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► To cite this version:

Haithem Awijen, Fateh Belaïd, Younes Ben Zaïed, Nazim Hussain, Béchir Ben Lahouel. Renewable energy deployment in the MENA region: Does innovation matter?. *Technological Forecasting and Social Change*, 2022, 179 (7), pp.121633. 10.1016/j.techfore.2022.121633 . hal-04542347

HAL Id: hal-04542347

<https://hal.science/hal-04542347v1>

Submitted on 22 Jul 2024

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Renewable energy deployment in the MENA region: Does innovation matter?

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Abstract:

This paper contributes to the renewable energy literature from two perspectives. First, we investigate the factors driving renewable energy deployment in the MENA countries using economic, financial, and political variables including financial development, government effectiveness and political stability. This investigation is empirically carried out by the Panel Smooth Transition Model (PSTR) (Gonzales et al., 2017) that explicitly explores the threshold effect within the determinants of renewable energy production. Second, we introduce innovation as a new determinant of renewable energy deployment to account for the mediating role of technological innovation in the achievement of SDGs and especially the SDG7. Using two proxies of innovation (i.e. ICT and percentage of internet users), we show that higher innovation performance is likely to increase the impact of governance quality on renewable energy deployment. Therefore, governance quality, innovation, political stability, and financial development are the main drivers of renewable energy deployment. The paper calls for sustainable policy options that increase innovation performance and governance quality to increase the production of renewable energy.

Keywords: Renewable energy; Innovation; PSTR model; MENA region

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1. Introduction

Achieving the sustainable development goals (SDGs) with a focus on climate change mitigation, poverty reduction, and social equity is an integrated economic and political goal that involves collaboration between the public and private sectors. In particular, SDG7 aims to provide access to affordable and clean energy by promoting the production and use of renewable energy as an alternative to the extensive use of conventional polluting energy resources. Given that about two-thirds of the world's carbon emissions come from the energy sector, accelerating the implementation of low-carbon energy technologies, such as renewable energy technologies, is critical to reduce emissions (IRENA, 2017).

In recent years, rapid technological advances have been made in new renewable energy technologies, particularly in solar photovoltaics, but also wind power, bringing substantial cost reductions, increased competitiveness, system usability, and a reduced environmental footprint (IRENA, 2020). In addition, battery technologies are rapidly maturing, enabling a widespread transition to battery-powered electric mobility, as well as storage facilitating the integration of variable renewable energy into the grid. Similarly, we observe that rapid innovation translates into rapid cost reductions in many other energy end-use technologies.

Despite the progress made worldwide in recent years, various barriers still stand in the way of large-scale deployment of green energy in the Middle East and North Africa (MENA) region and globally (Omri et al., 2021). As part of the efforts to reduce the risks and adverse effects of climate change and actively contribute to the mitigation of global warming in line with the Paris Climate Agreement, policymakers in developing countries in general and in the MENA region in particular are trying to diversify their energy mix by promoting the development of renewable energy. Among the critical issues, research to understand the key drivers of renewable energy deployment is of paramount importance. In this regard, existing literature using data from developing economies shows that several regulatory and institutional barriers are likely to hinder renewable energy deployment (Ahmed et al., 2021). In addition, other factors such as political stability, corruption, bureaucracy, lack of collaboration between the private and public sectors, and lack of transparency are not conducive to the development and large-scale use of renewable energy (e.g., Becker & Fischer, 2013; Bertheau et al., 2020;

Hille et al., 2020; Liang & Fiorino, 2013; Miremadi et al., 2019; Sonntag-O'Brien & Usher, 2004; Tolliver et al., 2020).

This empirical analysis is of great relevance to energy policy, but it also highlights a significant gap in the existing research literature on the barriers to large-scale renewable energy deployment in the MENA region and the corresponding policy responses.

The current study contributes to the renewable energy literature primarily from two perspectives. Firstly, we investigate the determinants of renewable energy deployment in MENA countries using economic, financial, and political variables, including financial development, governance effectiveness, and political stability. This investigation is conducted empirically by the panel smooth transition model (PSTR), which explicitly explores the threshold effect in the determinants of renewable energy generation (Gonzales et al., 2017). Secondly, we introduce innovation as a new determinant of renewable energy deployment to account for the role of technological innovation in achieving the SDGs in general and SDG7 in particular. To the best of our knowledge, there is a lack of evidence on the mediating role of innovation regarding the current state of renewable energy production in the MENA region.

We motivate our choice of the MENA region as a case study by its ongoing structural economic and social change, with rapid economic development over the past four decades. Policymakers in the MENA region are constrained by international commitments to achieve the SDGs by 2030. Therefore, an in-depth understanding of the key factors affecting the adoption of renewable energy, including innovation, could be very useful in terms of policy options and recommendations.

We show that technological innovation increases the impact of governance quality on renewable energy production. The adoption of innovation and communication technologies and the increase in the percentage of internet users in the MENA region will improve the quality of governance to adopt sustainable policy options and achieve the energy transition.

The rest of the paper is organized as follows. Section 2 is dedicated to the literature review. Section 3 describes data and their features. The methodology and the discussion are presented in section 4, before concluding the paper in section 5.

2. Literature review

The global energy sector is undergoing a rapidly accelerating transition. This accelerated transition is driven by a range of factors. Tackling climate change is a key element among

these drivers, but policymakers and governments are faced with other priorities, including ensuring affordable energy supplies, energy security, and energy access for all.

To address climate change at manageable levels and achieve the sustainable development agenda set out in the Paris Agreement, a rapid and significant shift in energy investments to low-carbon technologies is needed (Amri et al., 2018, 2019; Belaïd, 2021; IPCC, 2014; Mongo et al., 2021a, 2021b).

In recent years, the implementation of a low-carbon energy system has become one of the most essential concerns of policymakers around the world. In this context, decarbonized energy sources will undoubtedly play a crucial role not only in the long-awaited process of decarbonization of the energy mix, but also in the implementation of a new economic model, aiming to advance social welfare and sustainability (Ahmed et al., 2021; Belaïd et al., 2021a; Tiba & Belaïd, 2020, 2021). However, the actual implementation of such a transition remains technically and economically complex. A key ingredient for a successful transition process is accelerating the development and rapid adoption of high-impact clean energy technologies (Belaïd & Youssef, 2017; Belaïd & Zrelli, 2019; Cheikh & Zaïed, 2021).

While many technologies, such as batteries, solar power, and wind power, have achieved significant cost reductions and thresholds for widespread adoption, critical technology gaps exist in other sectors, including industry and transportation. Therefore, cooperative actions between public and private entities can accelerate the timeline for reaching these critical thresholds, sometimes by a decade or more. Continued focused R&D and implementation in areas such as long-term energy storage, hydrogen production, insulation materials, and industrial processes can facilitate the transition (Omri & Belaïd, 2021).

The recent energy economics literature has widely discussed the significant role of the renewable energy sector in achieving sustainability goals (Ahmed et al., 2021). In recent years, a considerable number of studies have emerged that can be divided into two important lines of research (Belaïd et al., 2021c). The first group of studies addresses the relationship between renewable energy and macroeconomic activities, while the second focuses on the determinants of renewable energy production or consumption. With respect to the first stream, the existing literature has mainly focused on examining causal relationships between renewable and non-renewable energy consumption and economic growth (Belaïd & Abderrahmani, 2013; Sadorsky, 2009). In addition, these studies have examined the

relationship between energy production or consumption and environmental impacts (Apergis et al., 2010; Vural, 2020).

In a recent study using a large sample of more than 100 countries, Le et al. (2020) re-examined the dynamic link between energy consumption (renewable and non-renewable), economic growth, and greenhouse gas (GHG) emissions. Their results highlight that both renewable and non-renewable energy have a significant impact on economic growth, providing evidence that renewable energy development plays a critical role in shaping economic wealth. Furthermore, the results of their study indicate that, unlike fossil fuels, the use of renewable energy helps reduce GHG emissions in developed economies but not in developing economies. This suggests that developed countries' success in controlling GHG emissions through renewable energy will have important lessons for developing nations. However, the results are contradictory between the different studies. Conflicting evidence on the interaction between the consumption of different energy sources and environmental quality can be explained by the variety of theoretical frameworks, samples, and econometric specifications adopted by researchers (Tian et al., 2021).

The second emerging stream of research consists of studies that examine the drivers of renewable energy production and demand (Belaid et al., 2021c). These analyses are relatively new compared to the first stream of research (Apergis et al., 2010). The majority of existing analyses have studied the effects of several factors, including economic growth (Ahmed et al., 2021), GHG emissions, trade openness, and oil prices. Recently, some studies have begun to look beyond the standard drivers of renewable energy use and have begun to incorporate institutional quality (Chen et al., 2021). Using a panel threshold approach, Chen et al. (2021) note that democratic institutions have a significant impact on renewable energy use in a selected sample of 97 countries. In addition, some studies examine the effect of financial development on renewable energy development, suggesting that financial development is one of the main drivers of renewable energy development (Burakov, 2017; Shahbaz et al., 2021). In the context of 22 emerging economies, Wu and Broadstock (2015) examine the effects of institutional quality and financial development on renewable energy use over the period 1990–2010. They find that institutional quality and financial development have a significant positive impact on renewable energy use. Furthermore, based on their empirical results, the authors suggest that the income impact and positive contribution of financial liberalization to renewable energy use must be complemented by strong institutional quality. Policymakers

targeting renewable energy infrastructure/production development should develop policies that ensure better coordination between financial development and improved governance.

However, despite the existence of a few studies examining the impact of institutional quality and financial development on renewable energy development, very little is known about the MENA region. The renewable energy potential of the MENA region is incredible, especially for solar and wind power. Moreover, given the geographic location of most MENA countries in the sun belt, there is a match between peak sunlight hours and peak electricity demand. Furthermore, the development of alternative energy sources will help meet the increasing demand for domestic energy in MENA economies resulting from general economic development, population growth, and rising living standards (Belaïd et al., 2021c). In addition to joining global forces to combat climate change and accelerate the necessary energy transition, MENA economies are driven by additional socioeconomic factors to develop alternative energy sources (Amri et al., 2019; Belaïd et al., 2021a, 2021b).

The transmission mechanism from innovation to renewable energy adoption is observed through the direct or indirect effect of innovation adoption and new communication technologies on the decision to invest in renewable energy. Indeed, smart renewable energy instruments cannot be adopted without access to the internet. In addition, decision-makers need information and communication technologies (ICT) to develop advertising and consumer awareness. Therefore, innovation is expected to increase the positive effect of governance quality on renewable energy deployment.

Given the above discussion, this paper, as an additional contribution to the second stream of research, differs from previous studies not only by examining the context of MENA countries, but also by considering the extent to which governance quality and financial development stimulate renewable energy development. This study fills the methodological gap in renewable energy deployment by considering a threshold regression that explicitly examines the mediating role of innovation in the relationship between renewable energy and governance effectiveness (Tian et al., 2021). The traditional method by which authors test for the mediating role by introducing the square form of the mediating variable into the regression cannot clearly show nonlinear impacts (Belaïd et al., 2021c; Chen et al., 2021). In addition, this paper introduces innovation as a new determinant of renewable energy deployment to consider the role of technological innovation in achieving the SDGs in general and SDG7 in particular. The related literature requires further clarification on the mediating

role of innovation in relation to the current state of renewable energy production in the MENA region.

Based on a brief yet targeted literature review, we hypothesize the following relationships:

- *Hypothesis 1:* Renewable energy deployment in MENA countries is closely related to the levels of political stability, financial development, and governance quality.
- *Hypothesis 2:* Technological innovation mediates the relationship between governance quality and the deployment of renewable energy in MENA countries.

3. Data description and analysis

We use original annual panel data for nine MENA countries covering a long period from 1984 to 2014. The MENA countries considered in this study are Morocco, Tunisia, Algeria, Egypt, Iran, Iraq, Jordan, Lebanon, and Yemen. We are limited by data availability when collecting panel data. We collect renewable energy production and consumption through the International Energy Agency (IEA) database. In contrast, policy and governance data are collected from the International Country Risk Guide (ICRG) database. The latter provides three risk indices by country, including political, economic, and financial risk. The political stability index and governance effectiveness were constructed using ten indicators from the ICRG database. These indicators primarily measure government stability, internal conflict, external conflict, and religious and ethnic tensions. Political stability measures the plausible risk of destabilization of the government through violent, unconstitutional, and military means, including terrorism and internal ethnic conflict.

The government effectiveness index represents the quality of public service, the independence of civil services from political pressure, and the credibility of government commitment. This governance quality index is measured by five indicators, which are the military in politics, corruption, law and order, democratic accountability, and the quality of bureaucracy. Finally, the innovation data are collected from the WDI database: they measure the growth of capital services provided by the change in information and communication technology assets and are expressed in natural log (ICT) and the percentage of internet users (ICTI). We are limited by the fact that only these factors are available as a measure of innovation in the MENA region.

Table 1. Definitions of variables and their data source

Variables	Abbreviation	Description	Source
Renewable energy production	REND	Total energy generation from various renewable sources, including hydroelectric, includes geothermal, solar, tides, wind, biomass, and biofuels.	IEA
Political Stability and Absence of Violence index	Pols	This index includes government stability, internal conflict, external conflict, religious tension and ethnic tension.	ICRG
Governance quality index	Gov	This index comprises bureaucracy quality, democratic accountability, law and order, military in politics and corruption.	ICRG
Domestic credit to private sector	FD	Private credit by deposit banks and other financial institutions (% of GDP)	WDI
Gross Domestic Product	GDP	GDP (constant 2010 billion US\$)	WDI
Total natural resources rents	RENT	Total rent from natural resources including oil, natural gas, coal, mineral and forest rents (% of GDP).	WDI
CO2 emissions	CO2	Carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring.	WDI
Foreign investment	FDI	Foreign Direct Investment net inflows (% of GDP).	WDI
Information and communication technology	ICT	the growth of capital services provide by the Information and Communication Technology assets change and is expressed in natural log (ICT)	WDI
Percentage of internet users	ICTI	Percentage of internet users	WDI
Total factor productivity	TFP	TFP used as a proxy for quality of investment, which represents growth in output due to technological changes,	TED

Notes: IEA: International Energy Agency; ICRG: International Country Risk Guide; WDI: World Development Indicators; and TED: Total Economy Database.

The variables used for the empirical survey are presented and defined in Table 1. They are collected from different sources, including the EAI, WDI, and ICRG. In Table 2, we report the basic statistics and provide a primary description of the variables to understand their evolution before confirming their interaction through econometric estimates. Table 3 presents the correlation matrix to understand the interaction between the variables. The average renewable energy production is 715.8 Ktoe, which is less than 50 percent of the maximum (3074 Ktoe). This is an indication of greater variability among MENA countries in terms of renewable energy deployment. However, for political stability and government effectiveness, the statistics indicate similar behavior across countries, with the average close to the maximum value. In addition, the estimated share of domestic credit to the private sector, which measures financial development, indicates an average of 40 percent.

Table 2: Descriptive statistics

Variables	Mean	Standard error	Min	Max
Gov	48.1	14.1	10.7	75
REND	715.8	809.6	1	3074
FD	40.5	26.9	0.3	98.7
POLS	63.3	17.6	4.8	91.3
RENT	11.3	12.6	0.001	64.11
CO2	86674	121611	7051.6	649481
GDP	92	100	5.7	500
FDI	2.7	4.1	-5.1	23.5
TFP	0.3	1.9	-17.5	7.09
ICT	0.6	0.5	0.03	0.9
ICTI	17	4.9	0.3	46

The correlation results presented in Table 3 indicate that renewable energy deployment is positively correlated with political stability, governance quality, economic growth, financial development, and environmental pollution. However, renewable energy deployment is negatively correlated with the country's dependence on natural resources and foreign direct investment. The correlation matrix results indicate a positive correlation between political stability and governance quality. In addition, the financial variables are positively related to political stability and governance quality.

As expected, economic growth could have a positive effect on CO₂ emissions, but it negatively affects foreign direct investment. The results all indicate that government efficiency, financial development, and political stability are the main determinants of renewable energy deployment. In addition, innovation variables are positively correlated with renewable energy production. This means that innovation is favorable to renewable energy deployment. It can mediate its relationship with government effectiveness.

Table 3. Correlation matrix

	REND	POLS	GOV	FD	GDP	RENT	CO2	FDI	TFP	ICT	ICTI
REND	1										
POLS	0.21*	1									
GOV	0.20*	0.65*	1								
FD	0.24*	0.48*	0.57*	1							
GDP	0.40*	0.18*	0.07	-0.08	1						
RENT	-0.17*	-0.27*	-0.30*	-0.56*	0.35*	1					
CO2	0.35*	-0.18*	0.08	-0.04	0.98*	0.34*	1				

FDI	0.04	0.33*	0.28*	.40*	-0.16**	0.18*	-0.14**	1			
TFP	0.25*	-0.09	-0.03	0.16**	0.13**	-0.12	0.13**	0.11	1		
ICT	0.13*	0.21*	0.18*	0.23*	-0.6	0.46	0.27	0.36	0.17*	1	
ICTI	0.18*	0.31*	0.26*	0.43*	0.74	0.52	0.17*	0.43	0.23*	0.78*	1

Note: * and ** indicate significance of the correlation coefficient at 1 and 5%, respectively.

4. Empirical methodology and results discussion

The objective of the empirical investigation is to assess the relationship between governance quality and renewable energy deployment through the adoption of ICT in the MENA region. We test the mediating role of ICT in the link between renewable energy deployment and governance quality. Using a panel of MENA countries, we extend the linear model, which relies on the link between renewable energy deployment and governance quality, to a nonlinear framework.

The main advantage of the nonlinear model is in assessing how technological innovation affects the quality of governance by influencing renewable energy deployment in MENA countries. The impact of governance quality on renewable energy deployment can vary across different technological innovation regimes. We test the panel unit root of all variables and report the results in Table A1 in the Appendix. Following Lahouel et al. (2022a, 2022b), we use two panel unit root tests called LLC (2002) and IPS (2003). These tests are generally recommended for use with macro panel data.

The first step of the nonlinear methodology is the linearity versus nonlinearity test. We use a set of linearity tests including LM_w , LM_F , and LR tests. The procedure consists in testing $H_0: r = l$ against $H_1: r = l + 1$ until the null assumption is accepted. The distribution of LM_F is a Fisher one following $F(k, TN - N - k)$. The LM_w and LR statistics are distributed as $\chi^2(k)$. We report the results of linearity versus nonlinearity tests in Table 3. The results clearly indicate that the nonlinear model is appropriate and that the relationship between renewable energy deployment and its determinants can be described by a smooth transition regression when the two ICT measures are the transition variables.

The p-values reported in parentheses (Table 3) indicate that the nonlinear model can be represented by a single transition function across two extreme regimes (i.e., high and low regimes of innovation and technology adoption performance). Using the results of Table 3, LM_w , LM_F , and LR tests reject the null hypothesis and accept it in the second step for both transition variables ICT and ICTI, which means that the nonlinear PSTR model is specified

with one transition function. Theoretically, compared to Hansen's (1999) panel threshold regression (PTR) model, the PSTR of Gonzales et al. (2017) is preferred because it ensures the smoothness of the transition between both regimes (Lahouel et al., 2020). However, the PTR model imposes an abrupt change between two extreme regimes. The PSTR is specified based on three specification tests.

Table 4. Testing for linear vs nonlinear model

Dependent variable	REND	REND
Threshold variables (q_{it})	ICT	ICTI
$H_0: r = 0$ vs $H_1: r = 1$:		
LM_W	6.34 (0.04)	8.35 (0.02)
LM_F	6.97 (0.03)	6.72 (0.04)
LR	9.97 (0.04)	11.56 (0.06)
$H_0: r = 1$ vs $H_1: r = 2$:		
LM_W	6.55 (0.56)	1.74 (0.45)
LM_F	5.76 (0.36)	0.89 (0.83)
LR	8.11 (0.58)	0.85 (0.34)

The standard linear panel regression previously used to test the impact of government effectiveness on renewable energy deployment is generally defined as follows:

$$REND_{it} = \alpha_i + \beta Gov_{it} + \lambda' Z_{it} + \varepsilon_{it} \quad (1)$$

where $REND_{it}$ represents the renewable energy deployment; Gov represents the government effectiveness or governance quality; and Z is a set of control variables including financial development (FD), political stability (POLS), total natural resources rent as a percentage of GDP (RENT), environmental pollution (CO₂), gross domestic product (GDP), foreign direct investment (FDI), and total factor productivity (TFP).

We follow the conclusion of the linearity versus nonlinearity tests and propose an extension of the linear model (1) to a nonlinear PSTR for both measures of innovation as a transition

variable to mediate the relationship between government effectiveness and renewable energy transition. The PSTR model developed by Gonzales et al. (2017) is thereby specified as follows:

$$REND_{it} = \alpha_i + \beta_0 Gov_{it} + \beta_1 Gov_{it} \varphi(q_{it}; \gamma, c) + \lambda' Z_{it} + \varepsilon_{it} \quad (2)$$

where φ represents the logistic transition function. Following the outcome of the linearity versus nonlinearity tests in Table 3, we have only one transition function and the impact of government effectiveness on renewable energy deployment ranges from a low regime of innovation performance to a high regime of innovation performance change.

$\varphi(q_{it}; \gamma, c)$ is the transition logistic function driving the nonlinear impact of governance quality. The transition function $\varphi(q_{it}; \gamma, c)$ is a continuous function of the transition variable q_{it} , where c denotes the threshold level and γ determines the smoothness of the transition across regimes change of innovation. Following González et al. (2017), a logistic transition function is considered as follows:

$$\varphi(q_{it}; \gamma, c) = \frac{1}{1 + \exp[-\gamma(q_{it} - c)]}, \text{ with } \gamma > 0$$

The nonlinear PSTR model 2 shows that the impact of governance quality on renewable energy deployment in the linear structure (model 1) is added to this impact when the innovation performance measure surpasses the threshold $c = 0.06$ for ICT and $c = 1,024$ for ICTI.

$$\frac{\delta REND_{it}}{\delta Gov_{it}} = \beta_0 + \beta_1 \times \varphi(q_{it}; \gamma, c) \quad (3)$$

The nonlinear impact of innovation on renewable energy deployment can be captured by the linear impact (β_0) plus the nonlinear impact (β_1) when the transition function takes the value one (equation 3) in a high regime of innovation. However, in a low regime of innovation, the transition function is equal to zero and the impact of governance quality on the country's renewable energy deployment is equal to the linear coefficient (β_0). Figures 1 and 2 depict the smooth transition between two extreme regimes of the change innovation measure.

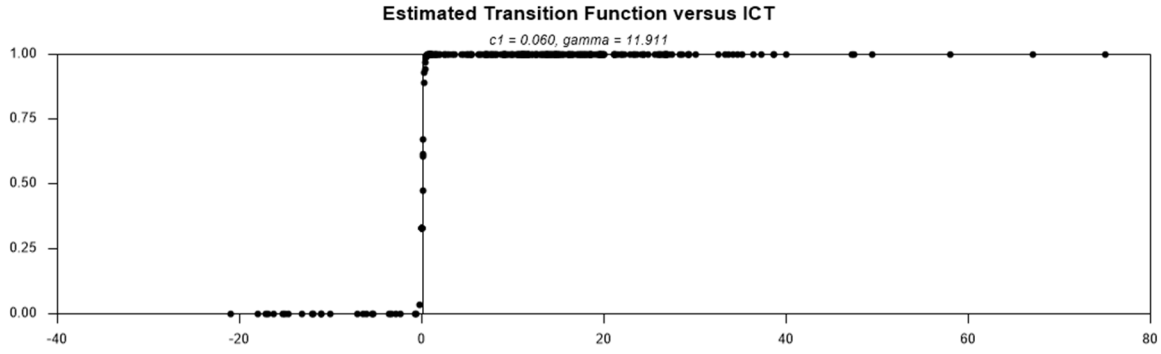


Figure 1. The transition function by the ICT

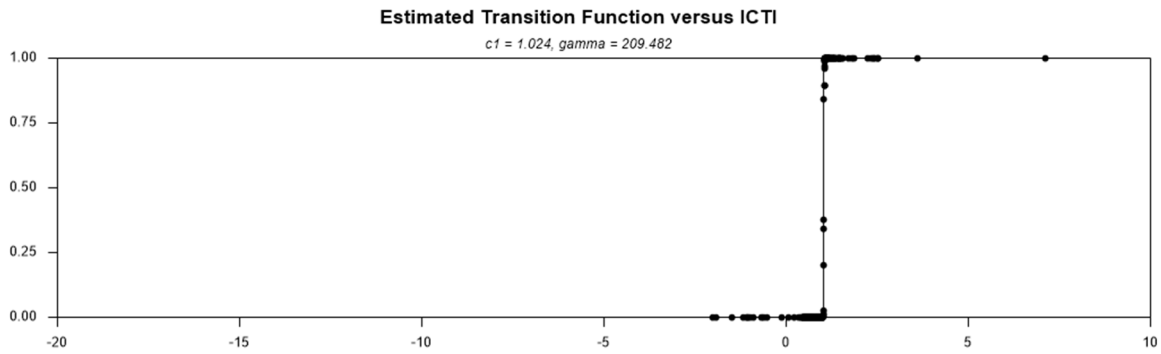


Figure 2. The logistic transition function by the internet users (ICTI).

Figures 1 and 2 show that the transition between the two regimes is somewhat smooth when the growth of capital services, provided by the ICT assets change, is expressed in natural log. The speed of the transition is 11.9. However, when we use the percentage of internet users as the transition variable, the transition between the two regimes is abrupt as the speed of the transition is higher and equal to 209.48.

Table 5. Estimation of the PSTR model: Renewable energy deployment

Dependent variable	Linear model	Nonlinear model	
	(1)	(2)	(3)
	<i>REND</i>	<i>REND</i>	<i>REND</i>
Threshold variable (q_{it})	-	<i>ICT</i>	<i>ICTI</i>
Threshold value (c)	-	0.06 (0.02)	1.02 (0.03)
Speed of transition (γ)	-	11.91 (1.63)	209.01 (2.48)
$g(q_{it}; \gamma, c) = 0$:			
Gov	0.03*** (0.001)	0.02*** (0.004)	0.027*** (0.005)

	0.004*** (0.002)	0.03*** (0.001)	0.003 (.003)
FD			
	0.001 (0.003)	0.001 (0.004)	0.006*** (0.003)
POLS			
	-0.18*** (0.039)	-0.19*** (0.02)	-0.14*** (0.041)
RENT			
	-0.36* (0.11)	-0.32* (0.14)	0.25 (0.22)
CO2			
	0.38*** (0.17)	0.35*** (0.14)	0.51*** (0.19)
GDP			
	0.03*** (0.01)	0.031*** (0.01)	0.03*** (0.01)
FDI			
	-0.004 (.01)	-0.004 (.01)	0.07*** (0.03)
TFP			
$g(q_{it}; \gamma, c) = 1$:			
Gov		0.04*** (0.002)	0.03*** (0.004)
	-	Estimations Tests and Statistics	
Observations		253	253
Adjusted R ²	0.91	0.92	0.92
Country fixed effect	Yes	Yes	Yes
SSR _{ratio}	-	5.66	8.67
Parameter constancy Test	-	6.72 (0.75)	6.58 (0.45)

Notes: Estimation results of the linear panel model reported in the second column are obtained from equation (1). When $g(q_{it}; \gamma, c) = 0$, this corresponds to only the linear part in equation (2). When $g(q_{it}; \gamma, c) = 1$, this corresponds to the non-linear PSTR as in equation (1). When $g_1(q_{it}; \gamma_1, c_1) = g_2(q_{it}; \gamma_2, c_2) = 1$, this corresponds to the non-linear PSTR as in equation (2). Numbers in parentheses are standard errors. ***, **, * indicate 1%, 5%, 10% statistical significance levels, respectively. SSR_{ratio} is the ratio of the sum of squared residuals between the PSTR model and the linear panel specification. The last rows report the Language Multiplier specification test of parameter constancy.

We develop an innovative approach to study the determinants of renewable energy deployment in a nonlinear manner. Specifically, we study the role of innovation in the impact on renewable energy deployment performance of governance quality in the MENA region. The innovation variables (i.e., ICT adoption and percentage of internet users) drive a nonlinear relationship in the renewable energy deployment model. The results of the PSTR model presented in Table 5 are highly significant at the 1 percent level. It appears, as expected, that governance quality, measured by government effectiveness, positively affects renewable energy deployment. However, innovation performance increases the impact of governance quality on renewable energy when it reaches a given innovation performance threshold. Using the smooth panel transition model, the threshold level is calculated from the data. The estimated impact increases from 0.02 to 0.04 when the innovation variable measured by ICT exceeds the 0.06 threshold. However, when innovation is measured by the percentage of internet users, the impact increases from 0.027 to 0.03. As we can see, the results of the nonlinear estimation are still robust to the change in the measure of innovation.

This result means that for a 1 percent increase in the governance quality index, there will be an increase in renewable energy production in the MENA region by 0.02 percent, and by 0.04 percent when the innovation measure exceeds the 0.06 change threshold. However, when innovation is represented by the percentage of internet users, an increase of 1 percent increases renewable energy production by 0.027 percent, and it reaches an increase of 0.03 percent when the percentage of internet users exceeds the threshold of 1.02.

Furthermore, we note that when we introduce the second innovation variable (percentage of internet users) as a transition variable, the results remain robust and have the same expected sign as in the panel fixed-effect linear model. The political stability index has a positive impact on renewable energy deployment, but this impact is statistically significant only when we use the percentage of internet users as the transition variable. This positive impact of political stability confirms our intuition and the hypothesis that political stability is an important factor that can improve renewable energy production in developing countries, and particularly in the MENA region. As we saw in section 2, political stability is closely linked to policy options for sustainable economic development. It provides real opportunities, through these sustainable policy options, to access green energy resources (Antonakakis et al., 2014; Popescu et al., 2010). Thus, a stable policy environment is a prerequisite for renewable energy deployment.

The result of the estimated impact of financial development, measured by private credit from depository banks and other financial institutions (percentage of GDP), is positive and significant at 1 percent. When the measure of financial development increases by 1 percent, renewable energy production increases by 0.03 percent. This confirms the correlation coefficient between renewable energy and financial development. Therefore, as expected, the development of the financial system is a key driver for renewable energy production. Indeed, financial development is a prerequisite and a key factor for developing research and development activities that can open up new horizons for consumer and shareholder engagement, sustainable solutions, and responsible green investment benefits. This conclusion is in line with several empirical studies that claim new perspectives regarding the importance of finance in the energy transition process (e.g., Doytch & Narayan, 2016; Frankel & Romer, 1999).

Control variables are used to control for the impact of the socio-economic and environmental context. We essentially introduce CO₂ emissions, GDP, foreign direct investment, the country's dependence on natural resources, and total factor productivity. We show that the

impact of GDP is positive and significant, having the highest magnitude impact compared to the rest of the variables. This result confirms the crucial role of economic development in the energy transition. Indeed, a 1 percent increase in the country's GDP will increase renewable energy production by 0.35 percent when ICT is used as a measure of innovation, and by 0.51 percent when we use the percentage of internet users as a proxy for innovation.

Green technologies cannot be easily developed and adopted in the absence of promising economic growth. Thus, we confirm the previous results of Sadorsky (2009), who concluded that in the case of G7 countries, an increase in real GDP could be the main driver of renewable energy consumption. Moreover, as shown by Omri and Nguyen (2014) for the 64-country case, the impact of economic growth on renewable energy development is closely related to the level of GDP. Moreover, the total rent (percentage of GDP) from natural resources, including oil, natural gas, coal, minerals, and forests, is used to monitor the impact of the country's dependence on natural resources. The results show that the impact is negative and significant. The availability of natural resources does not favor renewable energy deployment. This result highlights the resource curse in MENA countries. Resource endowments lead to inefficient and unsustainable policy options.

Foreign direct investment, as an indicator of openness to international investment, has a positive and significant impact on renewable energy production for both PSTR models, with ICT and the percentage of internet users as indicators of innovation. Total factor productivity is likely to increase renewable energy deployment; its impact is statistically significant only when the percentage of internet users, as an indicator of innovation, is the transition variable in the PSTR model that determines the relationship between governance quality and renewable energy production. Indeed, when TFP increases by 1 percent, renewable energy production increases by 0.07 percent. The role of TFP has previously been recognized in the related literature and several studies show its crucial role in renewable energy deployment (Badeeb et al., 2016; Lahouel et al., 2021).

Using the PSTR model to study renewable energy deployment validates the theoretical hypotheses in the research. Indeed, we have confirmed the first hypothesis by showing that political stability, quality of governance, and financial development are the main determinants of renewable energy deployment. Moreover, we empirically confirm the mediating role of innovation in the relationship between renewable energy deployment and governance quality in the MENA region. The higher the level of innovation, the greater the impact of governance quality on renewable energy production.

5. Conclusions and policy recommendations

Several MENA countries have an active agenda to achieve the United Nations' sustainable development goals by 2030. Various programs have been adopted, notably to ensure energy transition and increase renewable energy production. The specific climatic conditions of the MENA region represent an advantage for the implementation of power plants using solar energy. Solar energy is expected to meet the growing energy demand in the region. However, in most cases, financial development is the main driver for the adoption of renewable energy.

This paper has investigated the determinants of renewable energy adoption in the MENA region. We contribute to the green energy literature by testing the mediating role of technological innovation in driving the relationship between governance quality and renewable energy deployment. We use two proxies for innovation to show that higher levels of innovation should increase both governance quality and renewable energy adoption. We show that governance quality, innovation, policy stability, and financial development are the key drivers of renewable energy deployment. Accordingly, we recommend sustainable policy options that increase innovation performance and governance quality to increase renewable energy production.

Our results have several policy implications for improving renewable energy production and adoption in the MENA region. Policymakers are called upon to encourage and fund research and development programs that improve renewable energy technologies and achieve energy transition goals. There is also interest in improving the development of the financial system and encouraging investment in renewable energy deployment.

Renewable energy can enable climate-friendly growth in MENA countries, especially if it is exportable to high-income economies seeking to reduce the carbon footprint of their existing energy systems. The cost of low-carbon technologies is decreasing every year, but continued progress requires continued public policy support. Therefore, funds and measures to strengthen innovation and stimulate the market for low-carbon technologies will support the maturation of new energy industries and advance the next generation of low-carbon technologies, such as concentrated solar power and battery storage.

There is a clear need for specific financial instruments to stimulate investment in the adoption and development of renewable energy, particularly among small and medium-sized private

investors. In this context, direct cash grants and soft loans can be a strategic method to reduce the high upfront investment costs of low-carbon technologies. In addition, incentives designed to support investment in medium- and large-scale low-carbon technologies can serve as strong channels for creating competitive environments for renewable energy projects and conventional energy supply technologies.

Finally, the transition to a low-carbon energy system is cross-sectoral in nature, requiring holistic and cooperative action and coordination among actors representing different sectors and institutions. A collaborative effort between all stakeholders involved in renewable energy development—including private, public, and financial actors—is essential to enable a successful and coherent transition to a low-carbon energy system. This collective commitment will avoid potential overlaps and conflicts of interest while facilitating effective coordination of efforts. It will also facilitate the sharing of knowledge, experience, and lessons learned, as well as the flow of resources among stakeholders.

The study of renewable energy deployment is of critical importance to investors and policymakers. Most research articles in this literature are limited by the availability of data describing innovation and technology adoption. This paper uses aggregate data measuring the percentage of internet users and ICT usage. However, it may be interesting to conduct similar studies using disaggregated data to further investigate the role of innovation in renewable energy adoption. In addition, disaggregated data allow additional measures and proxies for innovation, which should improve the quality of the empirical investigation and allow useful policy recommendations. Future research on renewable energy deployment should estimate the same model using different types of renewables, which will be very helpful in recommending the most useful policy option. It is also important to mobilize several innovative econometric techniques when studying the link between innovation and renewable energy deployment.

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Appendix

Table A1. The results of the panel-data unit root tests LLC (2002) and IPS (2003)

Variables	LLC	IPS
REND	-9.28*** (0.000)	-9.78*** (0.000)
POLS	-4.15*** (0.000)	-3.02*** (0.000)
GOV	-2.82*** (0.000)	-3.58*** (0.000)
FD	-4.63*** (0.000)	-9.88*** (0.000)
GDP	-10.05*** (0.000)	-10.03*** (0.000)
CO2	-4.78*** (0.000)	-5.02*** (0.000)
FDI	-3.67*** (0.000)	-3.89*** (0.000)
TFP	-4.67*** (0.000)	-4.02*** (0.000)
ICT	-4.99*** (0.000)	-5.89*** (0.000)
ICTI	-6.76*** (0.000)	-7.03*** (0.000)
RENT	-6.155*** (0.000)	-8.066*** (0.000)

Note(s): LLC and IPS denote, respectively, Levin et al. (2002) and Im et al. (2003) panel unit root test. ***, **, * indicate statistical significance at 1, 5 and 10 percent level of significance, respectively.