the four-year period. This is done to avoid unfair comparisons over time by choosing the shortest possible period. It is stated that despite significant technical advances during the study period, their impact on OIC countries has been gradual, and comparisons of OIC countries' efficiency over the four-year period are still reasonable.

Result and Discussion

Table 1 describes the descriptive statistics of the input and output variables of OIC countries in achieving renewable energy transition during 2015–2021.

Table 1. Descriptive Statistics.

Variable	Max	Min	Mean	St.Dev
Input				
Labour Force (Number)	137425585	189497	14975549	26350642
GDP per Capita (USD)	43281	428	4303	6528
Export to Import (ratio)	2,50	0,11	0,80	0,37
Output				
Installed Renewable Electricity per Capita (Solar, in Watts)	320,59	0,01	10,57	30,65

Renewable Energy Share in the Total Final Energy Consumption (Percent)	96	1	38	33

Source: Authors' own estimate.

Based on the table above, it can be explained that in the input variable, the labor force shows a very wide gap in the size of the working population among OIC countries. This can also be seen from the large standard deviation value (exceeding the mean), which indicates a very scattered distribution, where there are outlier countries with a super-large workforce (e.g., Indonesia, Pakistan, Turkey) compared to small countries (such as the Maldives and Djibouti). Furthermore, from the GDP variable, it can also be concluded that there is a considerable economic disparity between rich and poor countries, especially when viewed from the high standard deviation and low average values, indicating structural economic inequality. The export to import ratio variable also shows that, on average, OIC countries experience a trade deficit. Furthermore, the output variable shows that Installed Renewable Electricity per Capita (Solar, in Watts) is very unevenly distributed, with some countries already having high solar capacity per capita, but most still having very low capacity. Similarly, the Renewable Energy Share shows a fairly high dependence on fossil fuels.

Table 2 shows the DEA-based analysis of the relative efficiency of OIC countries in the renewable energy transition from 2015 to 2021.

Table 2. VRS Efficiency Levels of OIC Countries During 2015–2021.

Country	**VRS Score**							**Mean**	**Rank**
	2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**		
Afghanistan	0,19	0,21	0,20	0,19	0,20	0,19	1,00	0,31	**31**
Albania	0,42	0,43	0,40	0,41	0,45	0,50	0,48	0,44	**26**
Azerbaijan	0,02	0,03	0,03	0,03	0,03	0,02	0,03	0,03	**42**
Bangladesh	0,35	0,31	0,29	0,28	0,28	0,29	0,27	0,30	**32**
Benin	0,52	0,47	0,47	0,46	0,48	0,48	0,57	0,49	**24**
Burkina Faso	0,82	0,80	0,78	0,78	0,77	0,77	0,75	0,78	**14**
Cameroon	0,81	0,82	0,82	0,82	0,82	0,82	0,82	0,82	**10**
Chad	0,76	0,76	0,76	0,76	0,76	0,75	0,73	0,75	**16**
Cote d'Ivoire	0,68	0,67	0,66	0,64	0,64	0,65	0,60	0,65	**21**
Djibouti	1,00	1,00	0,91	0,93	0,81	0,96	0,92	0,93	**5**
Egypt	0,06	0,05	0,06	0,07	0,11	0,12	0,13	0,09	**40**
Gabon	0,94	0,91	0,99	0,99	0,99	1,00	1,00	0,97	**3**
Gambia	1,00	1,00	0,86	0,72	0,61	1,00	1,00	0,88	**7**
Guinea	0,79	0,78	0,75	0,76	0,71	0,69	0,70	0,74	**17**
Guinea-Bissau	1,00	1,00	1,00	0,99	0,99	1,00	0,99	1,00	**2**
Guyana	0,76	0,59	0,66	0,51	1,00	0,51	0,54	0,65	**20**
Indonesia	0,28	0,29	0,26	0,23	0,21	0,23	0,21	0,25	**34**
Iran	0,01	0,01	0,02	0,02	0,02	0,03	0,03	0,02	**44**
Iraq	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	**45**
Jordan	0,03	0,21	0,28	0,47	0,75	1,00	1,00	0,53	**23**
Kazakhstan	0,03	0,03	0,03	0,06	0,13	0,21	0,24	0,10	**39**
Lebanon	0,05	0,06	0,07	0,11	0,14	0,17	0,38	0,14	**37**
Libya	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	**41**

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Malaysia	0,06	0,08	0,09	0,10	0,15	0,21	0,24	0,13	**38**
Maldives	1,00	1,00	0,78	0,86	0,84	1,00	1,00	0,92	**6**
Mali	0,84	0,81	0,80	0,80	0,78	0,77	0,75	0,79	**13**
Mauritania	0,33	0,39	0,31	0,33	0,31	0,30	0,31	0,33	**30**
Morocco	0,13	0,13	0,12	0,18	0,18	0,18	0,19	0,16	**35**
Mozambique	0,83	0,80	0,81	0,82	0,81	0,84	0,81	0,82	**12**
Niger	0,83	0,84	0,86	0,86	0,84	0,86	0,83	0,85	**8**
Nigeria	0,84	0,84	0,85	0,84	0,83	0,85	0,83	0,84	**9**
Pakistan	0,48	0,47	0,45	0,46	0,49	0,46	0,45	0,46	**25**
Palestine	0,17	0,21	0,21	0,26	0,44	0,58	0,79	0,38	**29**
Senegal	0,41	0,39	0,41	0,38	0,41	0,44	0,41	0,41	**28**
Sierra Leone	0,78	0,78	0,79	0,80	0,79	0,79	0,74	0,78	**15**
Somalia	1,00	1,00	1,00	0,99	0,99	1,00	0,99	1,00	**1**
Sudan	0,65	0,61	0,62	0,63	0,62	0,66	0,64	0,63	**22**
Suriname	0,68	0,61	0,78	0,83	0,72	0,78	0,71	0,73	**18**
Togo	0,85	0,85	0,82	0,80	0,82	0,79	0,80	0,82	**11**
Tunisia	0,14	0,13	0,14	0,14	0,15	0,16	0,15	0,14	**36**
Türkiye	0,14	0,17	0,24	0,31	0,37	0,39	0,41	0,29	**33**
Uganda	0,96	0,95	0,95	0,95	0,95	0,96	0,95	0,95	**4**
United Arab Emirates	0,06	0,06	0,13	0,21	0,66	0,81	1,00	0,42	**27**
Uzbekistan	0,02	0,02	0,02	0,02	0,02	0,01	0,02	0,02	**43**
Yemen	0,08	1,00	0,28	0,75	0,92	1,00	1,00	0,72	**19**
Mean per Year	**0,49**	**0,50**	**0,48**	**0,50**	**0,53**	**0,56**	**0,59**	**0,52**	

Source: Authors' own estimate.

Table 3 presents the average relative efficiency levels of 45 OIC countries using the Variable Return to Scale (VRS) approach. The levels tended to stagnate in the range of 0.48 and 0.59 from year to year during the research period. Based on the average efficiency level, there are still quite a few OIC countries with relative efficiency levels below 0.50. Of the 45 countries, only 23 have an average efficiency above 0.50. The countries with the highest efficiency levels are Somalia (1.00), Guinea-Bissau (1.00), Gabon (0.97), Uganda (0.95), Djibouti (0.93), and the Maldives (0.92). Meanwhile, the countries with the lowest efficiency are Iraq (0.01), Iran (0.02), Uzbekistan (0.02), Azerbaijan (0.03), and Libya (0.03). The significant difference in efficiency levels indicates a considerable disparity in the efficiency of the transition to renewable energy. This reflects that OIC countries with higher efficiency have more optimal performance in utilizing available resources, while countries with much lower efficiency may indicate constraints in operational management or resource management.

The next analysis relates to efficiency based on a Window DEA analysis. Window DEA can capture the general efficiency trends of OIC countries in the process of transitioning to renewable energy. The average column represents the average of all scores for each country. St. Dev indicates the standard deviation score, LDY (Long Distance of Year) indicates the most significant difference between OIC country scores in different windows in the same year, and LDP (Long Distance of Period) refers to the largest difference between OIC country scores during the entire research period. These measures are used to explain the stability of efficiency in each DMU. The lower the level of these four values, the more stable the efficiency level obtained by the DMU [47,48].

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Appendix 1 presents the results of the DEA window analysis for OIC countries from 2015 to 2021. The analysis is divided into four windows, with each window covering a four-year period.

Table 3. DEA Window Efficiency of OIC Countries.

Country	LDY	The Mean	St.Dev	LDW	LDP
Afghanistan	0,02	0,25	0,08	0,81	0,81
Albania	0,01	0,44	0,02	0,11	0,11
Azerbaijan	0,04	0,04	0,01	0,03	0,05
Bangladesh	0,02	0,30	0,02	0,06	0,09
Benin	0,01	0,48	0,01	0,11	0,11
Burkina Faso	0,03	0,79	0,02	0,03	0,09
Cameroon	0,01	0,83	0,00	0,01	0,01
Chad	0,01	0,76	0,01	0,03	0,04
Cote d'Ivoire	0,01	0,65	0,01	0,4	0,08
Djibouti	0,09	0,95	0,01	0,16	0,16
Egypt	0,08	0,90	0,01	0,11	0,11
Gabon	0,01	0,98	0,01	0,09	0,09
Gambia	0,21	0,90	0,05	0,35	0,35
Guinea	0,01	0,75	0,03	0,07	0,11
Guinea-Bissau	0,01	1,00	0,00	0,01	0,01
Guyana	0,15	0,71	0,05	0,47	0,47
Indonesia	0,01	0,25	0,02	0,09	0,09
Iran	0,04	0,03	0,00	0,04	0,04
Iraq	0,01	0,02	0,00	0,00	0,01
Jordan	0,53	0,66	0,10	0,96	0,96
Kazakhstan	0,12	0,12	0,03	0,23	0,23
Lebanon	0,16	0,16	0,03	0,27	0,32
Libya	0,01	0,04	0,00	0,00	0,01
Malaysia	0,18	0,17	0,03	0,16	0,19
Maldives	0,15	0,97	0,01	0,15	0,15
Mali	0,01	0,80	0,02	0,06	0,11
Mauritania	0,36	0,40	0,07	0,29	0,39
Morocco	0,22	0,20	0,03	0,21	0,27
Mozambique	0,01	0,82	0,00	0,03	0,04
Niger	0,16	0,89	0,04	0,15	0,17
Nigeria	0,01	0,85	0,01	0,02	0,03
Pakistan	0,03	0,47	0,01	0,04	0,05
Palestine	0,74	0,63	0,15	0,68	0,74
Senegal	0,10	0,42	0,20	0,07	0,10
Sierra Leone	0,00	0,79	0,01	0,06	0,06
Somalia	0,01	1,00	0,00	0,01	0,01
Sudan	0,01	0,63	0,00	0,05	0,05
Suriname	0,06	0,83	0,02	0,31	0,31
Togo	0,01	0,82	0,01	0,04	0,06
Tunisia	0,06	0,16	0,01	0,03	0,06
Türkiye	0,66	0,41	0,07	0,79	0,79

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Uganda	0,02	0,96	0,00	0,01	0,02
United Arab Emirates	0,77	0,54	0,10	0,92	0,92
Uzbekistan	0,01	0,03	0,01	0,01	0,02
Yemen	0,20	0,79	0,10	0,85	0,85

Source: Authors' own estimate.

Overall, OIC countries experienced fluctuating efficiency from window to window. The OIC countries with the highest and most stable efficiency levels in each window were Somalia and Guinea-Bissau, which had an average window of (1.00) and an average value in each window from 1 to 4 of (1.00). The next highest level of efficiency was achieved by Gabon, with an average window of (0.98), which also showed a high and fairly stable average efficiency per window, with average values in window 1 (0.96), window 2 (0.98), window 3 (0.99), and window 4 (0.99) showing an increase. Then there is Uganda, with an average window of (0.96), a fairly stable level of efficiency in window 1 (0.96) and window 2 (0.96), but experiencing a decline in window 3 (0.95) and window 4 (0.95). Djibouti also has a fairly high level of efficiency, with an average window of (0.95), an average per window of window 1 (0.96), window 2 (0.93), window 3 (0.96), and window 4 (0.95).

Meanwhile, the OIC country with the lowest efficiency level is Iraq, with an average window of (0.02) and an average per window of window 1 (0.02), window 2 (0.01), window 3 (0.01), and window 4 (0.01). Iran has an average window of (0.03) and an average per window of window 1 (0.03), window 2 (0.02), window 3 (0.03), and window 4 (0.03). Next, Uzbekistan has an average window of (0.03) and an average per window of window 1 (0.03), window 2 (0.03), window 3 (0.02), and window 4 (0.02). This shows that these countries have low and stagnant levels of efficiency and efficiency stability throughout the period.

When viewed from the perspective of efficiency stability analysis through Standard Deviation (SD), Long Distance per Window (LDW), Long Distance per Period (LPD), and Long Distance per Year (LDY), the majority of OIC countries have relatively high and stable efficiency stability scores, including Somalia, Uganda, Uzbekistan, Guinea-Bissau, Cameroon, Libya, Iraq, Nigeria, and Uganda. Somalia, Guinea-Bissau, and Cameroon have SD (0.00), LDW (0.01), LDP (0.01), and LDY (0.01). Iraq and Libya have SD (0.00), LDW (0.00), LDP (0.01), and LDY (0.01). Uganda has statistics of SD (0.00), LDW (0.01), LDP (0.02), and LDY (0.02). Uzbekistan has SD (0.01), LDW (0.01), LDP (0.02), and LDY (0.01). Meanwhile, the OIC countries with the lowest level of efficiency stability are the United Arab Emirates, which has SD (0.10), LDW (0.92), LDP (0.92), and LDY (0.77), and Palestine, with SD statistics of (0.15), LDW (0.68), LDP (0.74), and LDY (0.74). Based on this, it can be concluded that the level of efficiency and efficiency stability of OIC countries with DEA window analysis is quite varied. The majority of OIC countries show a relatively stable level of efficiency in windows 1 to 2, and begin to show a decline in windows 3 to 4.

Furthermore, the analysis of efficiency stability based on the Long Distance per Year (LDY) value of OIC countries can also be seen based on country groups, namely OIC-Africa, OIC-Arab, and OIC Asia. Table 4 presents the efficiency stability of OIC country groups.

Table 4. Efficiency Stability of OIC Country Groups.

OIC-Group	Max	Min	Mean	St.Dev
OIC-Africa	0,21	0,00	0,04	0,06
OIC-Arab	0,77	0,01	0,23	0,26
OIC-Asia	0,66	0,01	0,11	0,16

Source: Authors' own estimate.

Based on the table above, it can be explained that in the OIC-Africa group, the maximum LDY value is (0.21), which indicates that there are no extreme outliers. Furthermore, the minimum value is (0.00), the average efficiency stability is (0.04), and the standard deviation is (0.06), which means

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that this group of countries has a stable and very high level of efficiency stability as well as consistency among member countries. Therefore, it can be concluded that the OIC-Africa group is the most stable in terms of long-term efficiency. Furthermore, in the OIC-Arab group, we can see that the maximum value is (0.77), minimum is (0.01), average is (0.23), and standard deviation is (0.26). This shows that the OIC-Arab group is the most unstable, even though there are very stable countries, but other member countries are quite volatile. The high standard deviation compared to other country groups also indicates a large gap between countries. This is also evident from the average value, which is the highest among all groups. Finally, the OIC-Asia group shows a maximum value of (0.66), minimum of (0.01), average of (0.11), and standard deviation of (0.16), explaining that OIC-Asia is in a fairly stable position but not evenly distributed, or there are still disparities between member countries.

To further evaluate the performance of OIC countries in their transition to renewable energy, they can be classified into four quadrants based on their level of efficiency and stability. Figure 1 shows the efficiency-stability quadrants of OIC countries. Quadrant 1 consists of countries with high efficiency and stability as well as best performance. Quadrant 2 shows countries with high efficiency but low stability. Quadrant 3 describes countries with low efficiency and stable/high stability. Finally, quadrant 4 consists of countries with both, low efficiency and efficiency stability. The efficiency axis is obtained from the average efficiency level in the window analysis results, while efficiency stability is obtained from the Long Distance per Year (LDY) column. Figure 1 shows the quadrant categories for OIC countries.

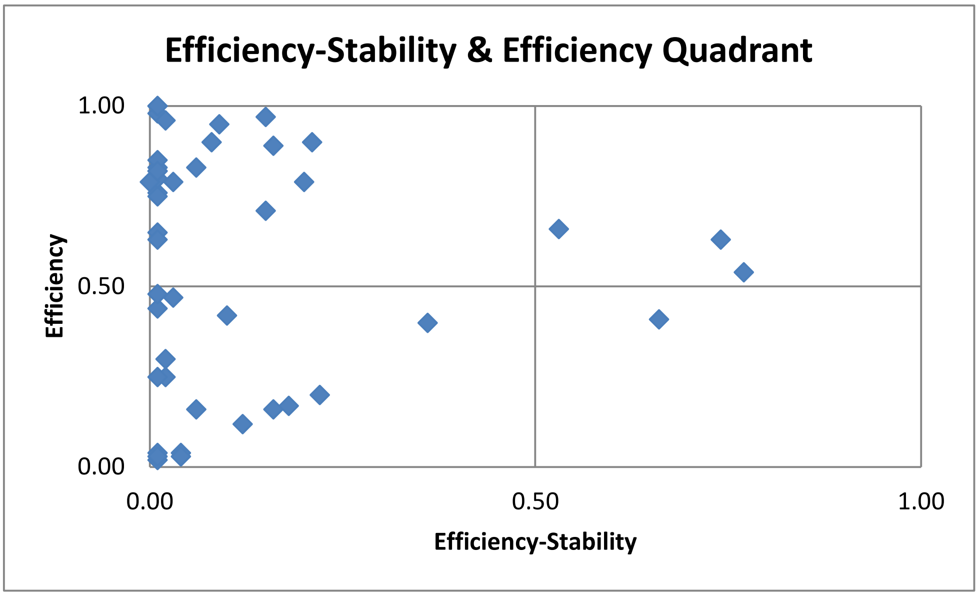

Figure 1. Efficiency-Stability Quadrants of OIC Countries. Source: Authors' own estimate.

Based on the figure, there are 23 countries in the first quadrant with high efficiency and efficiency stability, namely Burkina Faso, Cameroon, Chad, Cote d'Ivoire, Djibouti, Egypt, Gabon, Gambia, Guinea, Guinea-Bissau, Guyana, Maldives, Mali, Mozambique, Niger, Nigeria, Sierra Leone, Somalia, Sudan, Suriname, Togo, Uganda, and Yemen. In quadrant 2, there are three countries, namely Jordan, Palestine, and the United Arab Emirates, which means that these countries have high efficiency levels but relatively low stability. Quadrant 3 has 18 countries, namely Afghanistan, Albania, Azerbaijan, Bangladesh, Benin, Indonesia, Iran, Iraq, Kazakhstan, Lebanon, Libya, Malaysia, Mauritania, Morocco, Pakistan, Senegal, Tunisia, and Uzbekistan, with low efficiency levels and stable efficiency stability. Finally, quadrant 4 has one country, namely Türkiye, with both low efficiency and efficiency stability.

The next analysis relates to the potential for improvement in the efficiency of OIC countries. In addition to producing efficiency levels, DEA analysis can also be used to examine the potential for improvement through variables that cause inefficiency. Figure 2 shows the potential for improvement in OIC countries.

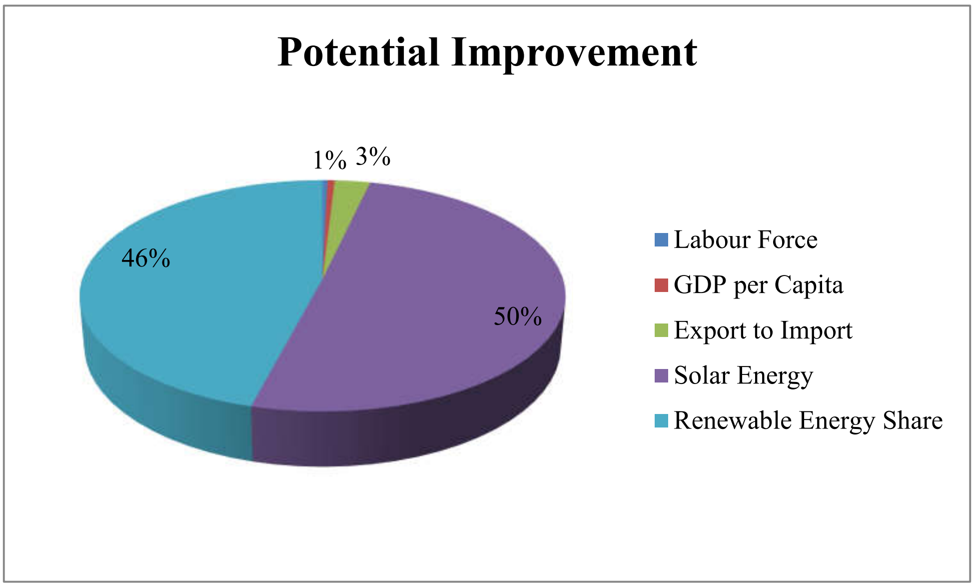

Figure 2. Potential Improvement of OIC Countries. Source: Authors' own estimate.

Based on the results of this analysis, it can be explained that the biggest cause of inefficiency in OIC countries in the transition to renewable energy comes from the output variables, namely Solar Energy and Renewable Energy. Therefore, to achieve optimum efficiency, these two variables must be increased by 50% for solar energy and 46% for renewable energy.

Findings

The analysis produced a number of interesting insights that reflect the stability of efficiency in OIC countries in the transition to renewable energy. First, based on DEA analysis, it is known that the efficiency levels of OIC countries vary and tend to be stagnant during the research period. However, there are still many countries with fairly low efficiency levels, especially below 0.50. For example, the country with the highest efficiency level is Somalia (1.00), while the one with the lowest is Iraq (0.01). This shows a large gap between OIC countries in the transition process toward renewable energy. This indicates a significant gap among OIC countries in the transition to renewable energy. This finding is consistent with the efficiency frontier theory, under which DMUs operating on this frontier are considered efficient, while those below it reflect institutional and structural inefficiencies—indicating suboptimal use of resources relative to best-performing peers.This inefficiency can be caused by various factors such as technological gaps, management practices, or external constraints. Furthermore, renewable energy technologies such as solar, wind, and biomass generally exhibit lower efficiency compared to conventional fossil fuel-based power plants. This implies that the differences in renewable energy efficiency across OIC countries are systemic in nature and not merely technical.

This lower efficiency is due to several factors. The conversion rate for many renewable sources is inherently limited by natural processes, such as the efficiency limit of photovoltaic solar cells and the Betz limit for wind turbines, which limits the amount of kinetic energy that can be captured from wind [49,50]. Furthermore, renewable energies such as solar and wind are intermittent and variable, depending on weather conditions, time of day, and location. This means they cannot always operate at optimal output and their capacity factors are often much lower than those of fossil fuel power plants [51]. Technical limitations, such as the current state of storage technology, further exacerbate efficiency losses, because energy often has to be stored for later use, resulting in additional conversion

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losses [49]. Furthermore, renewable energy sometimes requires more land for equivalent energy output and faces integration challenges in existing grids, which can reduce overall system efficiency [51]. Although these technical limitations are widely acknowledged, the findings of this study indicate that these constraints result in consistently low efficiency scores across OIC countries, suggesting that technological factors are further compounded by policy, infrastructure, and market readiness challenges.

The second finding, through the results of the DEA Window analysis, was that overall efficiency levels varied considerably and fluctuated in each window. The quadrant analysis also confirms that OIC countries have a fairly good level of efficiency stability, although their efficiency levels are still low. Interestingly, this highlights an important distinction between efficiency levels and efficiency stability, whereby countries can demonstrate stable performance over time even while remaining below the optimal efficiency threshold. The OIC countries with the highest and most stable efficiency levels in each window are Somalia and Guinea-Bissau, while the lowest is achieved by the United Arab Emirates (UAE). Somalia[3] and Guinea-Bissau,[4] both low-income countries with limited fossil fuel resources, prioritize renewable energy as the main driver of electrification and sustainable development, leading to targeted investments and capacity building in clean energy and energy efficiency programs, which are an important part of their climate action plans (approximately 20% and 37% for renewable energy, respectively) [52,53]. These countries also benefit from smaller, decentralized energy systems, such as off-grid solar power and mini-grids, which reduce transmission losses and are more aligned with local demand, thereby increasing effective energy utilization.

Conversely, the UAE's high dependence on hydrocarbon export revenues creates systemic incentives to prioritize fossil fuels over renewable energy, complicating the energy transition despite strong renewable energy targets on paper [56]. Furthermore, restrictions such as aesthetic and safety regulations on rooftop solar installations limit distributed generation capacity [57]. Other challenges hindering the efficient transition to renewable energy include high initial investment and operational costs, a lack of skilled labor, and the absence of government subsidies, which increase the cost of renewable energy production compared to conventional fossil fuels [57]. Public and market awareness of renewable technologies like solar energy is also limited, thereby hindering wider adoption [57]. Although the UAE government has introduced ambitious policies (e.g., the UAE Energy Strategy 2050, which targets a 44% share of renewable energy), the gap between policy goals and actual technological and economic performance remains due to these challenges [56,57]. The combination of economic dependence on oil, lack of market knowledge, infrastructure limitations, and lack of subsidies contributes to low efficiency and slow progress in renewable energy adoption compared to global standards.

For the third finding, based on the African, Arab, and Asian country groups, it can be concluded that the OIC-Africa group has the most stable long-term efficiency compared to other groups. This is followed by the OIC-Asia group, which is in a fairly stable position despite the continuing disparities in efficiency stability among member countries. The OIC-Arab group is the most unstable, with highly fluctuating levels of efficiency stability among member countries. This may be due to several regional and structural factors related to resource availability, technology adoption, economic diversification, and policy implementation.

On the other hand, resource endowments and environmental conditions are influential. OIC-African and OIC-Asian countries generally possess more abundant renewable resources—such as

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[3] For example, in Somalia supported by government initiatives such as the World Bank-funded Somalia Electrification and Solar Renewable Energy Project (SESRP), has implemented off-grid solar power plants and hybrid solar technologies that supply electricity to public institutions, including schools and health facilities.

[4] Similarly, Guinea-Bissau launched a significant solar energy scaling-up project with USD$ 78.15 million in investment from the World Bank, IDA, ESMAP, and the Green Climate Fund to build utility-scale solar parks and Mini grids, providing clean, reliable, and efficient energy to urban and rural areas, including remote islands. (Source: [54,55]).

hydropower, solar, and biomass—than many OIC-Arab countries, which are characterized by arid climates, limited water resources, and heavy reliance on fossil fuels. For instance, Saudi Arabia and the UAE remain strongly dependent on hydrocarbons; while economically beneficial, this dependence slows the transition to renewables and improvements in energy efficiency [58]. Moreover, differences in economic structure and diversification matter. OIC-African and OIC-Asian economies are often more diversified, with stronger agricultural and manufacturing bases that facilitate flexible energy use and renewable adoption. By contrast, OIC-Arab economies are more oil-export oriented and locked into fossil-fuel infrastructure, creating technological and financial barriers to large-scale renewable integration and sustained efficiency gains [13].These results indicate a structural link between resource availability, economic diversification, and energy efficiency performance, reinforcing the argument that the outcomes of the energy transition are shaped not only by technology but also by the broader economic and institutional context.

Finally, the results of the potential improvement analysis found that the largest sources of inefficiency came from the output variables of solar energy and renewable energy share, which emphasizes the importance of policies that support the transition to renewable energy. Therefore, it is crucial for OIC countries to achieve an efficient transition to renewable energy, which calls for access to affordable, reliable, sustainable, and modern energy for all. An efficient transition to renewable energy, particularly solar energy, requires a combination of technological advancements, policy support, and system integration. Photovoltaic solar and wind power are key pillars in most cost-optimized pathways toward a 100% renewable energy system, with PV solar often achieving a high share due to resource availability and declining costs [59,60]. Increasing the share of renewable energy involves accelerating the rate of deployment, enhancing grid infrastructure, and improving energy efficiency measures to complement renewable energy generation [61,62]. Integration challenges such as grid congestion, energy storage needs, sector coupling (linking electricity with transportation and industry), and power-to-X technologies[5] are critical for managing variability and ensuring reliability [63]. Community-based approaches such as Renewable Energy Communities (RECs) and peer-to-peer energy sharing can optimize the use of local resources, increase self-consumption of solar energy, and provide economic benefits while supporting the broader transition [64–66]. Overall, tailored policies, investment in innovation, and collaborative frameworks are essential to address institutional and infrastructure barriers for a sustainable and cost-effective transition to renewable energy with a significant contribution from solar energy.

Conclusion

This study analyzes the efficiency of OIC countries in the transition to renewable energy during the 2015–2021 period using the Window DEA method. The results show that the efficiency level of OIC countries tended to be stagnant during the study period, with the highest efficiency at 1.00 and the lowest at 0.01. This means that there is a fairly high efficiency disparity among OIC countries. Furthermore, the Window DEA analysis shows that the level of efficiency stability varies considerably and fluctuates in each window. The quadrant analysis also confirms that OIC countries have a fairly good level of efficiency stability, even though their efficiency levels are low. Based on the African, Arab, and Asian country groups, it can be concluded that the OIC-Africa group has the most stable efficiency levels, followed by the OIC-Asia group, which is in a fairly stable position despite the imbalance in efficiency stability among member countries, whereas the OIC-Arab group is the most unstable, with highly fluctuating levels of efficiency stability among member countries. Finally, the potential improvement analysis concludes that the largest source of inefficiency comes from the output variables, namely Solar Energy and Renewable Energy Share, which emphasizes the importance of policies that support the transition to renewable energy.

[5] Power-to-X technologies convert renewable energy to an energy source that can be readily stored, transported and utilized. (Source: [67].)

Based on the results and analysis of this study, there are a number of policy recommendations that can be adopted by relevant parties to maximize the stability and efficiency of OIC countries in the transition to renewable energy. One consideration is that it is important to strengthen renewable energy infrastructure and invest in technology and energy storage. This can be achieved by expanding electricity transmission and distribution infrastructure, especially in remote areas, building decentralized energy systems to increase energy access and reduce transmission losses, increasing investment in more efficient renewable energy technologies such as solar panels, biomass, or more modern wind turbines, and developing intermittent energy storage technologies so that they can be utilized optimally.

For example, UAE has implemented photovoltaic solar auction which has registered the lowest prices ever recorded for large-scale solar PV (i.e., the Mohammed bin Rashid Al Maktoum Solar Park) [14]. In Pakistan, the government has implemented a renewable energy policy model of micro/multi-village mini-grids based on solar and hybrid biomass/solar power for remote communities [68]. Turkey also runs tenders and competitive schemes (e.g., YEKA/auctions) for large-scale wind and solar projects and encourages private investment in modern facilities.

Another consideration is that it is necessary to reform subsidies and economic incentives, and to strengthen regulations and policy frameworks. This is important in order to gradually reduce fossil fuel subsidies and shift to the renewable energy sector. In that vein, the government or regulators can provide various incentive measures for example, sharia financing schemes, tax incentives, and green finance to encourage the adoption of renewable technologies. By the same token, regulators also need to develop supportive, competitive, and adaptive policy frameworks for the adoption of renewable technologies, as well as set realistic and measurable renewable energy targets. For example, the Egyptian government provides tax incentives including tax breaks and free land installing solar and wind power projects for attracting private investment [69]. Parallelly, the Indonesian government offers fiscal incentives (i.e., income tax reduction, exemption of import duties, land and property tax incentives, government guarantees) and non-fiscal incentives (i.e., guaranteed market access, tariff certainty, land acquisition facilitation) for renewable energy development.

A third consideration is to increase human resource capacity and public awareness by improving education and training for workers related to renewable energy technologies, as well as by conducting campaigns to raise public awareness that impart the benefits of renewable energy.

A fourth consideration is to optimize local potential and diversify energy according to the geographical conditions of each OIC country. For example, the OIC countries exhibit significant diversity in natural resources which range from the high solar irradiation in North Africa and the Middle East, to strong wind corridors in Central Asia to rich geothermal potentials in Indonesia, and Turkey. Leveraging these location-specific advantages help develop renewable energy systems that are both cost-effective and technically efficient. This approach will reduce the dependence on fossil fuels and strengthen national energy security.

Finally, it is important to establish regional cooperation and knowledge exchange. The OIC can encourage cooperation amongst its member countries in sharing best practices, technologies, and resources to accelerate the energy transmission process. It can also establish a renewable energy platform that functions as a forum for coordination and technology transfer among member countries. The commitment to this policy is evident from the Statistical, Economic and Social Research and Training Centre for Islamic Countries (SESRIC), which regularly organizes training, workshops, and short courses for OIC member countries on various themes which include (i.e., environment, green skills, technical and vocational education and training (TVET), institutional capacity, socio-economic development and data management). Similarly, the UAE regularly organizes public campaigns often delivered through social and digital platforms that highlight the importance of clean energy. This is complemented by education and training initiatives such as workshops, seminars, and school programs aimed at enhancing knowledge and developing skills to renewable energy technologies.

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Appendix 1

Country	Window	Efficiency Score							Summary Measures				
		2015	2016	2017	2018	2019	2020	2021	Mean/Window	The Mean	SD	LDW	LDP
Tunisia	W1	0,17	0,17	0,18	0,20				0,18	0,16	0,01	0,03	0,06
	W2		0,14	0,14	0,15	0,16			0,15				
	W3			0,14	0,15	0,15	0,17		0,15				
	W4				0,14	0,15	0,16	0,15	0,15				
	LDY	**x**	**0,03**	**0,04**	**0,06**	**0,01**	**0,01**	**x**	0,06				
Türkiye	W1	0,18	0,28	0,69	0,97				0,53	0,41	0,07	0,79	0,79
	W2		0,18	0,33	0,41	0,49			0,35				
	W3			0,28	0,37	0,43	0,46		0,38				
	W4				0,31	0,37	0,39	0,41	0,37				
	LDY	**x**	**0,09**	**0,41**	**0,66**	**0,12**	**0,07**	**x**	0,66				
Uganda	W1	0,97	0,96	0,96	0,97				0,96	0,96	0,00	0,01	0,02
	W2		0,96	0,96	0,96	0,96			0,96				
	W3			0,95	0,95	0,95	0,96		0,95				
	W4				0,95	0,95	0,96	0,95	0,95				
	LDY	**x**	**0,00**	**0,01**	**0,02**	**0,01**	**0,00**	**x**	0,02				
United Arab Emirates	W1	0,22	0,23	0,58	0,98				0,50	0,54	0,10	0,92	0,92
	W2		0,08	0,19	0,32	1,00			0,40				
	W3			0,16	0,27	0,84	1,00		0,57				
	W4				0,21	0,66	0,81	1,00	0,67				
	LDY	**x**	**0,14**	**0,42**	**0,77**	**0,34**	**0,19**	**x**	0,77				
Uzbekistan	W1	0,03	0,03	0,03	0,03				0,03	0,03	0,01	0,01	0,02
	W2		0,03	0,03	0,03	0,03			0,03				
	W3			0,02	0,02	0,02	0,01		0,02				
	W4				0,02	0,02	0,01	0,02	0,02				
	LDY	**x**	**0,01**	**0,01**	**0,01**	**0,00**	**0,00**	**x**	0,01				
Yemen	W1	0,15	1,00	0,42	1,00				0,64	0,79	0,10	0,85	0,85
	W2		1,00	0,34	0,94	1,00			0,82				
	W3			0,29	0,83	0,99	1,00		0,78				
	W4				0,77	0,97	1,00	1,00	0,93				
	LDY	**x**	**0,00**	**0,13**	**0,23**	**0,03**	**0,00**	**x**	0,20				

Country	Window	Efficiency Score							Summary Measures				
		2015	2016	2017	2018	2019	2020	2021	Mean/Window	The Mean	SD	LDW	LDP
Pakistan	W1	0,49	0,50	0,48	0,49				0,49	0,47	0,01	0,04	0,05
	W2		0,47	0,45	0,47	0,50			0,47				
	W3			0,45	0,46	0,49	0,46		0,46				
	W4				0,46	0,49	0,46	0,45	0,46				

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	LDY	**x**	**0,02**	**0,03**	**0,03**	**0,01**	**0,00**	**x**	0,03				
Palestine	W1	0,74	1,00	0,82	1,00				0,89	0,63	0,15	0,68	0,74
	W2		0,35	0,37	0,45	0,82			0,50				
	W3			0,30	0,38	0,75	0,93		0,59				
	W4				0,26	0,48	0,61	0,84	0,55				
	LDY	**x**	**0,65**	**0,53**	**0,74**	**0,34**	**0,32**	**x**	0,74				
Senegal	W1	0,41	0,42	0,48	0,49				0,45	0,42	0,02	0,07	0,10
	W2		0,40	0,42	0,40	0,43			0,41				
	W3			0,41	0,39	0,42	0,45		0,42				
	W4				0,38	0,41	0,44	0,41	0,41				
	LDY	**x**	**0,02**	**0,07**	**0,10**	**0,02**	**0,01**	**x**	0,10				
Sierra Leone	W1	0,78	0,78	0,79	0,80				0,79	0,79	0,01	0,06	0,06
	W2		0,78	0,79	0,80	0,79			0,79				
	W3			0,79	0,80	0,79	0,79		0,79				
	W4				0,80	0,79	0,79	0,74	0,78				
	LDY	**x**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**x**	0,00				
Somalia	W1	1,00	1,00	1,00	1,00				1,00	1,00	0,00	0,01	0,01
	W2		1,00	1,00	1,00	1,00			1,00				
	W3			1,00	0,99	0,99	1,00		1,00				
	W4				0,99	0,99	1,00	1,00	1,00				
	LDY	**x**	**0,00**	**0,00**	**0,01**	**0,01**	**0,00**	**x**	0,01				
Sudan	W1	0,65	0,62	0,62	0,64				0,64	0,63	0,00	0,05	0,05
	W2		0,62	0,62	0,64	0,63			0,63				
	W3			0,62	0,63	0,62	0,66		0,63				
	W4				0,63	0,62	0,66	0,64	0,64				
	LDY	**x**	**0,00**	**0,01**	**0,01**	**0,01**	**0,00**	**x**	0,01				
Suriname	W1	1,00	0,69	0,86	0,92				0,87	0,83	0,02	0,31	0,31
	W2		0,69	0,88	0,94	0,81			0,83				
	W3			0,82	0,88	0,75	0,83		0,82				
	W4				0,88	0,75	0,83	0,75	0,80				
	LDY	**x**	**0,00**	**0,06**	**0,06**	**0,06**	**0,00**	**x**	0,06				
Togo	W1	0,85	0,85	0,82	0,81				0,84	0,82	0,01	0,04	0,06
	W2		0,85	0,82	0,81	0,83			0,83				
	W3			0,82	0,80	0,82	0,79		0,81				
	W4				0,80	0,82	0,79	0,80	0,80				
	LDY	**x**	**0,00**	**0,01**	**0,01**	**0,01**	**0,00**	**x**	0,01				

Country	**Window**	**Efficiency Score**							**Summary Measures**				
		2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**Mean/Window**	**The Mean**	**SD**	**LDW**	**LDP**
Malaysia	W1	0,15	0,19	0,22	0,29				0,21	0,17	0,03	0,16	0,19
	W2		0,09	0,11	0,13	0,19			0,13				
	W3			0,10	0,12	0,17	0,26		0,16				
	W4				0,10	0,15	0,21	0,24	0,18				
	LDY	**x**	**0,10**	**0,12**	**0,18**	**0,04**	**0,05**	**x**	0,18				
Maldives	W1	1,00	1,00	0,90	1,00				0,97	0,97	0,01	0,15	0,15
	W2		1,00	0,91	1,00	1,00			0,98				
	W3			1,00	0,95	0,85	1,00		0,95				
	W4				1,00	0,86	1,00	1,00	0,97				
	LDY	**x**	**0,00**	**0,10**	**0,05**	**0,15**	**0,00**	**x**	0,15				
Mali	W1	0,85	0,82	0,81	0,81				0,83	0,80	0,02	0,06	0,11

	W2		0,82	0,81	0,81	0,79			0,81				
	W3			0,80	0,80	0,78	0,77		0,79				
	W4				0,80	0,78	0,77	0,75	0,77				
	LDY	**x**	**0,00**	**0,01**	**0,01**	**0,01**	**0,00**	**x**	0,01				
Mauritania	W1	0,41	0,48	0,41	0,70				0,50	0,40	0,07	0,29	0,39
	W2		0,40	0,33	0,46	0,43			0,40				
	W3			0,32	0,40	0,37	0,36		0,36				
	W4				0,33	0,32	0,31	0,31	0,32				
	LDY	**x**	**0,08**	**0,09**	**0,36**	**0,11**	**0,05**	**x**	0,36				
Morocco	W1	0,19	0,19	0,18	0,40				0,24	0,20	0,03	0,21	0,27
	W2		0,14	0,13	0,23	0,22			0,18				
	W3			0,13	0,19	0,19	0,20		0,18				
	W4				0,18	0,18	0,18	0,19	0,18				
	LDY	**x**	**0,05**	**0,06**	**0,22**	**0,05**	**0,02**	**x**	0,22				
Mozambique	W1	0,84	0,81	0,82	0,83				0,83	0,82	0,00	0,03	0,04
	W2		0,81	0,82	0,83	0,82			0,82				
	W3			0,81	0,82	0,81	0,84		0,82				
	W4				0,82	0,81	0,84	0,81	0,82				
	LDY	**x**	**0,00**	**0,01**	**0,01**	**0,01**	**0,00**	**x**	0,01				
Niger	W1	0,83	0,84	0,87	0,87				0,85	0,89	0,04	0,15	0,17
	W2		1,00	0,99	0,94	0,89			0,95				
	W3			1,00	0,90	0,85	0,86		0,90				
	W4				0,88	0,84	0,86	0,84	0,85				
	LDY	**x**	**0,16**	**0,13**	**0,07**	**0,04**	**0,00**	**x**	0,16				
Nigeria	W1	0,85	0,85	0,87	0,85				0,86	0,85	0,01	0,02	0,03
	W2		0,85	0,86	0,85	0,84			0,85				
	W3			0,85	0,84	0,83	0,85		0,85				
	W4				0,84	0,83	0,85	0,83	0,84				
	LDY	**x**	**0,00**	**0,01**	**0,01**	**0,01**	**0,00**	**x**	0,01				

Country	**Window**	**Efficiency Score**							**Summary Measures**				
		2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**Mean/Window**	**The Mean**	**SD**	**LDW**	**LDP**
Guyana	W1	1,00	0,62	0,83	0,67				0,78	0,71	0,05	0,47	0,47
	W2		0,63	0,72	0,57	1,00			0,73				

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	W3			0,69	0,53	1,00	0,53		0,69				
	W4				0,53	1,00	0,53	0,57	0,66				
	LDY	**x**	**0,01**	**0,15**	**0,14**	**0,00**	**0,00**	**x**	0,15				
Indonesia	W1	0,29	0,30	0,27	0,24				0,28	0,25	0,02	0,09	0,09
	W2		0,30	0,27	0,24	0,21			0,25				
	W3			0,26	0,23	0,21	0,23		0,23				
	W4				0,23	0,21	0,23	0,21	0,22				
	LDY	**x**	**0,01**	**0,01**	**0,01**	**0,00**	**0,00**	**x**	0,01				
Iran	W1	0,02	0,02	0,04	0,06				0,03	0,03	0,00	0,04	0,04
	W2		0,01	0,02	0,03	0,03			0,02				
	W3			0,02	0,02	0,03	0,04		0,03				
	W4				0,02	0,02	0,03	0,03	0,03				
	LDY	**x**	**0,00**	**0,02**	**0,04**	**0,01**	**0,01**	**x**	0,04				
Iraq	W1	0,02	0,02	0,02	0,02				0,02	0,02	0,00	0,00	0,01
	W2		0,01	0,01	0,01	0,01			0,01				
	W3			0,01	0,01	0,01	0,01		0,01				
	W4				0,01	0,01	0,01	0,01	0,01				
	LDY	**x**	**0,01**	**0,01**	**0,01**	**0,00**	**0,00**	**x**	0,01				
Jordan	W1	0,04	0,47	0,62	1,00				0,53	0,66	0,10	0,96	0,96
	W2		0,33	0,44	0,71	1,00			0,62				
	W3			0,30	0,51	0,84	1,00		0,66				
	W4				0,47	0,77	1,00	1,00	0,81				
	LDY	**x**	**0,14**	**0,32**	**0,53**	**0,23**	**0,00**	**x**	0,53				
Kazakhstan	W1	0,07	0,06	0,07	0,18				0,09	0,12	0,03	0,23	0,23
	W2		0,04	0,04	0,08	0,19			0,08				
	W3			0,03	0,07	0,16	0,26		0,13				
	W4				0,06	0,13	0,21	0,24	0,16				
	LDY	**x**	**0,03**	**0,03**	**0,12**	**0,06**	**0,05**	**x**	0,12				
Lebanon	W1	0,07	0,11	0,16	0,27				0,15	0,16	0,03	0,27	0,32
	W2		0,08	0,11	0,18	0,22			0,15				
	W3			0,08	0,12	0,15	0,19		0,14				
	W4				0,12	0,14	0,18	0,38	0,20				
	LDY	**x**	**0,03**	**0,08**	**0,16**	**0,08**	**0,02**	**x**	0,16				
Libya	W1	0,04	0,04	0,04	0,04				0,04	0,04	0,00	0,00	0,01
	W2		0,04	0,04	0,04	0,04			0,04				
	W3			0,03	0,03	0,03	0,03		0,03				
	W4				0,03	0,03	0,03	0,03	0,03				
	LDY	**x**	**0,01**	**0,01**	**0,01**	**0,00**	**0,00**	**x**	0,01				

Country	**Window**	**Efficiency Score**							**Summary Measures**				
		2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**Mean/Window**	**The Mean**	**SD**	**LDW**	**LDP**
Chad	W1	0,77	0,77	0,77	0,77				0,77	0,76	0,01	0,03	0,04
	W2		0,77	0,77	0,77	0,77			0,77				
	W3			0,76	0,76	0,76	0,75		0,76				
	W4				0,76	0,76	0,75	0,73	0,75				
	LDY	**x**	**0,00**	**0,01**	**0,01**	**0,01**	**0,00**	**x**	0,01				
Cote d'Ivoire	W1	0,68	0,67	0,66	0,64				0,67	0,65	0,01	0,04	0,08
	W2		0,67	0,66	0,64	0,64			0,66				
	W3			0,66	0,64	0,64	0,65		0,64				
	W4				0,64	0,64	0,65	0,60	0,63				
	LDY	**x**	**0,00**	**0,01**	**0,01**	**0,01**	**0,00**	**x**	0,01				
Djibouti	W1	1,00	1,00	0,91	0,93				0,96	0,95	0,01	0,16	0,16
	W2		1,00	0,92	0,95	0,84			0,93				
	W3			1,00	1,00	0,85	1,00		0,96				
	W4				1,00	0,85	1,00	0,96	0,95				
	LDY	**x**	**0,00**	**0,09**	**0,07**	**0,01**	**0,00**	**x**	0,09				
Egypt	W1	0,07	0,06	0,08	0,15				0,09	0,10	0,01	0,11	0,11
	W2		0,06	0,06	0,09	0,17			0,09				
	W3			0,06	0,08	0,14	0,14		0,10				
	W4				0,07	0,11	0,12	0,13	0,11				
	LDY	**x**	**0,00**	**0,02**	**0,08**	**0,06**	**0,02**	**x**	0,08				

Gabon	W1	0,94	0,91	1,00	1,00				0,96	0,98	0,01	0,09	0,09
	W2		0,92	1,00	1,00	1,00			0,98				
	W3			1,00	0,99	0,99	1,00		0,99				
	W4				0,99	0,99	1,00	1,00	0,99				
	LDY	**x**	**0,01**	**0,00**	**0,01**	**0,01**	**0,00**	**x**	0,01				
Gambia	W1	1,00	1,00	0,95	0,89				0,96	0,90	0,05	0,35	0,35
	W2		1,00	0,92	0,79	0,65			0,84				
	W3			1,00	0,79	0,65	1,00		0,86				
	W4				1,00	0,73	1,00	1,00	0,93				
	LDY	**x**	**0,00**	**0,08**	**0,21**	**0,07**	**0,00**	**x**	0,21				
Guinea	W1	0,80	0,79	0,76	0,77				0,78	0,75	0,03	0,07	0,11
	W2		0,79	0,76	0,77	0,72			0,76				
	W3			0,75	0,76	0,71	0,69		0,73				
	W4				0,76	0,71	0,69	0,70	0,71				
	LDY	**x**	**0,00**	**0,01**	**0,01**	**0,01**	**0,00**	**x**	0,01				
Guinea-Bissau	W1	1,00	1,00	1,00	0,99				1,00	1,00	0,00	0,01	0,01
	W2		1,00	1,00	1,00	1,00			1,00				
	W3			1,00	1,00	0,99	1,00		1,00				
	W4				1,00	1,00	1,00	1,00	1,00				
	LDY	**x**	**0,00**	**0,00**	**0,01**	**0,01**	**0,00**	**x**	0,01				

Country	**Window**	**Efficiency Score**							**Summary Measures**				
		2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**Mean/Window**	**The Mean**	**SD**	**LDW**	**LDP**
Afghanistan	W1	0,19	0,22	0,21	0,20				0,20	0,25	0,08	0,81	0,81
	W2		0,21	0,21	0,20	0,20			0,21				
	W3			0,20	0,19	0,20	0,19		0,20				
	W4				0,19	0,20	0,19	1,00	0,39				
	LDY	**x**	**0,00**	**0,01**	**0,02**	**0,00**	**0,00**	**x**	0,02				
Albania	W1	0,42	0,43	0,41	0,42				0,42	0,44	0,02	0,11	0,11
	W2		0,43	0,41	0,42	0,46			0,43				
	W3			0,41	0,42	0,45	0,51		0,45				
	W4				0,41	0,45	0,51	0,48	0,46				
	LDY	**x**	**0,00**	**0,00**	**0,00**	**0,01**	**0,01**	**x**	0,01				
Azerbaijan	W1	0,03	0,06	0,06	0,07				0,05	0,04	0,01	0,03	0,05
	W2		0,03	0,03	0,04	0,04			0,04				
	W3			0,03	0,03	0,03	0,03		0,03				
	W4				0,03	0,03	0,02	0,03	0,03				
	LDY	**x**	**0,02**	**0,03**	**0,04**	**0,01**	**0,00**	**x**	0,04				
Bangladesh	W1	0,36	0,33	0,31	0,30				0,32	0,30	0,02	0,06	0,09
	W2		0,32	0,30	0,29	0,28			0,30				
	W3			0,30	0,29	0,28	0,29		0,29				
	W4				0,28	0,28	0,29	0,27	0,28				
	LDY	**x**	**0,01**	**0,01**	**0,02**	**0,01**	**0,00**	**x**	0,02				
Benin	W1	0,53	0,47	0,47	0,46				0,48	0,48	0,01	0,11	0,11
	W2		0,47	0,47	0,46	0,48			0,47				
	W3			0,47	0,46	0,48	0,48		0,47				
	W4				0,46	0,48	0,48	0,57	0,50				
	LDY	**x**	**0,00**	**0,00**	**0,00**	**0,01**	**0,00**	**x**	0,01				
Burkina Faso	W1	0,83	0,81	0,81	0,80				0,81	0,79	0,02	0,03	0,09
	W2		0,81	0,79	0,79	0,78			0,79				
	W3			0,79	0,78	0,77	0,77		0,77				
	W4				0,78	0,77	0,77	0,75	0,76				
	LDY	**x**	**0,00**	**0,02**	**0,03**	**0,01**	**0,00**	**x**	0,03				
Cameroon	W1	0,82	0,83	0,83	0,83				0,83	0,83	0,00	0,01	0,01
	W2		0,83	0,83	0,83	0,83			0,83				
	W3			0,82	0,82	0,82	0,82		0,82				
	W4				0,82	0,82	0,82	0,82	0,82				
	LDY	**x**	**0,00**	**0,01**	**0,01**	**0,01**	**0,00**	**x**	0,01				

Source: Authors' own estimate.

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