African Journal of Economics
and Financial Issues (Volume 1, No. 1)
ISSN: 3085-4628

African Journal of Economics & Financial Issues

https://www.ajefi.ma

Impact of renewable energy on total factor productivity in MENA countries

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Received: January 19, 2025 Accepted: April 17, 2025

Abstract

This study examines the impact of renewable energy consumption on total factor productivity (TFP) in the countries of the Middle East and North Africa (MENA) region. The energy transition to renewable sources is a major priority for these nations. However, they face significant challenges linked to heavy dependence on fossil fuels and institutional weaknesses. Using panel data covering the period 1990-2019 and applying panel quantile regression and the generalized method of moments (GMM), we assess the relationship between renewable energy and TFP. The results indicate that renewable energies positively influence TFP only at the highest productivity levels, suggesting that the region's most developed economies benefit most from this transition. In contrast, non-renewable consumption remains a central driver of productivity, underlining the region's persistent dependence on traditional energies. Furthermore, innovation and trade openness are key factors in increasing productivity, while human capital has an insignificant impact. This study highlights the importance of targeted policies for investment in renewable energy infrastructure, the promotion of green innovation, and comprehensive strategies to facilitate an efficient and sustainable energy transition in the region.

Keywords: total factor productivity, renewable energy, quantile regression, MENA region

JEL Classification: C21, D24, Q20, O53

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1. Introduction

Over the last few decades, renewable energy (RE) integration into production processes has increased considerably. The substantial transition from fossil fuels to cleaner energy sources and technological advances has impacted total factor productivity (TFP) in various ways. In a global context characterized by sustainable development objectives and the fight against climate change, renewable energies now hold a central position on economic and environmental agendas, promoting the development and increased adoption of new energy technologies.

Energy transition has become a priority for MENA countries, as illustrated by recent discussions at COP27. However, as major fossil fuel exporters, these countries face specific challenges. Moreover, despite the complexity of the current global context, it remains important to build strong institutions and resilient societies in this region. Although several countries in the region have begun to develop solutions for this transition, structural problems such as a lack of institutional legitimacy often hamper progress[1].

Energy, like capital and labor, is an essential factor of production. Traditionally, research has focused mainly on the impact of renewable energies on economic growth. However, interest has recently grown in their relationship with TFP, a fundamental indicator of economic performance (Afridi & Farooq, 2019). TFP reflects production gains that cannot be attributed to traditional inputs such as capital or labor. According to Mahadevan (2003), it can be analyzed using two main approaches, the frontier approach, which compares production units to an optimal frontier, and the non-frontier approach, which directly estimates the contributions of inputs to growth. Although Solow's (1957) growth model does not deal specifically with renewable energies, it nevertheless constitutes an essential theoretical framework for analyzing the determinants of economic growth, with the emphasis on TFP. Romer (1991) highlights the importance of innovation and technological investment in understanding how renewable energies influence productivity. Stern (2004) has explored the relationship between energy consumption, economic development, and energy efficiency, providing an essential basis for assessing the role of renewable energies in contemporary economies. For their part, Acemoglu & al. (2012) highlight the central role of green technological innovation in the energy transition.

However, the impact of renewable energies on TFP remains a subject of debate, with empirical results often contrasting. Some studies emphasize that the integration of renewable energies boosts productivity via innovation, infrastructure modernization, and improves energy efficiency (Sohag & al., 2021). The energy transition would also help reduce carbon emissions, thereby improving the quality of the workforce and the sustainable management of natural resources (Tugcu & Tiwari, 2016). However, other research indicates that the high costs and intermittency of renewable technologies could limit TFP gains, particularly in developing economies (Dogan & al., 2020). In addition, the specific composition of the energy sources used would directly influence the overall resource efficiency required to produce goods and services.

Our study aims to fill this gap by assessing the impact of renewable energy on TFP in countries in the MENA region. Unlike previous research, which generally focuses on developing countries or focuses primarily on economic growth, this study focuses on the economic and institutional specificities of this region. We consider three key control variables, namely human capital, innovation, and trade openness, due to their plausible role in the TFP explanation. This approach will allow us to more accurately assess the impact of renewable energy in a specific context, taking into account the particular challenges these countries face.

2. Literature Review

The issue of energy in the context of economic growth has been the subject of numerous studies. The relationship between energy consumption and economic growth has been widely explored

[1] Report Washington, D.C.: Center for Global Development. https://www.cgdev.org/publication/mena-and-global- energy-conundrum.

in the literature (Ouedraogo, 2013 ; Ozcan & Ozturk, 2019 ; Shahbaz & al., 2018), giving rise to three main strains of analysis. The first suggests a positive relationship between renewable energy consumption and economic growth, indicating that increased use of renewable sources could serve as a driver of economic development. The second adopts a more critical view, highlighting the constraints associated with renewable energies, notably the high initial costs and production inefficiencies, which could hinder back growth. Finally, the third current highlights the lack of scientific consensus, particularly on the impact of renewable energies on TFP, an aspect still insufficiently studied in the empirical literature (Sohag & al. 2021).

The existing literature provides a substantial basis for analyzing the impact of renewable energies on TFP. However, divergences emerge depending on regional contexts, the methodologies employed, and underlying assumptions. Some studies highlight the long-term benefits of renewable energies, such as improved energy efficiency, the creation of new technologies, and economic diversification. On the other hand, others point to major constraints, notably the high cost of infrastructure required for the energy transition and the variable short-term impacts on productivity.

Numerous studies argue that integrating renewable energies into the energy mix promotes innovation and enhances productive efficiency. For example, Sohag & al. (2021) employed a CS-ARDL approach on 25 OECD countries over the period 1980-2015 to demonstrate that the adoption of renewable energies, combined with high levels of human capital and innovation, enhances the efficiency of production processes while reducing the environmental footprint. This study highlights the essential role of public policies and institutional frameworks in maximizing the benefits of renewable energies. Similarly, Al Mamun & al. (2018) have shown that renewable energies reduce dependence on imported fossil fuels, thereby reducing pressure on external accounts and enhancing energy security. Paul & al. (2022) used a NARDL model to investigate the asymmetric effects of renewable and non-renewable energies on TFP in the Asia-Pacific region. Their results reveal that renewable energy has a positive long-term effect on TFP, while non-renewable energy induces negative externalities in the short term. Tugcu (2013) reaches similar conclusions in Turkey, demonstrating that renewable energy consumption has a positive effect on TFP.

Nevertheless, while the studies mentioned tend to emphasize the advantages of renewable energies, other research emphasizes the high costs and their differentiated impacts according to economic contexts. Dogan & al. (2020) show that the transition to renewable energies involves significant short-term investment costs, which can temporarily reduce TFP. This negative effect is particularly visible in developing countries, where access to financing for renewable technologies is limited. Rath & al. (2019) offer nuanced insights by examining the impact of fossil and renewable energies on TFP in a sample of 36 countries. Their results show that fossil energy consumption has a negative effect on TFP in developed countries and Latin America, but paradoxically, a positive effect in developing countries and Asia. This difference could be attributed to the underlying economic structures in some countries, with fossil fuels remaining a relatively efficient source of production due to the lack of viable alternatives. In their seminal work, Tugcu &Tiwari (2016) examined the impact of renewable and non-renewable energy consumption on TFP separately. The researchers focused on coal, nuclear, hydropower, total renewable electricity, and total non-renewable electricity consumption as energy variables. For non-renewables, the findings indicated unidirectional causality from coal to TFP, from TFP to nuclear power, from nuclear power to TFP in South Africa, and from natural gas to TFP in Brazil. Furthermore, the investigation revealed no discernible correlation between renewable energy consumption and the growth of TFP within the BRICS countries.

Moreover, the literature review also highlights the importance of moderating factors in the relationship between renewable energies and TFP. Benos & al. (2015) have shown that countries with high human capital and innovation-friendly policies benefit more from renewable energies. Furthermore, Wang & al. (2022) demonstrate that the positive effects of RE on carbon productivity in 114 countries are moderated levels of income inequality and urbanization. Although these energies contribute to increasing carbon productivity, these effects are attenuated in countries marked by high inequality or rapid urbanization, highlighting the need for a holistic approach integrating education, infrastructure, and governance in the energy transition. Altınöz (2021) quantifies the impact of RE on TFP and shows that it increases it by 0.007% in the long term, while fossil fuels have no statistically significant impact. This study highlights a key point: the transition to RE must be accompanied by massive investment in infrastructure and clean technologies to maximize its benefits.

The energy transition to renewable sources represents a central challenge for sustainable growth, particularly in MENA countries, where dependence on fossil fuels is historically high. While existing literature highlights the positive effects of renewable energies on TFP in several regions of the world, it also underlines the importance of institutional conditions, infrastructure, and moderating factors such as human capital and innovation. In light of this literature review, the present study makes an additional contribution by analyzing these interactions in the specific context of MENA countries, taking into account the challenges and opportunities specific to this region. By combining an empirical approach based on panel data and an analysis of structural factors. It aims to fill a gap in the literature by specifically targeting these countries.

3. Methodology

3.1 Data description

The present study employs annual panel data extending from 1990 to 2019 for a selected group of MENA countries, encompassing Morocco, Egypt, Tunisia, Jordan, Iraq, and Iran. The selection of the country and the subsequent analysis followed a predetermined process. First, countries with incomplete data were excluded from the analysis. Then, a panel data homogeneity test was applied. The data for the various research variables, including renewable and non-renewable energy, innovation, human capital, and trade openness, were obtained from reliable sources such as the World Bank's development indicators, the International Energy Agency (IEA), the Penn World Table (PWT) databases, and the World Intellectual Property Organization (WIPO). The dependent variable, total factor productivity (TFP), is calculated from a production function, where aggregate output is divided by the weighted average of inputs, represented by labor and capital. The value of this index ranges from 0 to 1, with 1 representing the maximum efficiency frontier and 0 denoting the furthest distance from this frontier. The primary explanatory variables encompass renewable energy consumption (RE), measured as a percentage of total energy consumption, and fossil energy consumption (NRE). In order to enhance the explanatory power of the model, three control variables were incorporated: human capital (HC), measured by the average level of education; innovation (INO), approximated by the number of patents filed; and trade openness (TO), the sum of exports and imports relative to GDP. Table 1 comprehensively defines the primary research variables examined in this study.

To effectively model the impact of renewable energies on TFP, it is essential to take into account a comprehensive set of variables. In addition to renewable energy as the main independent variable, other relevant factors need to be integrated into the production function. This approach provides a more holistic understanding of the mechanisms by which renewable energy adoption affects productivity, highlighting the interaction between energy systems and wider economic dynamics. Recent studies, including those by Sohag & al. (2021), Altinöz (2021), and Rath & al. (2019), have examined the impact of renewable energy on TFP, taking into account key economic factors such as human capital, innovation, and trade openness. More specifically, TFP depends not only on the energy transition but also on these complementary factors. Benos & al. (2015) have shown that economies with high human capital and innovation-friendly policies are better placed to take advantage of renewable energies. Furthermore, market openness encourages technology transfer and strengthens economic competitiveness, which has a positive impact on TFP. The inclusion of these control variables in the analysis is therefore essential to better understand the effect of renewable energies on production processes.

3.2 Method

We employed a multi-stage econometric approach to assess the impact of renewable energy on

TFP. Initially, after presenting the descriptive statistics, we determined the stationarity of each variable using panel unit root tests and cross-sectional dependence tests. If these tests showed that all variables were stationary at the first difference or level, we proceeded with panel cointegration tests to explore potential long-term relationships among the variables. Subsequently, we applied a quantile regression model to analyze how renewable energy influences TFP across different productivity levels in the countries studied. This technique allows us to capture heterogeneous effects between nations and to assess the role of explanatory variables across various points in the conditional TFP distribution. Finally, to address endogeneity concerns and enhance the robustness of our results, we utilized the Generalized Method of Moments (GMM) within a dynamic panel framework. This approach corrects for potential biases from omitted variables and measurement errors, while also considering the temporal dynamics of TFP.

Drawing on the studies by Sohag & al. (2021), Altinöz (2021), and Rath & al. (2019), we employed the empirical model outlined in Equation (1) below:

$$TFP_{it} = f(ER_{it}, NER_{it}, HC_{it}, INO_{it}, TO_{it}) \quad (1)$$

Equation (1) may be reformulated using the standard conditional regression approach, as shown in Equation (2) below:

$$TFP_{it} = \alpha_0 + \alpha_1 ER_{it} + \alpha_2 NER_{it} + \alpha_3 HC_{it} + \alpha_4 INO_{it} + \alpha_5 TO_{it} + \varepsilon_{it} \quad (2)$$

In this model, *i* and *t* refer to the country and the period, respectively, while α_1 to α_5 represent the estimated coefficients. The dependent variable, total factor productivity (TFP), captures the overall productivity performance. The explanatory variables include the proportion of renewable energy consumption in total final energy use (RE), the share of fossil fuel consumption in total energy consumption (NRE), human capital (HC), technological progress (INO), and trade openness (TO). The term ε_{it} denotes the stochastic error term associated with the model.

Table1. Description of variables

Variable	Definition	Source
TFP	Total output divided by a weighted average of the inputs. TFP in measured at constant national prices (2017=1).	Penn World Table version 10.01
RE	Renewable energy consumption (% of total final energy consumption)	WDI, 2023
NRE	Fossil fuel energy consumption (% of total)	WDI, 2023
HC	Average year of schooling	PWT version 10.01
INO	Worldwide Patent applications filed through the Patent Cooperation Treaty procedure or with a national patent office for exclusive rights for an invention (by residents and non-residents)	World Intellectual Property Organization (WIPO)
TO	The sum of exports and imports of goods and services was measured as a share of output.	WDI, 2023

3.3.1 Panel quantile regression model

Quantile regression is employed to estimate the conditional median or specific quantiles of the dependent variable's distribution. This methodology was introduced by Koenker & Bassett (1978). Unlike conventional linear regression, which focuses solely on estimating the conditional mean, quantile regression allows for a more comprehensive analysis across different points of the distribution. In econometric applications, economic variables frequently display outliers and non-linear distributions (Lin & Xu, 2018), conditions under which Ordinary Least Squares (OLS) estimations may yield biased or inconsistent results (Arbia & Sobhi, 2024). In contrast, quantile regression is inherently robust to outliers and distributional non-linearity (Koenker & Bassett, 1978), positioning it as a robust alternative to OLS. This technique is particularly effective in addressing issues of heteroskedasticity and non-standard data distributions. The corresponding model is formalized in Equation (3) as follows:

$$Q_{yt}\ (\theta / x_t) = \alpha_\theta + X_t^T\ \beta_\theta \tag{3}$$

In this specification, $Q_{yt}(\theta/x_t)$ denotes the θ quantile of the dependent variable y_t, conditional on the explanatory variables x_t. The term α_θ captures the unobserved individual effect, while β_θ represents the vector of coefficients associated with the explanatory variables at the specified quantile.

This approach has been widely applied in environmental economics research to account for the varying effects of independent variables across different levels of the dependent variable (Esmaeilpour & Karami, 2024; Le & al., 2025; Bui & al., 2021). To extend the analysis to panel data, Equation (3) is adapted into a panel quantile regression framework with the appropriate modifications, as presented in Equation (4):

$$Q_{yt}\ (\theta / \alpha_i,\ x_{it}) = \alpha_i + X_{it}^T\ \beta_\theta \tag{4}$$

Quantile regression estimation is based on minimizing the weighted sum of absolute errors in Equation (5) as follows:

$$\min \sum \theta\ / y_t - X_t^T\ \beta\ / + \sum(1-\theta)\ / y_t - X_t^T \beta\ / \tag{5}$$

This ensures that the model fits all levels of the $y_{(t)}$ distribution, not just the mean.

The primary aim of this study is to analyze the impact of renewable energy on total factor productivity within MENA countries. Accordingly, the panel quantile regression equation has been adapted and is formulated as follows:

$$Quant_\theta\ (TFP_{it}) = \alpha_0 + \alpha_{\theta 1}\ ER_{it} + \alpha_{\theta 2}\ NER_{it} + \alpha_{\theta 3}\ HC_{it} + \alpha_{\theta 4}\ INO_{it} + \alpha_{\theta 5}\ TO_{it} + \varepsilon_{it} \tag{6}$$

In the equation, *Quant* stands for the parameter θ of the quantile in the dependent variable, which represents TFP.

The use of quantile regression is justified by the need to capture structural differences between MENA economies. Indeed, some countries have advanced infrastructures facilitating the adoption of renewable energies, while others face difficulties linked to initial costs and institutional constraints. GMM, on the other hand, makes it possible to deal with problems of autocorrelation and endogeneity, thus ensuring more reliable econometric results.

This combined approach allows us to better understand the mechanisms by which the adoption of renewable energies influences TFP.

4. Results and discussion

4.1 Descriptive statistics

Table 2, showing descriptive statistics, highlights a marked dependence on fossil fuels (average 94.27%) and limited adoption of renewable energies (average 6.93%). In terms of innovation, the distribution is highly asymmetrical and polarized, while human capital appears relatively homogeneous. Trade openness, meanwhile, varies considerably between the countries studied. Finally, TFP shows moderate dispersion and negative asymmetry. These results reveal significant structural heterogeneity, which is likely to influence the impact of renewable energies on TFP.

Table 2. Descriptive statistics

	Mean	Std. Dev.	Min	Max	p1	p99	Skew.	Kurt.
PTF	1.026	0.157	0.308	1.435	0.394	1.425	-0.898	7.295
ER	6.933	6.288	0.3	23	0.3	22.4	0.642	2.149
NER	94.265	5.329	81.49	99.804	84.227	99.791	-0.593	1.677
HC	2.054	0.399	1.327	2.902	1.347	2.888	0.307	2.191
TO	74.595	31.292	15.126	154.23	28.135	149.448	0.585	2.406
INO	1639.03	3358.959	72	16259	84.6	15955	3.135	11.691

4.2 Cross-sectional dependence tests

To guarantee a rigorous estimation of the relationships among the variables in the model, it is crucial to first examine their statistical properties. In this context, the analysis of cross-sectional dependence holds particular significance, as neglecting it may introduce substantial biases in the empirical results. Cross-sectional dependence, often arising from unobserved common factors, can significantly compromise the reliability of panel data estimation techniques if not properly addressed. Therefore, explicitly accounting for this interdependence is essential to obtain robust and unbiased parameter estimates. The results of the various tests applied to the equation integrating all variables are summarized in Table 3. These tests include the LM test by Breusch & Pagan (1980), the LM and CD tests by Pesaran (2004), and the bias-corrected LM test introduced by Baltagi & al. (2012). All these tests lead to the rejection of the null hypothesis of cross-sectional independence, confirming the existence of cross-sectional dependence in the series studied. The next question concerns the examination of the possible presence of unit roots.

Another problem with panel data is the homogeneity of the slopes, meaning that the coefficients are either similar from panel to panel or estimated individually. The Delta test proposed by Pesaran and Yamagata (2008) was applied to assess this, yielding delta values of 10.536 and adjusted delta values of 12.033, as well as p-value values of 0.000, as described in Table 4. These results refuted the null hypothesis of slope homogeneity, thus confirming the heterogeneity of slopes on transverse panels. It is simply a matter of noting that the influence of independent variables on economic performance varies, which underlines the importance of taking slope heterogeneity into account for accurate modeling and understanding of these effects.

Table 3. The results of cross-sectional dependence tests

Test	Breusch-Pagan LM	Pesaran scaled LM	Bias-corrected LM	Pesaran CD
Statistic	73.0.23***	10.593***	10.490***	-2.210**

Note. LM stands for the Lagrange multiplier test, while CD represents the cross-sectional dependence test.

The significance levels of 1%, 5%, and 10% are indicated by ***, **, and *, respectively

Table 4. The results heterogeneity tests

	Delta	p-Value
Delta	10.536	0.000***
Adj-delta	12.033	0.000***

Note. The significance levels of 1%, 5%, and 10% are indicated by ***, **, and *, respectively

4.3 Stationarity analysis

Having identified and taken into account the problem of cross-sectional dependence, we move on to the next step, which is to test the unit root property of the variables. Stationarity tests for panel data are used to determine whether or not our panel series is stationary. According to Danish & al. (2018), panel unit root tests can be divided into two categories: first-generation tests and second-generation tests. First-generation tests, such as the LLC test developed by Levin & al. (2002) and the IPS test proposed by Im & al. (2003), are based on the assumption of cross-sectional interdependence and homogeneity, but do not take into account cross-sectional dependence between units. Consequently, to take this dependence into account, we use a second-generation unit root test, namely the CIPS test developed by Pesaran (2007). The latter has the advantage of not requiring explicit estimation of factor loadings to eliminate cross-sectional dependency. In practice, this test consists of an ADF-type augmented regression, including the lagged cross-sectional means of the levels and their first differences in order to capture the cross-sectional dependence arising from a common factor model. The null hypothesis of the CIPS test corresponds to the presence of a unit root. This test is specified in Equation (7) as follows:

$$CIPS(N,T) = N\text{-}1 \ \sum_{i=1}^{N} ti\ (N,T) \tag{7}$$

Where CIPS (N,T) is the augmented cross-sectional form of the IPS unit root test developed by Im & al. (2003), and ti (N,T) is the augmented Dickey-Fuller cross-sectional statistic.

The results of the LLC and IPS tests are reported in Table 5. However, it is important to note that these tests do not account for cross-sectional dependence. To ensure a more robust evaluation of the integration properties of the analyzed series while considering potential interdependencies, we also employed the CIPS test developed by Pesaran (2007). This test remains reliable even in the context of small sample sizes.

As presented in Table 5, the results of the aforementioned tests indicate that all model variables follow either a zero-order integration process I(0) or a first-order integration process I(1). This finding suggests that the series are stationary either at their level or after taking the first difference. Specifically, the outcomes of the second-generation unit root test show that the TFP and human capital variables are stationarity at the level, whereas the remaining variables achieve stationarity after first differencing. This difference in stationarity between the variables provides the basis for examining their cointegration. To verify this, we apply the cointegration test proposed by Kao (1999), which represents an extension of the Dickey-Fuller (DF) and Augmented Dickey-Fuller (ADF) tests to panel data.

4.4 Cointegration test

Table 6 shows the results of the Kao panel cointegration test. At the 5% significance level, the probability associated with the test's T statistic is equal to 0.000, a value below this threshold. Consequently, the null hypothesis (H_0) of no cointegration is rejected, confirming the existence of a cointegrating relationship between the variables studied.

Table 5. The results of panel unit root tests

	Level			First difference		
	LLC	IPS	CIPS	LLC	IPS	CIPS
PTF	-1.916**	-0.247	-2.734***	-4.213***	-6.842***	
RE	2.883	2.188	-0.851	-3.681***	-3.970***	-4.460***
NRE	-1.010	-1.044	-2.460**	-6.451***	-5.987***	-4.692***
TO	-0.721	-0.532	-1.265	-3.609***	-4.288***	-4.290***
HC	-3.854***	-3.480***	-2.505***			
INO	1.234	0.751	-1.445	-3.053***	-3.683***	-3.740***

Note. The significance levels of 1%, 5%, and 10% are indicated by ***, **, and *, respectively

Table 6. Kao cointegration test

Test	Statistic	P-value
ADFmodified	-4.67115	0.000***

Note. The significance levels of 1%, 5%, and 10% are indicated by ***, **, and *, respectively

4.5 Model estimation

To examine the impact of renewable and non-renewable energy consumption on TFP across different levels of the dependent variable, we employed quantile regression, focusing on five specific quantiles: the 10th, 25th, 50th, 75th, and 90th percentiles. This statistical method accounts for the heterogeneous nature of the data and enables the distribution of the dependent variable across various quantiles. We subsequently compared these findings with those derived from the GMM regression, incorporating labor and capital as control variables within the model. The results of this analysis are summarized in Table 7.

Table 7. The estimation results

Independent variables	Quantile					GMM
	Q.10	Q.25	Q.50	Q.75	Q.90	
RE	0.0278 (0.170)	-0.0040 (0.650)	0.0036 (0.513)	0.0097 (0.322)	0.0406*** (0.000)	0.0169*** 0.006
NRE	2.1765 (0.338)	0.0437 (0.965)	1.5328** (0.016)	2.2785** (0.039)	5.9957*** (0.000)	2.6130*** 0.000
HC	0.0771 (0.472)	0.0454 (0.342)	-0.0406 (0.172)	-0.0771 (0.139)	-0.2076*** (0.000)	-0.0610* 0.091
TO	0.3127*** (0.006)	0.0820 (0.106)	0.1276*** (0.000)	-0.0157** (0.049)	0.2619*** (0.000)	0.1752*** 0.001

INO	0.0740**	0.0160	0.0048	-0.0157	0.0434***	0.0323**
	(0.029)	(0.286)	(0.600)	(0.336)	(0.002)	0.027
const	-11.1877	0.2539	-6.4421**	-9.5308*	-27.2994***	-11.78***
	(0.293)	(0.957)	(0.030)	(0.066)	(0.000)	0.000

Note. The significance levels of 1%, 5%, and 10% are indicated by ***, **, and *, respectively

4.5 Discussion

The quantile regression results reveal that the coefficients for renewable energy are significant only at high TFP levels (Q90), suggesting that renewable energy has a positive effect on TFP only for the most efficient economies. Estimates obtained by GMM regression confirm its positive and significant impact on TFP. These results are in line with those of Sohag & al. (2021), Altinöz (2021), and Rath & al. (2019), who have shown that the benefits of renewable energy are more pronounced in countries with an advanced technological infrastructure. In addition, Hasanov & al. (2024) pointed out that in natural gas exporting countries, the energy transition to renewables may not generate immediate gains in productivity, which may explain the lack of significant effect at low quantiles. These results suggest that renewable energy consumption has contributed to TFP growth. Renewable energies require advanced infrastructure and technologies. Yet, many MENA countries still lack sufficient investment to develop these sectors. Massive fossil fuel subsidies, particularly in the Gulf countries, reduce the incentive to develop and use renewable energies, thus limiting their impact on productivity.

In contrast, renewable energy consumption (NRE) shows a positive and significant effect on TFP at intermediate and high levels of productivity (Q50, Q75, and Q90), suggesting that fossil fuel dependency continues to play a central role in economic growth in MENA countries. The GMM regression results corroborate these findings, with a positive and significant coefficient. This observation is aligned with the results of Hasanov & al. (2024), which show that fossil fuel consumption remains a major source of TFP growth in natural gas-exporting economies, although this poses problems in terms of ecological sustainability. As highlighted by (Hasanov & al., 2024), energy-exporting countries need to diversify their economies and invest in renewables to ensure an effective energy transition and maintain their productivity.

As regards the control variables, the effect of human capital (HC) on TFP is globally insignificant, and even negative at the upper quantile (Q90), suggesting that in productive economies, an increase in human capital may not automatically translate into an improvement in TFP. In the GMM estimation, the HC effect is negative and insignificant. This result calls into question the effectiveness of education and vocational training systems in the region. These findings confirm the analyses of Sohag & al. (2021), who emphasize that the effectiveness of human capital in the energy transition depends largely on the quality of training institutions and policies. However, the impact of trade openness (TO) on TFP is positive and significant at the Q10 and Q50 levels, indicating that openness to international trade mainly benefits economies with intermediate productivity. The GMM method indicates a positive and significant effect, confirming the importance of international trade for TFP. This finding is partly in line with (Wang & al., 2022), who show that trade openness is a growth factor provided it is accompanied by technological upgrading. Furthermore, innovation (INO) has a significant positive effect only at the extreme quintiles (Q10 and Q90), meaning that innovation mainly benefits the least and most productive economies. This dynamic is in line with the findings of Altinöz (2021), who argues that innovation plays an essential role in the economic transformation of developing countries and in maintaining the competitiveness of advanced economies. Similarly, for the GMM method, the positive effect is significant, confirming its role in improving TFP.

5. Conclusion

This study examines the impact of renewable energies on total factor productivity in the MENA region (Morocco, Tunisia, Egypt, Jordan, Iraq, and Iran) over the period 1990-2019. To do so, we adopted a methodology combining panel quantile regression with the GMM, enabling us to analyze the heterogeneous effects of renewable energies according to the different productivity levels of the countries studied.

The results clearly indicate that the impact of renewable energy consumption on TFP varies significantly according to the country's level of economic development. Thus, in countries with high levels of TFP, the impact of renewable energies is positive and statistically significant. On the other hand, in countries with lower productivity, this impact proved insignificant, underlining the relative importance of other economic and institutional factors in these contexts. Moreover, fossil fuel consumption continues to exert a central influence on productivity, despite the long-term environmental challenges it entails. Furthermore, technological innovation and trade openness are proving to be key determinants in strengthening TFP, particularly in intermediate and advanced economies. However, the limited impact of human capital observed in this study may reflect institutional and educational shortcomings prevalent in the region.

These results suggest several major policy implications for accelerating the transition to renewable energies in the MENA region. Firstly, it is necessary to increase investment in modern energy infrastructure via public-private financing mechanisms. In addition, the gradual reform of fossil fuel subsidies would enable resources to be reallocated to sustainable energy projects, while promoting more efficient energy consumption. Similarly, the establishment of a transparent and stable regulatory framework is essential to attract investment and promote effective energy governance. Finally, the development of human and technological capacities through investment in education and training is a sine qua non for a successful energy transition.

Nevertheless, this study presents certain methodological and empirical limitations that open up avenues for future research. In particular, data availability and reliability are major constraints in the MENA region. Furthermore, the analysis carried out does not take into account recent shocks such as the global energy crisis, and could be extended by the use of more advanced and dynamic econometric techniques to better apprehend long-term effects. A comparative analysis of the various renewable energy sources (solar, wind, hydroelectric) would also be relevant for identifying high-potential sectors in this region.

In sum, this study contributes to the existing literature by highlighting the differentiated impact of renewable energies on productivity in MENA countries and the crucial role of complementary factors such as innovation and institutional governance. To ensure an efficient and sustainable energy transition, policymakers need to adopt integrated strategies combining economic incentives, strategic investments, and appropriate institutional reforms.

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