Environmental Science and Pollution Research (2023) 30:105293–105307
https://doi.org/10.1007/s11356-023-29823-9

RESEARCH ARTICLE

The transition to renewable energy is inevitable as geopolitical risks drag on: a closer empirical look at MENAT oil importers

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Received: 25 February 2023 / Accepted: 7 September 2023 / Published online: 15 September 2023

Abstract

This paper investigates the impact of geopolitical risks on renewable energy generation in MENAT oil-importing countries, namely, Egypt, Tunisia, and Turkey over the period 1990–2020 using the autoregressive distributed lag (ARDL) model. The main findings emphasize that geopolitical risks play a crucial role in inducing renewable energy development in MENAT oil-importing countries in the short and long run. Financial development appears to positively and significantly affect renewable energy generation in the three countries. Furthermore, the speeds of adjustment towards the long-run equilibrium are 36.78%, 66.03%, and 17.81% annually in Egypt, Tunisia, and Turkey, respectively. In today's volatile and turbulent world, dramatically rising geopolitical risks make the transition to renewable energy an inevitable reality. Consequently, it is incumbent upon policymakers and relevant authorities in MENAT oil-importing countries to preemptively redirect their efforts and strategies to conform to the demands of the inevitable transition to renewable energy sources and boost energy self-reliance.

Keywords Renewable energy · Geopolitical risks · MENAT oil-importing countries

JEL classification numbers F51 · F52 · N40 · O53 · O55 · Q42

Introduction

Energy is unquestionably the lifeblood that keeps the economy moving forward. Needless to say, both achieving sustainable economic growth and maintaining national security hinge primarily upon the continuity of energy supplies. Equally importantly, oil wealth is viewed as a significant geostrategic advantage in light of the scarcity of resources. Energy-poor countries are, therefore, more prone than any other countries to undergo unavoidable suffering when geopolitical risks impede energy supplies. Caldara and Iacoviello (2022) contended that the geopolitical risk can be defined as the threat, realization, and escalation of adverse events associated with wars, terrorism, and any tensions erupting among states and political actors that affect the peaceful course of international relations. Scholten (2018) emphasized that fossil fuel reserves are limited and mostly located in countries that are hallmarked by incessant political instability and are typically vulnerable to geopolitical risks.

Overland (2019) and Sweidan (2021a, b) maintained that renewable energy sources, utterly regardless of their nature, namely solar, biomass, geothermal, wind, and hydropower energy are among the most used and indeed the most effective and feasible substitutes for fossil fuels when geopolitical risks increase. In a similar vein, Sweidan (2021b) argued that renewable energy deployment cannot be sensibly divorced from the geopolitical events taking place on a global scale. For example, the 2006 gas crisis between Russia and Ukraine significantly exacerbated the conflict between Russia and the European Union, which has eventually resulted in prompting the latter to speed up the transition

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to renewable energy (Flouri et al. 2015; Rodríguez-Fernández et al. 2020).

The shift towards renewable energy as a potentially rewarding mechanism for attaining energy security and energy independence has truly become a realistic and inevitable matter following the Russian–Ukrainian war, which led to the materialization of an unprecedented energy crisis in Europe and forcefully placed a high priority on energy security (Umar et al. 2022; Zhou et al. 2023). Prior to the 2022 Russian invasion of Ukraine, the European Union was highly dependent on Russian gas that was usually cheaper, easy to transport, and almost always available. In 2021, Russian gas exports to EU countries totaled nearly 155 billion m^3, accounting for about 45% of EU total gas imports and 40% of its total gas consumption. Due to the unprecedented energy crisis and long-lasting challenges triggered by the Russo–Ukrainian war, the EU plans to speed up the transition to renewables and replace 25 to 50 billion m^3 per year of imported Russian gas with renewable hydrogen by 2030 (International Energy Agency 2022). Such events are considered outstanding realistic examples of the immediate contribution of geopolitical risks to spurring energy-poor countries to act so swiftly for the ultimate end of ensuring energy security by quadrupling the production of renewable energy.

MENAT[1] oil-importing countries have not been immune from the lethal repercussions of the global energy crisis; many economists believe that the sole salvation of these countries from the energy crisis can only be earned by betting on renewable energies (Kahia et al. 2017; Razi and Dincer 2022); Adun et al. 2022; Timmerberg et al. 2019).

The Russian invasion of Ukraine may have been a boon for oil-rich countries, but it seemed a bane for oil-poor countries. MENA oil exporters, in contrast to MENA oil importers, benefited from Russia–Ukraine war fallout through rising petrodollar inflows, witnessed a GDP surge of 4.7% and 5.7% in 2021 and 2022 respectively, and enjoyed an increase in the current account surplus from US$118.2 billion in 2021 to US$124.3 billion in 2022 (IMF 2023).

One of the MENAT countries which has been hit hardest by the acute energy crisis is Tunisia. To protect itself against a forecast calamitous scenario following this global crisis that has had prominent effects on its economy, Tunisia is speedily launching renewable energy projects. To further solidify itself against the manifold looming perils, this North African country has sought the necessary international financial support to establish solar energy projects (Gori and Menkulasi 2022). Egypt is also suffering from high energy prices (Belaïd 2022); it has been endeavoring to rationalize electricity consumption and increase the volume of electricity generated from renewable resources. To be well equipped to face the crisis of declining foreign exchange reserves, Egypt has been setting up ambitious plans to allocate quantities of natural gas for export to Europe. Turkey is also not immune from the energy crisis that is suffocating Europe because it relies upon outside energy supplies. Hence, covering the energy bills is becoming a mind-bogglingly serious issue for the Turkish foreign exchange reserves. By implication, Turkey has been striving to invest more productively in renewable energies and encourage full exploitation of solar energy (IMF 2022). In 2023, the World Bank has lent Tunisia $268.4 million to finance the Tunisia–Italy interconnector project that aims to position this North African country as a regional hub for renewable energy (World Bank 2023c). The World Bank also approved $549 million for increasing the use of renewable energy in public buildings in Turkey in 2023 (World Bank 2023d). In 2017, the World Bank provided a $653 million debt package to finance the construction of 13 solar power plants in Egypt that also received in the same year a €140 million loan from the European Bank for Reconstruction and Development (EBRD), the French Development Agency (AFD), the European Investment Bank (EIB), and the European Union (EU) to promote green investments (World Bank 2017). It is worthwhile to note that this foreign funding is of utmost importance for renewable energy development given the difficult economic and political situation these countries are facing.

Before the Egyptian revolution of 2011, power cuts had become daily occurrences, and fuel prices rocketed. The Egyptian government is now cognizant of the fact that grievances about rapid fuel price increases can ignite large-scale protests against the spiraling cost of living crisis. Therefore, the Egyptian government has set renewable energy targets and intends to increase renewable energy generation in order to escape a deepening energy crisis caused by fuel shortages, soaring energy demand, and unsustainable fossil fuel subsidies (Belaïd 2022; World Bank 2023a).

In fact, geopolitical risks are rising in Tunisia, owing to a multitude of political and economic failures, security threats, and the continuing infighting among groups jockeying for the post-Qaddafi era in Libya. Tunisia is suffering in a such hostile geopolitical environment that threatens its energy security. Furthermore, the failures of the 2011 revolution fuel instability in Tunisia, which could thus be shaken by a wave of protests against austerity measures at any time. It is worthwhile to note that international financial institutions urged Tunisia to gradually eliminate fossil fuel subsidies and privatize the production of electricity from renewable resources (World Bank 2023b). Therefore, the Tunisian government has recently shown greater interest in developing renewable energy sources and removing barriers to private

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[1] MENAT refers to the Middle East, North Africa, and Turkey region.

investments in renewable energies in order to escape energy security risks.

Turkey has emerged as a major swing player in the protracted Russia–Ukraine war and has prioritized the diversification of energy resources in the face of heavy dependence on foreign energy supplies. Turkey truly looks eager to monetize its renewable energy potential (IMF 2022).

Overland (2019) stressed that examining the relationship holding between geopolitical risks and renewable energy represents a promising new and fruitful avenue for future research. In fact, there is a remarkable dearth of research undertakings that have investigated the impact of geopolitical risks on renewable energy development (Sweidan 2021a, b; Dutta and Dutta 2022; Flouros et al. 2022; Appiah-Otoo 2021). This can perhaps be attributable to the lack of an accurate and reliable index that measures geopolitical risks prior to the publication of Caldara and Iacoviello's (2018) seminal work.

The present study, therefore, aims to examine the impact of geopolitical risks on renewable energy development. It will enrich the literature on this subject and fill the existing gap. It will also cast light on MENAT oil-importing countries that are at the epicenter of geopolitical turmoil with a special emphasis on Egypt, Tunisia, and Turkey over the period 1990–2020. This selection is based on the fact that these three counties are the only MENAT oil-importing countries included in the Caldara and Iacoviello geopolitical risk index. This paper uses the autoregressive distributed lag (ARDL) approach developed by Pesaran et al. (1996, 2001) and Pesaran et al. (1999). This approach has several advantages and superiorities over conventional cointegration techniques introduced by Engle and Granger (1987), Johansen (1988, 1991), and Johansen and Juselius (1990).

The rest of the paper is structured as follows. "Literature review" reviews the relevant literature. "Data and econometric methods" introduces the data and presents the econometric methodology in detail. "Results and discussion" reports and discusses the estimation results. "Conclusion" concludes with some recommendations.

Literature review

The foregoing decade has been saliently marked by a range of eye-catching developments in the number of studies that have attempted to identify the determinants of renewable energy development and deployment and shed light on energy, economic, environmental, political, regulatory, and demographic variables (Darmani et al. 2014; Şener et al. 2018; Bourcet 2020). There is, however, a remarkable paucity of studies dealing with the impact of geopolitical risks on renewable energy development, such as those conducted by Sweidan (2021a, b), Dutta and Dutta (2022), and Flouros et al. (2022). By contrast, there has been an increasingly growing interest in analyzing the impact of geopolitical risks on oil price volatility, oil markets, and stock markets (Mei et al. 2020; Smales 2021; Li et al. 2022; Zhang et al. 2022; Xiao et al. 2022).

Tuathail et al. (1998) described the term geopolitics as an inevitable causal relationship between geography and international relations that is set in motion by virtue of a number of overlapping factors, viz. ongoing competition, regional expansion, and military strategies of imperial powers. Accordingly, geopolitical risks can be rightly viewed as threats linked inextricably to wars, terrorist attacks, and conflicts erupting between countries.

Caldara and Iacoviello (2022) meaningfully defined the geopolitical risk as the threat, realization, and escalation of adverse events associated with wars, terrorism, and any tensions among states and political actors that affect the peaceful course of international relations. The co-authors went on to suggest that two salient, clear-cut sets of geopolitical risks strike the observer's eye, namely the risks of current events and new risks associated with the escalation of current events. Drawing on these distinctions, they came up with the GPR index. What hallmarks this index is that it measures real-time geopolitical tensions using an algorithm that calculates the share of articles that mention and cover geopolitical events of global interest and all the threats associated therewith in the following 10 leading newspapers: Chicago Tribune, the Daily Telegraph, Financial Times, the Globe and Mail, the Guardian, Los Angeles Times, New York Times, USA Today, the Wall Street Journal, and the Washington Post. For attaining a proper and reliable calculation of this index, the co-authors have recourse to the search for words falling into the following six groups of words: geopolitical threats, nuclear threats, war threats, terrorist threats, war acts, and terrorist acts.

It is worthy of mention that the GPR index took extremely high values in the following events: Iraq's invasion of Kuwait, the Second Gulf War, the events of September 11, the US invasion of Iraq in 2003, the military intervention in Libya in 2011, Russia's annexation of Crimea in 2014, the 2015 Paris terror attacks, the 2017–2018 North Korea crisis, and Russia's invasion of Ukraine in 2022.

In a study encompassing 26 countries over the period 1900–2019, Caldara and Iacoviello (2022) arrived at the conclusion that higher values of the GPR index are strongly associated with higher probability of economic disasters and lower expected GDP growth. Similarly, they inferred that geopolitical threats are bound to exert an immediate influence on macroeconomic variables through a number of channels, such as human losses, destruction of capital stock, higher military spending, exacerbation of precautionary behavior, and increased implementation of preventive measures.

Sweidan (2021a) stressed that geopolitical tensions can directly give rise to a high degree of uncertainty and can even function as a true impediment to the flow of oil to the world's economies. This may eventually result in motivating oil-importing countries to press ahead with their efforts for reducing their virtually chronic dependence on fossil fuels and developing renewable energy sources. A good case in point is the Russo–Ukrainian war, which baffled in innumerable ways the energy markets, destabilized energy security, plunged Europe into its worst energy crisis in decades, and gave an unprecedented impetus to the transition towards renewable energy. This war exerts far more pressure on European oil and gas importing countries to accelerate the transition to renewables, keep their economies moving forward, and turn their strategic plans into actions (Umar et al. 2022; Zhou et al. 2023).

The pressing urgency of renewable energy deployment could be rightly ascribable to the Russian invasion of Ukraine. This has been further intensified when oil and gas rich countries began to more boldly use oil and gas supplies as geopolitical weapons to achieve their political goals. After all, renewable energy is a powerful and efficient alternative to fossil fuels and a key driver of sustainable growth. Indeed, Overland (2019) was utterly convinced that the study of the relationship holding between geopolitical risks and renewable energy represents a novel avenue for future research.

Major channels through which geopolitical risks affect renewable energy development

Geopolitical risks can be considered a veritable source of economic instability and fears about the future and a threat to the flow of fossil fuels. By implication, they push countries that depend on fossil fuels towards working hard to eagerly seek alternative energy sources and achieve energy independence. Thus, geopolitical risks contribute significantly to inducing technological advances that would make renewable energy cheaper and widely available. Consequently, they can indirectly support sustainable development and reduce the harmful and hazardous effects of fossil fuels on the environment.

In this context, Uddin et al. (2019) pointed out that uncertainties in energy markets might potentially trigger off a decline in conventional energy prices, lowering the prices of clean energy assets that are the closest alternatives to oil assets. Owing to the steadily increasing geopolitical uncertainty, countries that lack fossil fuels are turning towards energy self-reliance and are using their available resources to generate clean energy in order to keep the wheels of their industries rolling and stay away from the edge of the collapse. Antonakakis et al. (2017) and Liu et al. (2019) confirmed that oil markets and clean energy markets are relatively close substitutes for each other and emphasized that changes in oil prices are highly sensitive to geopolitical tensions. Dutta and Dutta (2022) reported that rising geopolitical risks are driving crude oil importers to shift towards clean energy sources in order to replace traditional energy sources that are highly vulnerable to external shocks and out-of-control geopolitical conflicts.

National security goes hand in hand with access to energy. Maintaining energy security and achieving energy independence through investment in renewable energy have become more urgent than ever before. This could be put down to quite a number of factors. Russia–Ukraine war, persistent tensions between the West and Russia, and the closure of the Maghreb–Europe gas pipeline "MedGaz" linking Algeria to Spain via Morocco as a result of the severance of Algerian–Moroccan diplomatic relations are some of the most noteworthy ones. Similarly, tensions in the Middle East have been one of the overt contributory factors. Needless to say, the European Union has been a pioneer in launching several initiatives to phase out Russian fossil fuels and cut dependence on other oil and natural gas producing countries that have been using energy as a geopolitical weapon in order to safeguard their interests. The ambitious "European Green Deal" policy initiative that was launched on December 11, 2019 with the aim of promoting a renewables-based energy mix is one of the most prominent and most influential initiatives. It was put in place to boost the efficient use of available resources and financing tools, reach the investment levels required for the transition to a renewable resource economy, and put a brake on climate change (Panarello and Gatto 2023).

It is worth noting that when it comes to sustainable environment and climate change, the geopolitical risk is a double-edged sword. On the one hand, Anser et al. (2021) maintained that high geopolitical risks are associated with increased carbon dioxide emissions in the BRICS countries. On the other hand, Sweidan (2021a, b) and Dutta and Dutta (2022) emphasized that the exacerbation of geopolitical risks encourages the search for alternatives to fossil fuels and empowers countries to steadily move towards more environmentally friendly solution pathways and resort to green alternatives, thereby contributing to reducing carbon dioxide emissions and combating climate change.

We should highlight yet another equally important point, which is that crude oil and natural gas are depleting non-renewable assets and are mostly located in politically unstable countries that are highly exposed to geopolitical risks. This perforce entails that although it might take huge amounts of time to be fully implemented, the process of transitioning to renewable and sustainable energy sources is simply inevitable (Scholten 2018).

It is sensible to argue that the use of real-life examples is useful in shedding more light on the impact of geopolitical risks and conflicts on renewable energy deployment.

Conflicts and wars have led to widespread use of solar energy in conflict-stricken Arab countries and have fueled a solar power revolution that even stable Arab countries themselves have not witnessed. This giant stride would not have been achieved in normal circumstances, to say the least. Wars and conflicts have caused the collapse of old electricity systems and frequent power outages, have hindered fossil fuel supplies needed to generate electricity on a large scale, and have rendered them unaffordable. This has encouraged the spread of solar energy use in conflict-ridden Arab countries due to the need to adapt to new, uncongenial, and difficult conditions caused by conflicts. Vivid examples of the dominance of solar-generated electricity in domestic and agricultural use over electricity generated from fossil fuels that pollute the atmosphere are found in Somalia, Yemen, the Sahrawi refugee camps in Algeria, and Syria's northern Idlib province which is controlled by opposition forces (World Bank 2022a, b; Hubbard 2021).

Few studies have specifically dealt with the impact of geopolitical risks on renewable energy development. Sweidan's (2021a) study is a pioneering research work in this regard. Its uniqueness lies in the fact that it examined whether geopolitical risks stimulate energy independence and encourage reliance on renewable energy sources in the USA over the period 1973–2020. One of the key and prominent contributions of this research undertaking is that it endorsed the widely held view that geopolitical risks have a positive and significant effect on renewable energy development in the USA. Sweidan's (2021b) study focused directly on scrutinizing the impact of geopolitical risks on renewable energy deployment in 10 oil-importing countries over the period 1985–2017. One of this study's main findings is that geopolitical risks positively and significantly affect renewable energy deployment and development. The findings of Dutta and Dutta's (2022) study are well aligned with the fact that increasing geopolitical risks are driving crude oil importers to switch from their predominantly imported fossil fuel–based energy supplies to renewable energy sources. Similarly, Su et al. (2021) disclosed that geopolitical risks lead to an increase in renewable energy production and vice versa.

On the other hand, Flouros et al. (2022) investigated the effect of geopolitical tensions on renewable energy investments in 171 economies using the autoregressive distributed lag (ARDL) model. They concluded that geopolitical risks have a significantly measurable effect on green investments both in the short and long run. Appiah-Otoo (2021) emphasized that uncertainties stemming from geopolitical tensions seem to have an insignificant negative effect on renewable energy development in 20 countries over the period 2000–2018.

There are some other studies that dealt with the impact of geopolitical risks on renewable energy consumption, such as that of Alsagr and van Hemmen (2021), which analyzed the impact of geopolitical risks on renewable energy consumption in 19 emerging economies over the period 1996–2015. The obtained results patently demonstrated that geopolitical risks that create an atmosphere of chaos and uncertainty exert a positive and significant impact on renewable energy consumption.

In their study on renewable energy consumption in the USA, Cai and Wu (2021) concluded that geopolitical risks positively and significantly influence renewable energy consumption. They, likewise, confirmed that renewable energy development could be rightfully deemed as an ideal indispensable option for energy-poor countries.

Data and econometric methods

Data

This study uses annual time series data covering the time interval 1990–2020 for 3 MENAT oil-importing countries, namely, Egypt, Tunisia, and Turkey (see Fig. 2 in Appendix 1). The choice of this time period was mainly driven by data availability and, in particular, by data on renewable energy production that have been extracted from the OECD energy statistics database, which in turn covers the period from 1990 onwards. The OECD database was chosen because of its ability to offer the maximum number of observations compared to other databases such as the BP Statistical Review of World Energy that does not even include Tunisia and the International Energy Agency's (IEA's) Renewables 2021 dataset that is not available for free. We obtained data on geopolitical risks, financial development, and per capita gross domestic product from several data sources, such as Caldara and Iacoviello (2022), IMF's Financial Development Index database, and the World Bank's World Development Indicators database. More details regarding variables and data sources are provided in Table 5 in Appendix 2.

Estimation procedures

Autoregressive distributed lag (ARDL) bound testing approach

Cointegration tests are used to examine the existence of a long-run relationship between a dependent variable and a set of regressors. Conventional cointegration tests introduced by Engle and Granger (1987), Johansen (1988, 1991), and Johansen and Juselius (1990) require that the set of variables is integrated of the same order. Such fact constitutes an important limitation on these cointegration tests. Fortunately, this problem can be overcome by using the ARDL approach developed by Pesaran et al. (1996,

2001) and Pesaran et al. (1999). The crucial advantage of this approach is that it examines the long-run relationship between variables that are stationary at different levels after confirming that none of the series are integrated of the second order (Pesaran 2015). Another important advantage of this estimation method is that it provides robust and consistent results when dealing with small sample sizes; it also uses an unrestricted error correction model, and thus it has better statistical properties than the Engle–Granger cointegration test and provides better and more reliable results in small sample sizes than Engle–Granger and Johansen cointegration tests (Pesaran et al. 1999; Pesaran et al. 2001; Pesaran 2015). In an ARDL model, all variables can enter the right-hand side of the equation with different lags (Hill et al. 2018). Additionally, the ARDL approach tackles specific estimation-related issues such as serial correlation and endogeneity (Pesaran 2015).

This study applies the ARDL estimation technique because of its inherent benefits. Based on Pesaran et al. (1996, 2001) and Pesaran et al. (1999), we first use unit root tests in order to make sure that the variables are not integrated of order two $I(2)$, and then we apply the ARDL bounds test to detect cointegrating relations among the variables. If this test confirms the presence of a long-term cointegration relationship between the variables, we will employ the error correction model (ECM) to explore the short-term dynamic relationship. Then, we will apply some diagnostic and stability tests to investigate the goodness of the models.

Based on earlier contributions of Sweidan (2021a, b), our empirical model can be described by the following equation:

$$\mathrm{RE} = f\left(\mathrm{GPR}_t, \mathrm{FD}_t, \mathrm{GDP}_t\right) \tag{1}$$

where RE, GPR, FD, and GDP indicate renewable energy generation, geopolitical risk, financial development, and per capita gross domestic product, respectively.

Based on equation (1), the autoregressive distributed lag (ARDL) (p, q_1, q_2, q_3) model is specified in the following general form:

$$\begin{aligned}\Delta\mathrm{RE}_t &= a_0 + \sum_{i=1}^{p-1} a_{1i}\Delta\mathrm{RE}_{t-i} + \sum_{i=0}^{q_1-1} a_{2i}\Delta\mathrm{GPR}_{t-i} + \sum_{i=0}^{q_2-1} a_{3i}\Delta\mathrm{FD}_{t-i}\\ &\quad + \sum_{i=0}^{q_3-1} a_{4i}\Delta\mathrm{GDP}_{t-i} + b_1\,\mathrm{RE}_{t-1} + b_2\,\mathrm{GPR}_{t-1} + b_3\,\mathrm{FD}_{t-1}\\ &\quad + b_4\,\mathrm{GDP}_{t-1} + \varepsilon_t\end{aligned} \tag{2}$$

where Δ denotes the first difference operator, a_0 is the intercept, and ε_t is the error term and is assumed to be white noise. All variables are as previously defined. The parameters b_1, b_2, b_3, and b_4 are long-run multipliers. Lagged values of $\Delta\mathrm{RE}_t$ and current and lagged values of ΔGPR, ΔFD, and ΔGDP are used to model the short-run dynamics. The optimal lag length is selected based on the minimum Akaike information criterion (AIC) that takes the following form:

$$\mathrm{AIC} = \ln\left(\hat{\sigma}^2\right) + \frac{2k}{T}$$

where $\hat{\sigma}^2$ is the residual variance (also equivalent to the residual sum of squares divided by the number of observations), k is the total number of parameters estimated, and T is the sample size (Akaike 1974; Brooks 2014).

ARDL bounds test for cointegration Pesaran et al. (2001) proposed a test based on the F-statistic for the joint significance of lagged level variables in order to determine the existence of a long-run relationship among variables. This approach involves testing the null hypothesis of absence of a cointegration relationship: $H_0: b_1 = b_2 = b_3 = b_4 = 0$.

If the null hypothesis of no cointegration is rejected, then we must accept the alternative hypothesis of the existence of a long-run relationship: $H_1: b_1 \neq b_2 \neq b_3 \neq b_4 \neq 0$.

According to Pesaran et al. (2001), the asymptotic distribution of the F-statistic is non-standard under the null hypothesis of no cointegration among the variables, regardless of whether the variables are integrated of order zero $I(0)$ or one $I(1)$. As a result, the co-authors provided two sets of asymptotic critical values. One set represents the lower bound critical value and assumes that all variables are $I(0)$, and the other represents the upper bound critical value and assumes that all variables are $I(1)$. This is why this test is known as the bounds test. If the calculated F-statistic falls above the upper bound critical value, then the null hypothesis of no cointegration is rejected. In contrast, the null hypothesis is accepted if the calculated F-statistic is below the lower bound critical value. Otherwise, the results are inconclusive if the computed F-statistic lies between these two bounds.

Error correction model (ECM) After confirming the existence of a long-term relationship, the error correction model (ECM) can be derived straightforwardly from the ARDL model and specifically through a simple linear transformation that is able to integrate short-run dynamics with long-run equilibrium using the previously selected optimal number of lags as follows:

$$\begin{aligned}\Delta\mathrm{RE}_t &= a_0 + \sum_{i=1}^{p-1} a_{1i}\Delta\mathrm{RE}_{t-i} + \sum_{i=0}^{q_1-1} a_{2i}\Delta\mathrm{GPR}_{t-i}\\ &\quad + \sum_{i=0}^{q_2-1} a_{3i}\Delta\mathrm{FD}_{t-i} + \sum_{i=0}^{q_3-1} a_{4i}\Delta GDP_{t-i} + \lambda\,\mathrm{ECT}_{t-1} + \varepsilon_t\end{aligned} \tag{3}$$

where Δ is the first difference operator, a_0 is the intercept, a_1, a_2, a_3, and a_4 are the short-run dynamic coefficients, λ is the coefficient of the lagged error correction term (ECT), and ε_t is the error term. λ determines the speed of adjustment to the long-run equilibrium, and it is worthwhile to note that this coefficient must be negative and statistically significant, and its value must range from −1 to 0.

Diagnostic tests

Breusch–Godfrey LM test The Breusch–Godfrey test, also known as the Lagrange multiplier (LM) test, was developed by Breusch (1978) and Godfrey (1978) with the purpose of detecting higher order autocorrelation. It assumes that the error term ε_t follows a pth-order autogressive AR(p) scheme as follows:

$$\varepsilon_t = \rho_1\varepsilon_{t-1} + \rho_2\varepsilon_{t-2} + \cdots + \rho_p\varepsilon_{t-p} + \upsilon_t \tag{4}$$

The null hypothesis of no serial correlation to be tested is as follows:

$$H_0 : \rho_1 = \rho_2 = \cdots = \rho_p = 0 \tag{5}$$

The Breusch–Godfrey test involves the following steps:

1. Estimating the linear regression using OLS and obtaining the residuals e_t
2. Regressing the residuals e_t on all independent variables as follows:

$$\begin{aligned} e_t = a_0 + a_1x_{1t} + a_2x_{2t} + \cdots + a_kx_{kt} + \rho_1e_{t-1} \\ + \rho_2e_{t-2} + \cdots + \rho_pe_{t-p} + \upsilon_t \end{aligned} \tag{6}$$

3. Obtaining R^2 from this auxiliary regression
4. The Breusch–Godfrey LM test statistic is given by

$$(n-p)R^2 \sim \chi^2(p)$$

where n is the number of observations and p is the specified number of lags.

$(n-p)R^2$ follows a chi-square distribution with p degrees of freedom. If the test statistic exceeds the critical chi-square value at the chosen level of significance, the null hypothesis of no serial correlation is rejected (Gujarati 2004; Brooks 2008).

Heteroscedasticity test (ARCH) The ARCH (autoregressive conditional heteroscedasticity) test, originally proposed by Engle (1982), is a Lagrange multiplier test aimed at checking autoregressive conditional heteroscedasticity of the series.

The ARCH test involves the following steps:

1. Running the OLS regression and obtaining the residuals e_t.
2. Running an OLS regression of the squared residuals on p own lags in order to test for ARCH of order p as follows:

$$e_t^2 = \alpha_0 + \sum_{i=1}^{p} \alpha_i e_{t-i}^2 + v_t \tag{7}$$

where v_t is the error term.

3. Obtaining R^2 from this regression.
4. The test statistic is defined as nR^2 (the number of observations multiplied by the coefficient of R-squared) which is distributed as $\chi^2(p)$.
5. The null and alternative hypotheses are as follows:

$$H_0 : \alpha_1 = \alpha_2 = \cdots = \alpha_p = 0$$

$$H_1 : \alpha_1 \neq 0 \; or \; \alpha_2 \neq 0 \; or \ldots or \; \alpha_p \neq 0$$

If the value of the test statistic nR^2 is greater than the critical value of the χ^2 distribution, then the null hypothesis of no autoregressive conditional heteroscedasticity is rejected, confirming the presence of ARCH effects in the errors (Brooks 2008).

Jarque–Bera normality test The Jarque–Bera test is one of the most popular and straightforward tests for normality. The JB test statistic is given by the following:

$$\mathrm{JB} = \frac{n}{6}\left(\mathrm{skew}^2 + \frac{(\mathrm{kurt}-3)^2}{4}\right) \tag{8}$$

where n is the sample size, *skew* denotes the sample skewness, and kurt denotes the sample kurtosis.

The Jarque–Bera is a goodness-of-fit test statistic aimed at assessing whether the skewness and kurtosis of the series are consistent with those of the normal distribution. Under the null hypothesis of a normal distribution, the Jarque–Bera statistic has a χ^2 distribution with 2 degrees of freedom. It is worthwhile to note that every normal distribution has coefficients of skewness and kurtosis equal to 0 and 3, respectively. If the calculated chi-square value is greater than the critical value of the χ^2 distribution, then the null hypothesis of a normal distribution is rejected (Jarque and Bera 1980; Bera and Jarque 1981).

Ramsey RESET test Ramsey's regression equation specification error test (RESET), proposed by Ramsey (1969), is by far the most popular test used to verify the correctness of the model specification.

Ramsey RESET test involves the following three steps:

Table 1 Unit root tests results

	Egypt		Tunisia		Turkey	
	ADF	PP	ADF	PP	ADF	PP
GPR						
Level	−3.812141 (0.0071)***	−3.837795 (0.0066)***	−4.358559 (0.0018)***	−4.354028 (0.0018)***	−2.415779 (0.1461)	−2.353584 (0.1629)
1st difference	–	–	–	–	−6.628738 (0.0000)***	−7.751506 (0.0000)***
RE						
Level	−1.341515 (0.5969)	−1.376710 (0.5802)	−1.618030 (0.4613)	−1.385850 (0.5758)	−1.439653 (0.5496)	−1.488291 (0.5257)
1st difference	−7.063648 (0.0000)***	−7.253229 (0.0000)***	−8.416205 (0.0000)***	−8.375091 (0.0000)***	−4.584674 (0.0010)***	−4.627884 (0.0009)***
FD						
Level	−1.556669 (0.4918)	−1.561589 (0.4893)	−0.529776 (0.8716)	−0.529776 (0.8716)	−1.533543 (0.5033)	−2.047474 (0.2662)
1st difference	−5.145153 (0.0002)***	−5.144843 (0.0002)***	−6.350583 (0.0000)***	−6.350583 (0.0000)***	−6.716187 (0.0000)***	−6.788035 (0.0000)***
GDP						
Level	−3.609974 (0.0121)**	−3.062117 (0.0405)**	−2.555990 (0.1131)	−2.476625 (0.1309)	−5.745876 (0.0000)***	−5.997616 (0.0000)***
1st difference	-	-	−7.073563 (0.0000)***	−7.985745 (0.0000)***	-	-

All unit root tests include an intercept. Probability values are reported in parentheses. (***), (**), and (*) indicate that the estimated parameters are significant at the 1%, 5%, and 10% confidence levels, respectively

1. Estimating an initial regression model using OLS and retaining the estimated values of $\hat{y}_t$ as follows:

$$\hat{y}_t = \hat{a}_0 + \hat{a}_1 x_{1t} + \hat{a}_2 x_{2t} + \cdots + \hat{a}_k x_{kt} \tag{9}$$

2. Estimating the augmented equation by OLS as follows:

$$y_t = b_0 + b_1 x_{1t} + b_2 x_{2t} + \cdots + b_k x_{kt} + \phi_2 \hat{y}_t^2 + \phi_3 \hat{y}_t^3 + \cdots + \phi_h \hat{y}_t^h + v_t \tag{10}$$

3. Testing the null hypothesis $H_0 : \phi_2 = \phi_3 = \ldots = \phi_h$ using a standard restriction test such as the F- or Wald test. The null hypothesis is that the model is correctly specified. The acceptance of the null hypothesis indicates that the model does not suffer from misspecification problems (Ramsey 1969).

Stability tests

Brown et al. (1975) proposed two important tests for parameter instability. These tests, known as the CUSUM and CUSUMSQ tests, are based on recursive residuals that are used to test for structural change over time.

According to Brown et al. (1975), the CUSUM test is given by the following:

$$W_r = \sum_{t=k+1}^{r} w_t / \hat{\sigma} \text{ for } r = k+1, \ldots, n \tag{12}$$

where $\hat{\sigma}$ denotes the estimated standard deviation, k is the number of regressors, and n is the number of observations. W_r denotes the recursive residuals.

If W_r lies outside the interval defined by the two lines: $\left[K, \mp\sqrt{n-k}\right]$ and $\left[n, \mp 3\alpha\sqrt{n-k}\right]$ (with α =1.143, 0.948, and 0.850 at the 1%, 5%, and 10% levels, respectively), then there is evidence of some form of parameter instability. Whereas, the CUSUMSQ test is given by the following:

$$W_r^* = \sum_{t=k+1}^{r} w_t^2 / \sum_{t=k+1}^{n} w_t^2 \text{ for } r = k+1, \ldots, n \tag{13}$$

where W_r^* denotes the squared recursive residuals.

If W_r^* lies outside the interval $\left[\mp C \frac{(t-k)}{(n-k)}\right]$, where C is the Kolmogorov–Smirnov statistic, then there is evidence of some form of parameter instability.

Results and discussion

Unit root test results

Table 1 summarizes the results of the ADF and PP unit root tests for all variables in levels and first differences. The results

Table 2 ARDL bounds test results

	Model 1: Egypt	Model 2: Tunisia	Model 3: Turkey
Optimal lag structure	(1,1,3,2)	(1,1,2,2)	(1,1,1,2)
F-statistics	10.08650	5.528483	6.471863
K	3	3	3
	Critical values	Lower bounds *I*(0)	Upper bounds *I*(1)
	10%	2.37	3.2
	5%	2.79	3.67
	2.5%	3.15	4.08
	1%	3.65	4.66

k is the number of independent variables. Asymptotic critical values are obtained from Table CI(iii) in Pesaran et al. (2001)

show that the null hypothesis of a unit root (non-stationarity) is rejected at the level for the following variables: geopolitical risk (GPR) of Egypt and Tunisia, and the GDP of Egypt and Turkey, implying that these variables are stationary in their level form. While, the null hypothesis of a unit root cannot be rejected for all remaining variables in levels; the findings reveal that these variables become stationary after taking first differences. The next step is to proceed with the ARDL bounds test that is used to examine the presence of a long-run association among variables due to its authenticity and accuracy.

Table 2 illustrates the optimal lag orders chosen based on the Akaike information criterion (AIC) and presents the results of the ARDL bounds test with appropriate critical values and estimated *F*-statistics. The findings indicate that calculated *F*-statistics in the three models are higher than the upper bound critical value *I*(1) at the 1%, 2.5%, 5%, and 10% significance levels, confirming the rejection of the null hypothesis of no cointegration in favor of the alternative hypothesis of cointegration. The next step is to determine the long-run and short-run elasticities.

Table 3 shows the short-run and long-run relationships between variables in the three models. In the long run, geopolitical risk (GPR) positively and significantly affects renewable energy generation in the three countries, confirming what have been reported by Sweidan (2021a, b), Dutta and Dutta (2022), and Su et al. (2021). An increase of 1% in geopolitical risk (GPR) sparks an 8.07%, 10.84%, and 2.05% increase in renewable energy production in Egypt, Tunisia, and Turkey, respectively. This can be explained by the fact that heightened geopolitical risks provide a strong impetus for the development of renewable energy sources. It is worth noting that geopolitical risks are rising in Tunisia, owing to a multitude of political and economic failures, security threats, and the continuing infighting among groups jockeying for post-Qaddafi era in Libya. Tunisia is suffering in such a hostile geopolitical environment.

According to the regression results reported in columns (a), (b), and (c) of Table 3, financial development (FD) appears to positively and significantly affect renewable energy generation in the three countries; this is consistent with the results of Shahbaz et al. (2021) and Khan et al. (2021). In fact, high financial development provides renewable energy investors with much needed start-up funds and plays an undeniably crucial role in facilitating a smooth transition to renewable energy. An increase of 1% in financial development (FD) leads to an increase of 25.37%, 4.01%, and 29.07% in renewable energy generation in Egypt, Tunisia, and Turkey, respectively. It is worthwhile to note that Turkey has made major strides in accelerating financial sector development compared with Egypt and Tunisia.

As can be readily seen in columns (a), (b), and (c) of Table 3, GDP per capita is positively and significantly linked to renewable energy generation in the three countries. This result matches well with the results of Pfeiffer and Mulder (2013), Aguirre and Ibikunle (2014), and Abban and Hasan (2021); higher GDP per capita indicates the availability of wealth to cope with renewable energy costs and motivate renewable energy deployment. An increase of 1% in GDP generates an increase of 0.45%, 0.02%,

Table 3 ARDL long-run and short-run results

	(a): Egypt	(b): Tunisia	(c): Turkey
Long-run coefficients			
GPR	8.070627 (0.0416)**	10.84574 (0.0220)**	2.058531 (0.0001)***
FD	25.37523 (0.0003)***	4.013044 (0.0379)**	29.07555 (0.0698)*
GDP	0.451017 (0.0444)**	0.021461 (0.0004)***	0.679678 (0.0217)**
Constant	13.58670 (0.0001)***	15.63545 (0.0415)**	8.225663 (0.0094)***
Short-run coefficients			
ΔGPR	5.127020 (0.0031)***	1.589573 (0.0112)**	6.622424 (0.0018)***
ΔFD	7.328378 (0.0396)**	0.679678 (0.0001)***	12.91168 (0.0126)**
ΔGDP	0.267941 (0.0000)***	0.237369 (0.0880)*	0.103671 (0.0014)***
The error correction term (ECT_{-1})	−0.367856 (0.0000)***	−0.660392 (0.0000)***	−0.178163 (0.0000)***

Dependent variable is renewable energy (RE). Probability values are reported in parentheses. The asterisks (*), (**), and (***) indicate that the estimated coefficients are statistically significant at the 10%, 5%, and 1% significance levels, respectively

Table 4 Diagnostic tests of ARDL models

	Model 1: Egypt		Model 2: Tunisia		Model 3: Turkey	
	F-version	χ^2 version	*F*-version	χ^2 version	*F*-version	χ^2 version
Breusch–Godfrey LM test	0.145402 (0.8656)	0.437167 (0.8037)	0.356645 (0.7046)	1.013129 (0.6026)	1.063533 (0.3649)	2.819031 (0.2443)
Jarque–Bera normality test	-	0.227778 (0.892357)	-	3.380967 (0.184430)	-	1.111888 (0.573531)
Heteroscedasticity test (ARCH)	0.042895 (0.8375)	0.046119 (0.8300)	1.872430 (0.1523)	8.168130 (0.1472)	1.000351 (0.3268)	1.038812 (0.3081)
Ramsey RESET test	0.924407 (0.3590)	-	0.907736 (0.3516)	-	0.816262 (0.3827)	-

The probability value is given in parentheses below the test statistic

and 0.67% in renewable energy production in Egypt, Tunisia, and Turkey, respectively.

In the short run, geopolitical risk (GPR) exerts a significant positive impact on renewable energy generation in the three countries. An increase of 1% in geopolitical risk (GPR) causes the renewable energy production to increase by 5.12%, 1.58%, and 6.62% in Egypt, Tunisia, and Turkey, respectively. In fact, Turkey has emerged as a major swing player in the protracted Russia–Ukraine war and has prioritized the diversification of energy resources in the face of heavy dependence on foreign energy supplies. Turkey truly looks eager to monetize its renewable energy potential.

As shown in columns (a), (b), and (c) of Table 3, financial development (FD) has a significant positive impact on renewable energy production in the three MENAT oil-importing countries, confirming that a rapid growth in renewable energy generation can be driven by financial development. An increase of 1% in financial development (FD) causes the renewable energy production to increase by 7.32%, 0.67%, and 12.91% in Egypt, Tunisia, and Turkey, respectively. In the short run, Turkey's financial sector can step up its role in mobilizing capital for the development of clean and renewable sources of energy and unlocking renewable energy investments (World Bank 2022c).

Columns (a), (b), and (c) of Table 3 indicate that renewable energy production is positively and significantly affected by GDP in the three countries. An increase of 1% in GDP generates an increase of 0.26%, 0.23%, and 0.10% in Egypt, Tunisia, and Turkey, respectively.

According to the results shown in columns (a), (b), and (c) of Table 3, the coefficient of the error correction term (ECT) is negative and statistically significant in the three models, confirming the consistency of the ARDL models. Furthermore, the error correction term (ECT) approves the long-run relationship between renewable energy generation and independent variables in the three countries and indicates that the speeds of adjustment towards the long-run equilibrium are 36.78%, 66.03%, and 17.81% annually in Egypt, Tunisia, and Turkey, respectively.

A variety of diagnostic tests have been used to confirm that there are no issues of serial correlation, heteroskedasticity, and omitted variable bias in the three models. The results of these diagnostic tests are shown in Table 4.

According to the results shown in Table 4, the Breusch–Godfrey serial correlation LM test indicates that there is no serial correlation in residuals in the three models as the *p*-value is greater than 0.05 in the three ARDL estimations. The results of the Jarque–Bera normality test indicate that residuals are normally distributed in the three models as the null hypothesis of normal distribution of the residuals cannot be rejected (because all corresponding *p*-values are greater than 0.05). The ARCH results conclude the absence of heteroscedasticity in the residuals in the three models as all corresponding p-values are greater than 0.05. Furthermore, the Ramsey RESET test is used to check for misspecification of the models, and it is concluded that the three ARDL models are correctly specified as all corresponding *p*-values are greater than 0.05. In fact, the three ARDL models have successfully passed all diagnostic tests.

In order to check the robustness and stability of estimated ARDL models, the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) tests have been used. A visual representation of CUSUM and CUSUMSQ is provided in Fig. 1.

As shown in Fig. 1, the plots of CUSUM and CUSUMSQ statistics stay within the critical bounds of the 5% significance level (represented by the pair of straight lines drawn at the 5% significance level), indicating the stability of the three models. To sum up, all these tests reflect the validity and reliability of the results which in turn confirm that geopolitical risks play a crucial role in inducing renewable energy development in MENAT oil-importing countries in the short and long run.

Conclusion

The present study found that geopolitical risk positively and significantly affects renewable energy generation in the three countries in the long run. An increase of 1% in geopolitical risk sparks an 8.07%, 10.84%, and 2.05% increase in renewable energy production in Egypt, Tunisia, and Turkey,

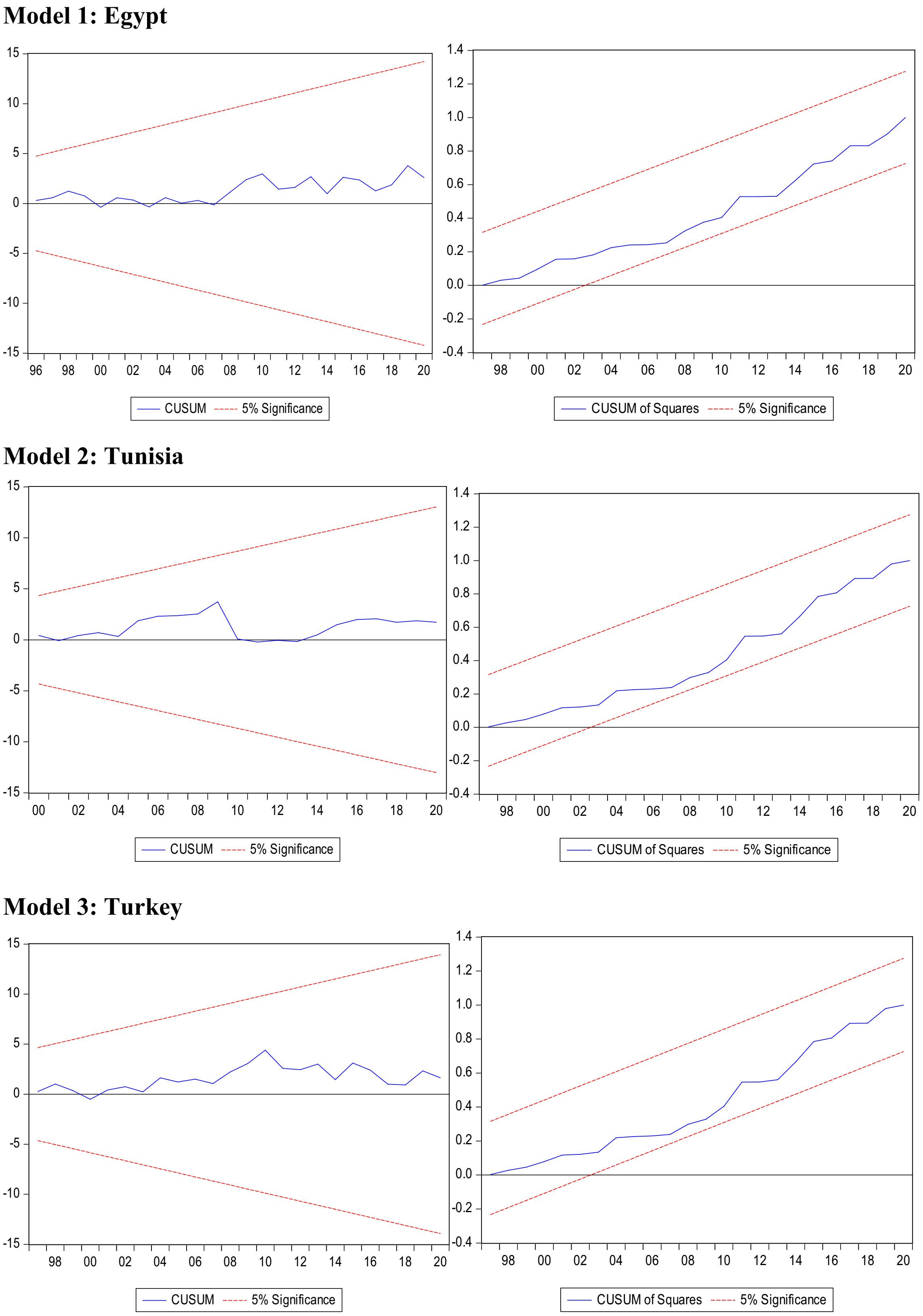

Fig. 1 Plots of CUSUM and CUSUMSQ of recursive residuals. The straight lines represent critical bounds at the 5% significance level

respectively. In the short run, the geopolitical risk exerts a significant positive impact on renewable energy generation in the three countries. An increase of 1% in geopolitical risk causes renewable energy production to increase by 5.12%, 1.58%, and 6.62% in Egypt, Tunisia, and Turkey, respectively.

Equally importantly, the present paper has demonstrated that exacerbated geopolitical risks constitute a strong motive to work towards achieving energy independence and prove to be a powerful incentive to promote renewable energy generation and phase out fossil fuels.

Although it is genuinely undeniable that the path towards renewable energy is long, difficult, and almost always fraught with an endless array of obstacles, what is even more difficult and far more perilous is to procrastinate on critical reforms, put off implementing agreed-upon programs to exploit renewable energy sources, thwart renewable energy investment, and incessantly delay the task of promoting renewables to subsequent governments.

Based on this set of interesting finding, the following recommendations are made:

- It is incumbent upon the governments of MENAT oil-importing countries to involve the private sector in the development of renewable energy sources right from the outset and encourage it to responsibly contribute to the continuous development and implementation of renewable energy technologies. These countries ought to strengthen their preparedness by providing additional tax benefits to renewable energy-related patent holders and companies that use renewable energy and develop clean energy technologies.
- MENAT oil-importing countries are in dire need of obtaining international funding to make significant strides towards the transition to renewable energy sources.
- Progress in renewable energy development in MENAT oil-importing countries can be best achieved by intensifying cooperation at both regional and international levels, as the outstanding fructuous cooperation provides a common platform for strengthening the exchange of experience and best practices and re-equipping cadres and increasing their qualifications.
- The governments of MENAT oil-importing countries ought to encourage and promote the manufacture and use of electric cars and various public transportation modes fueled by solar-generated electricity.
- Future research on this topic can extend the existing limited sample of countries when/if the Caldara and Iacoviello geopolitical risk (GPR) index is expanded to include more countries in the foreseeable future.

Future in-depth case studies can also cast more light on investments in renewable energy infrastructure that could give a strong impetus to the renewable energy sector in countries where the share of renewables in the energy mix is still low. Future studies can, likewise, shed light on the role of the great powers in triggering off relentless geopolitical conflicts with the hidden aim of controlling the flow of oil and natural gas instead of laying out an ambitious roadmap to reduce carbon dioxide emissions and help curb the planet-threatening menace of runaway global warming.

Appendix 1

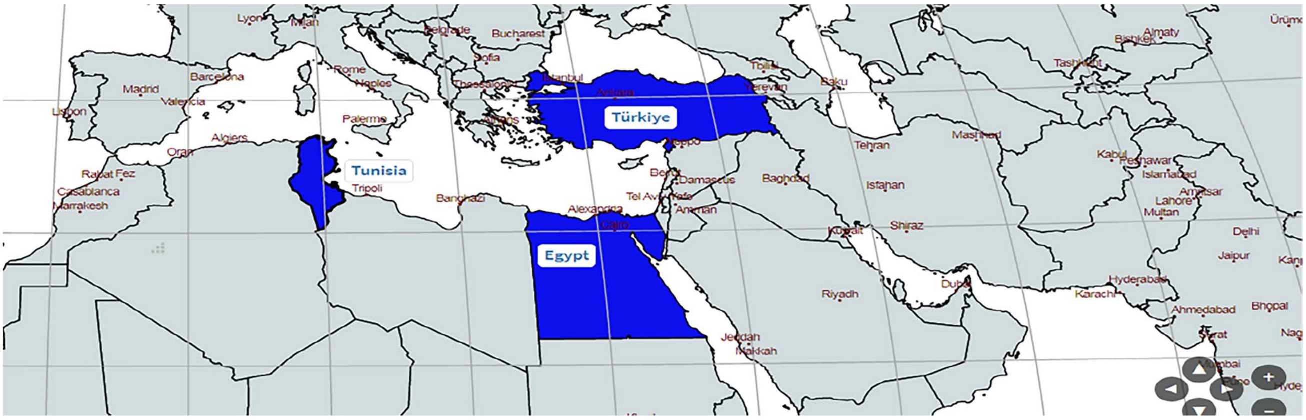

Fig. 2 The sample of countries under study. Source: https://www.mapchart.net/

Appendix 2

Table 5 Variable descriptions and data sources

Variable	Description and data source
RE	Renewable energy (RE) which is directly measured by the percentage contribution of renewables to total primary energy supply. Data Source: OECD energy statistics database https://data.oecd.org/energy/renewable-energy.htm
GPR	The geopolitical risk index developed by Caldara and Iacoviello (2022). Data Source: Caldara and Iacoviello (2022) https://www.matteoiacoviello.com/gpr_country.htm#country
FD	The Financial Development Index summarizes how developed financial institutions and financial markets are in terms of their depth (size and liquidity), access (ability of individuals and companies to access financial services), and efficiency (ability of institutions to provide financial services at low cost and with sustainable revenues and the level of activity of capital markets). Data Source: IMF's Financial Development Index database https://data.imf.org/?sk=F8032E80-B36C-43B1-AC26-493C5B1CD33B
GDP	Per capita gross domestic product. Data Source: World Development Indicators database https://data.worldbank.org/country

Acknowledgements The authors would like to express their sincere appreciation and thanks to the Editor Pr. Roula Inglesi-Lotz and anonymous referees for their helpful comments and suggestions that have greatly helped to improve the paper.

Author contribution Siham Matallah (the corresponding author): supervision, conceptualization, methodology, software, validation, formal analysis, data curation, writing—original draft, writing—review and editing, visualization. Amal Matallah: methodology, software, validation, formal analysis, data curation, writing—review and editing. Nathalie HILMI: review and editing.

Data availability Data and material will be made available upon request.

Declarations

Ethical approval and consent to participate The authors declare that this study does not involve human participants, human data, or human tissue.

Consent for publication The authors declare that they do not have any individual's personal data in any form.

Competing interests The authors declare no competing interests.

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