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Renewable energy, energy efficiency, and economic complexity in the middle East and North Africa: A panel data analysis

Vahid Mohamad Taghvaee [a,*], Behnaz Saboori [b], Susanne Soretz [c], Cosimo Magazzino [d,e], Moosa Tatar [f]

[a] Business School, University of Mannheim, Mannheim, Germany
[b] Department of Natural Resource Economics, College of Agricultural and Marine Sciences, Sultan Qaboos University, Muscat, Oman
[c] Chair of Economic Growth, Structural Change and Trade, University of Greifswald, Germany
[d] Department of Political Science, Roma Tre University, Rome, Italy
[e] Economic Research Center, Western Caspian University, Baku, Azerbaijan
[f] Department of Pharmaceutical Health Outcomes and Policy, University of Houston, Houston, TX, USA

A R T I C L E I N F O

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A B S T R A C T

This paper aims to investigate how economic complexity and structural transformation affect energy security. This study differs from previous research by focusing on energy efficiency and renewable energy transition as indicators of energy security. The employed methods include econometric techniques such as Panel-Corrected Standard Errors, Driscoll and Kraay's Spatial Correlation Consistent (SCC) method, and Generalized Least Squares, covering data from the Middle East and North Africa (MENA) countries between 1990 and 2017. The results show that economic complexity has a negative effect on energy efficiency but a positive impact on renewable energy. However, economic growth positively affects energy efficiency but negatively influences renewable energy. These results imply that economic complexity is energy-intensive but green, whereas economic growth is energy-saving but brown. The comparative analysis reveals that the negative effects of economic complexity and growth are larger than their positive effects, highlighting the necessity of restructuring economic activities and sectors. Accordingly, decision-makers should encourage the utilization of more energy-efficient technologies in economic activities and production, while promoting renewable energy consumption to enhance energy security in the MENA region.

1. Introduction

In recent years, climate change, resource scarcity, and energy security have made energy efficiency increasingly important [1,2]. Energy efficiency has become a key means of reducing greenhouse gas (GHG) emissions, conserving energy resources, and boosting economic productivity, which are essential components of sustainability [3–5]. Energy efficiency plays a vital role in achieving Sustainable Development Goals (SDGs), allowing countries to meet economic and social objectives (Omri et al., 2024) while reducing energy consumption [6–8,]. The global community has recognized the significance of energy efficiency, as evident in the United Nations' SDG 7.3, which aims to double energy efficiency improvement rates worldwide by 2030 [9,10]. However, despite this commitment, the rate of improvement in energy efficiency has fallen short of the 2.6 % annual target required to achieve SDG 7.3, with only a meager improvement of 0.8 % in global primary energy intensity in 2020 (Tracking SDG7 Report, 2021). To meet the goal, an average annual rate of 3 % is necessary from 2018 through 2030.

To mitigate the detrimental effects of the energy sector on the environment and security, countries have redirected from pure economic growth to economic complexity focusing more on knowledge and innovation [11,12]. Economic complexity refers to the variety and sophistication of economic activities within a country or region. Economic complexity reduces energy consumption and its environmental dangers by developing energy-efficient technologies as a result of promoting further research and development. In this way, economic complexity can increase energy efficiency [13–15]. In addition, countries with higher complexity have a larger share of knowledge-based products

* Corresponding author.
E-mail addresses: vahidestan@yahoo.com (V. Mohamad Taghvaee), b.saboori1@squ.edu.om (B. Saboori), soretz@uni-greifswald.de (S. Soretz), cosimo.magazzino@uniroma3.it (C. Magazzino), mtatar@uh.edu (M. Tatar).

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instead of energy-consuming production. This point is particularly cogent when it comes to energy-producing states such as the Middle East and North Africa (MENA) countries with inexpensive and high access to fossil fuels. To replace fossil fuels, economically complex regions assess more advanced technologies for diversification of their own energy portfolios to increase the share of renewable energies [16–18]. Consequently, economic complexity can both promote renewable energy and improve energy efficiency.

However, economic complexity and growth can reduce renewable energy and energy efficiency through various channels [19–21]. For example, it can cause technological lock-in where network impacts, path dependence, and regulatory capture pave the way for the adoption of specific infrastructure and technologies with an energy-inefficient and intensive nature [22–24]. In addition, the rapid growth of economic complexity may outpace the current energy infrastructure decreasing energy inefficiency of the production process. Moreover, economic complexity may reduce the energy efficiency of the global supply chain by extending distances between more diverse materials in different regions, which requires further transportation and energy consumption. This increase in energy demand stimulates further consumption of fossil fuel as more inexpensive and accessible energy in the short-run, leading to a reduction in the share of renewable energy; in fact, this needs a long-run horizon to reach high accessibility and low cost [25–27]. Therefore, economic complexity may decrease energy efficiency and the share of renewable energy, damaging the environment and energy security in countries with high economic complexity.

These conflicting views on economic complexity complicate the understanding of how it affects energy efficiency and renewable energy, necessitating further exploration, especially in countries with high capacity of fossil fuel energy like the MENA region. Although many countries in this area have developed strategies to boost their economies via the promotion of economic complexity, the implementation can differently and ambiguously impact renewable energy and energy efficiency. The MENA region has traditionally experienced brown economic growth, heavily dependent on the export of fossil fuels for its economic development. However, in recent years, many MENA countries have recognized the need to diversify their economies and reduce their dependence on fossil fuels. This shift necessitates a structural transformation and the adoption of energy efficiency measures. To achieve an energy-efficient growth structure, they should focus on energy-efficient development and technologies in the economic sectors. Additionally, they should develop their economic complexity, which refers to the diversity and sophistication of their economic activities.

Energy efficiency and economic complexity stand as two pillars vital for the sustainable development of MENA countries. In this diverse region, characterized by abundant natural resources like oil and gas, optimizing energy use is paramount to ensure long-term prosperity and mitigate environmental degradation [28]. Energy efficiency measures encompass a spectrum of strategies ranging from technological advancements to policy frameworks aimed at reducing energy consumption while maintaining or enhancing productivity. MENA nations, with their burgeoning populations and expanding economies, face the dual challenge of meeting rising energy demand and curbing greenhouse gas emissions. Therefore, embracing energy efficiency not only conserves valuable resources but also fosters economic resilience and environmental sustainability.

The economic complexity of MENA countries, on the other hand, denotes the intricacy and diversity of their industrial structures and exports. While endowed with significant oil and gas reserves, many nations in the region recognize the vulnerability of their economies to fluctuations in global energy markets. Hence, fostering economic complexity through diversification becomes imperative for long-term stability and growth. Energy efficiency initiatives play a pivotal role in this diversification process by unlocking opportunities for innovation and investment in renewable energy, manufacturing, and services sectors. By reducing reliance on fossil fuels and promoting cleaner technologies, MENA nations can enhance their economic resilience and competitiveness in a rapidly evolving global landscape.

Challenges abound in the pursuit of energy efficiency and economic complexity in MENA countries. Despite the region's vast renewable energy potential, including solar and wind resources, the transition towards a sustainable energy future requires substantial investments in infrastructure and human capital. Moreover, entrenched interests in the fossil fuel industry, coupled with institutional inertia and bureaucratic hurdles, often impede progress towards energy efficiency targets. Similarly, diversifying economies away from hydrocarbon dependency demands bold policy reforms, targeted investments, and concerted efforts to develop nascent industries and value chains.

Nevertheless, several MENA countries have embarked on ambitious energy efficiency and economic diversification initiatives, leveraging their unique strengths and resources. The United Arab Emirates (UAE), for instance, has emerged as a global leader in renewable energy deployment, with ambitious targets to increase the share of clean energy in its total energy mix. Through initiatives like the Masdar City project and investments in solar power plants, the UAE aims to not only reduce its carbon footprint but also position itself as a hub for green technology and innovation.

Similarly, Saudi Arabia, the largest economy in the region, has unveiled Vision 2030, a comprehensive blueprint for economic transformation and diversification. Central to this vision is the development of renewable energy sources, including solar and wind, to meet growing domestic demand and create new employment opportunities. By investing in renewable energy projects and fostering partnerships with international stakeholders, Saudi Arabia seeks to reduce its reliance on oil exports and foster a more sustainable and inclusive economy.

This paper aims to address the influence of economic complexity on energy security, particularly in the context of renewable energy adoption and energy efficiency. The transition to renewable energy and energy efficiency plays a crucial role in enhancing energy security and mitigating climate change. Thus, this study explores the impact of economic growth, economic complexity, and oil prices on renewable energy and energy efficiency, while also incorporating industry share as an indicator of structural transformation in the analysis. Unlike previous research, this study focuses on energy efficiency and renewable energy transition as key indicators of energy security and examines the role of economic complexity in shaping these factors. By including structural transformation as an additional dimension in the empirical investigation, the paper seeks to provide valuable insights for policymakers and businesses aiming to foster sustainable economic growth and enhance energy security.

The research contributes to the literature investigating the influence of economic complexity on the transition to renewable energy and energy efficiency, which are essential components of energy security and SDGs. While many studies have examined the effect of economic complexity on environmental degradation so far, only a few have explicitly explored its impact on energy efficiency and renewable energy adoption. This paper aims to fill this gap by analyzing the effect of economic growth, economic complexity, and oil prices on renewable energy and energy efficiency, while also considering industry share as an indicator of structural transformation. The study can also provide valuable insights into the role of economic complexity in promoting the transition to renewable energy and energy efficiency, which can inform policymakers and stakeholders in developing effective strategies for sustainable development.

The remaining sections of the paper are structured as follows. To provide a comprehensive understanding of the research area, Section 2 presents a review of the relevant literature. Section 3 describes the data used, the model employed, and the methodology applied in the study. Section 4 presents the empirical results, while Section 5 discusses the implications of the paper's findings for policy. Finally, Section 6 provides the conclusions.

2. Literature review

Several studies in the literature have explored the concept of economic complexity and its environmental, social, and economic impacts. An expanding body of research indicates that directing investments towards more complex and less ubiquitous goods can enhance a country's prospects for economic growth, while also recognizing the significance of physical assets, human capital, and institutional arrangements [29–31]. Recently, some papers contributed to the understanding of the influence of economic complexity on various aspects, such as economic growth [32], income inequality [33,34], national health [35], human development [36], gender equality [37], environmental degradation [38–40], natural resource rents [41], and energy consumption [42].

A cluster of studies focused on scrutinizing the influence of economic complexity on environmental degradation, yielding mixed results. Ali et al. [43] investigated the impact of economic complexity on ecological footprint in China, revealing that energy innovation and economic complexity have a positive short- and long-term effect on reducing ecological footprint. Yilanci and Pata [44] examined the effect of economic complexity and energy consumption on the ecological footprint in China, finding that both factors positively influence the ecological footprint. Conversely, Can and Gozgor [45] reported that economic complexity amplifies carbon dioxide (CO_2) emissions in France. Doğan et al. [38] disclosed that economic complexity spurs environmental degradation in lower- and higher-middle-income countries but curbs CO_2 emissions in high-income countries. Lapatinas et al. (2019) revealed that economic complexity decreases the aggregate indicators of environmental pollution while increasing some indicators of air quality indicators in 88 developing and developed countries. Neagu and Teodoru [46] determined that an increase in economic complexity elevates GHG emissions in both low- and high-economic complexity EU countries. Swart and Brinkmann [47] demonstrated that economic complexity heightens forest fires, diminishes waste generation, and has no bearing on deforestation and air pollution in Brazil. Magazzino [48] analyzed the relationship among ecological footprint, electricity consumption, and Gross Domestic Product (GDP) in China using annual data ranging from 1960 to 2019, highlighting that electricity consumption and real GDP increase environmental degradation, while trade and urbanization reduce the ecological footprint.

Despite numerous studies investigating the relationship between economic complexity and environmental degradation, there is still a gap in understanding the specific effects of economic complexity on energy efficiency and renewable energy adoption. While some research focused on environmental indicators such as ecological footprint and CO_2 emissions, only a few explicitly examined the impact of economic complexity on the transition to renewable energy and energy efficiency.

3. Theoretical framework

To achieve green growth, many countries are now adopting renewable and clean energy sources to improve energy efficiency [49–51]. To this end, they generate significant structural changes and introduce technological innovations [52,53]. The shift towards renewable energy is mainly driven by concerns about climate change, reducing dependence on foreign fossil fuels, and securing energy supplies amidst changing global energy markets [54,55]. Although the transition to renewable energy poses challenges, many countries consider it a vital approach to ensure long-term energy security while reducing their carbon footprint [56–59]. Even though this transition slowly progresses, as evidenced by the 1.4 % increase in CO_2 emissions in 2017 after maintaining steady levels for three years [36,56,60], it is strongly expected to increase energy efficiency and renewable energy.

Countries implement these initiatives by focusing on economic complexity with an energy-saving feature. Complexity refers to the range and diversity of economic activities within a region or country, which can influence the efficiency of energy use and the adoption of renewable energy sources. Countries with higher economic complexity are adopting knowledge-intensive technologies, which facilitate renewable energy generation and more efficient energy use, thereby contributing to environmental quality [61–64]. Such economies with energy-efficient technologies have energy-saving complexity. Incentives to promote renewable energy technologies have resulted in the expansion of renewable energy sources and the development of electricity infrastructures, stimulating the creation of smart grid systems and enabling more energy-efficient processes (Sampaio et al., 2018; [65]). These economies with a high share of renewable energy have green complexity.

The analysis proposes the following two research hypotheses.

Hypothesis 1. Economic complexity increases energy efficiency.

Hypothesis 2. Economic complexity increases renewable energy.

4. Model's specification

This study uses a panel dataset including 22 countries in the MENA region to estimate how economic complexity affects energy intensity and renewable energy consumption between 1990 and 2017.

Following Lee and Ho [66] and Zhou et al. [67], this research estimates the effect of economic complexity on energy intensity as summarized in Equation (1) [66]:

$$EI_{it} = C + \alpha_1 EC_{it} + \alpha_2 PO_{it} + \alpha_3 Y_{it} + \varepsilon_{it} \tag{1}$$

where EI is the energy intensity, measured as the proportion of energy supply in Megajoules (MJ) to GDP in Purchasing Power Parity (2017 US Dollar in PPP); EC is the economic complexity; PO is the oil price measured as US dollars per barrel; Y is the GDP at constant 2015 US Dollar; C is the intercept; ε is the residuals' series; α are the parameters; i gives the cross-section dimension; and t is for the time dimension. If α_1 is negative, Hypothesis 1 is not rejected.

Equation (2) follows Kazemzadeh et al. [68], Lee and Ho (2023), and Numan et al. [69] to estimate the impact of economic complexity on renewable energy:

$$RE_{it} = C + \beta_1 EC_{it} + \beta_2 PO_{it} + \beta_3 Y_{it} + \varepsilon_{it} \tag{2}$$

where RE is renewable energy consumption measured in Exajoules and β s are the parameters. If β_1 is positive, Hypothesis 2 is not rejected.

Furthermore, this research follows Taghvaee et al. [70], considering a sector-wise analysis by adding different sector value-added variables into Equations (1) and (2) to specify Equations (3) and (4):

$$EI_{it} = C + \theta_1 EC_{it} + \theta_2 PO_{it} + \theta_3 IN_{it} + \theta_4 SE_{it} + \theta_5 AG_{it} + \varepsilon_{it} \tag{3}$$

where IN, SE, and AG are industry, services, and agriculture value added, respectively, as a percentage of GDP; and θ are the parameters. If θ_1 is negative, Hypothesis 1 is not rejected.

$$RE_{it} = C + \gamma_1 EC_{it} + \gamma_2 PO_{it} + \gamma_3 IN_{it} + \gamma_4 SE_{it} + \gamma_5 AG_{it} + \varepsilon_{it} \tag{4}$$

where γ are the parameters. If γ_1 is positive, Hypothesis 2 is not rejected.

All the variables are in natural logarithms, except for EC which shows a lower range of fluctuations compared with other variables.

The estimated coefficients of economic complexity in these equations represent the relationships of this variable with energy intensity and renewable energy consumption. In addition, the estimated coefficients of economic sectors in Equations (3) and (4) show the relationships of each economic sector with energy intensity and renewable energy.

Economic complexity and growth are energy-saving if complexity and GDP with its disaggregated sectors have a negative relationship with energy intensity; otherwise, they are energy-intensive. The economic complexity and growth are green if complexity and GDP with its disaggregated sectors have a positive effect on renewable energy; otherwise, they are brown. The concept of brown growth is adopted following

Shirazi et al. [71], who revealed that oil-exporting countries have brown growth at initial levels of the growth process, but green growth at later steps. In addition, these relationships are comparable with each other since the coefficients are in natural logarithms, and they can be interpreted as elasticities.

5. Estimation techniques

Before the estimations phase, the stationarity of the variables is examined using the Cross-section Augmented Dickey–Fuller (CADF) test, which is a second-generation unit root test [72]. Here, cross-sectional dependence is considered in accordance with one single common factor existing among all the states impacting the variables of the model. This test is advantageous since it does not need to estimate the factor. Instead, the test uses the cross-section means of the lagged levels in addition to the first difference of the variable according to the following CADF regression in Equation (5) [72,73]:

$$\Delta y_{it} = \alpha_i + b_i y_{i,t-1} + c\bar{y}_{t-1} + d_i \Delta \bar{y}_t + e_{it} \tag{5}$$

where y is the tested variable, $\bar{y}_{t-1}$ represents the cross-section mean of the lagged values of y, $\Delta\bar{y}_t$ denotes the first difference of the cross-section mean of y. Equation (5) estimates the t-statistics of b_i to check the null hypothesis.

After checking the stationarity of the variables, the eventual presence of a long-run relationship between the variables is analyzed through the Kao [74] cointegration test. This test is based on the Engle-Granger approach and follows the Pedroni [75] cointegration test to allow heterogeneous intercepts as well as the existence of trend coefficients across the cross-section. However, the first stage regression presumes a certain intercept and homogenous coefficients across sections [76–79]. Equation (6) represents a bivariate Kao's model [80]:

$$Y_{it} = \alpha_i + bx_{it} + c_{it} \tag{6}$$

where $Y_{it} = y_{i,t-1} + u_{it}$, $x_{it} = x_{i,t-1} + v_{it}$, $t = 1, \ldots, T; i = 1, \ldots, N$. This model can conduct the first stage regression. Kao's techniques examine the residual series using a mix of auxiliary regressions [74].

Finally, Equations (1)–(4) are estimated using the Panel-Corrected Standard Errors (PCSE) estimator, the Driscoll and Kraay's method [81,82], and the Generalized Least Squares (GLS) estimator [82]. PCSE may produce inaccurate results for data with a short time dimension; however, it can reach reliable estimates even in the presence of contemporaneous correlation and heteroskedasticity in panel data [83,84]. Driscoll and Kraay's method may produce biased results if it disregards the cross-sectional correlation of the variables. In other words, it can produce accurate estimates when associated with a large number of cross-sectional units [85]. For this reason, the study examines the cross-sectional dependence. However, this method creates highly reliable results if cross-sectional dependence exists. Although GLS has some challenges in precisely estimating covariance structure in small samples, the dataset that we collected covers more than 500 observations enabling the method to provide valid results. The GLS estimator is reliable when the Ordinary Least Squares (OLS) estimator is found not to be the Best Linear Unbiased Estimator (BLUE) because of heteroskedasticity and serial correlation [86].

6. Data collection

All the data is derived from the World Development Indicators (WDI) by the World Bank [87], except for the economic complexity, which is collected from the Observatory of Economic Complexity (2021). The sample includes Algeria, Azerbaijan, Egypt, Georgia, Iran, Israel, Jordan, Kuwait, Lebanon, Libya, Mauritania, Morocco, Oman, Pakistan, Qatar, Saudi Arabia, Sudan, Syria, Tunisia, Turkey, United Arab Emirates, and Yemen. Table 1 gives the symbols, definitions, units, and sources of each variable. Table 2 provides the relevant descriptive statistics. Fig. 1 reports the scatterplot matrix of the variables.

Table 1
Overview of the dataset.

Symbol	Variable	Definition	Unit	Source
EI	Energy intensity	Energy supply/GDP	Megajoules/US Dollar 2017 PPP	[87]
RE	Renewable energy	Renewable power generation	Exajoules	[88]
Y	GDP	Gross Domestic Product	Constant price of US Dollar 2015	[87]
EC	Economic complexity	Diverse export capability		[89]
PO	Oil price	Spot Prices for Crude Oil and Petroleum Products	US dollars per barrel	[88]
AG	Agriculture sector	Agriculture value added/GDP	Percent	[87]
IN	Industry sector	Industry value added/GDP	Percent	[87]
SE	Services sector	Services value added/GDP	Percent	[87]

7. Empirical results

The regression estimates show a significant and positive relationship between economic complexity, energy intensity, and renewable energy consumption in the MENA region. This result implies that economic complexity has a damaging role in economic efficiency and a positive impact on the environment. However, economic growth and its main sectors indicate a substantial and negative relationship with energy intensity and renewable energy consumption. This result implies that economic growth and its main sectors have a positive effect on economic efficiency but a negative impact on the environment.

Table 3 presents the results of CD tests. The findings indicate that cross-sectional dependence emerges. In fact, the Pesaran, Power enhanced, and Biased corrected CD tests reject the null hypothesis of weak cross-sectional dependence, against the alternative hypothesis of strong cross-sectional dependence. Therefore, all variables are cross-sectional dependent, paving the way for using the second-generation unit root test.

Table 4 shows the results of the CADF second-generation panel unit root test, which implies that all the variables have the same integration order. Based on these findings, all variables have a unit root at levels, but they are stationary at first differences.

Table 5 gives the results of the Kao cointegration test. The null hypothesis of no cointegration is rejected by all four t-statistics.

Table 6 shows the positive effect of economic complexity and the negative effect of oil price and economic growth on energy intensity as the economic efficiency indicator. According to the results, the coefficient of economic complexity is positive and statistically significant at a 5 % level. This result implies that economic complexity positively affects energy intensity. However, the coefficient of oil price is −0.2693, which is negative and statistically significant at a 1 % level. It shows that oil price has a negative impact on energy intensity. Nonetheless, one unit increase in oil price cause only 26 % decrease in energy intensity, implying that energy intensity has a low elasticity corresponding to changes in oil price. The estimated negative coefficient of GDP means a negative effect of economic growth on energy intensity. Despite this negative nexus, energy intensity is inelastic in response to the changes in economic growth as a whole since an increase in economic growth can reduce energy intensity only by 3 %. Although the results from alternative estimators show different P-values, the coefficients are consistently similar, confirming the robustness of the results. Therefore, economic complexity increases energy intensity as a proxy for economic efficiency while oil price and economic growth can decrease it in favor of the economic pillar of sustainability, albeit slightly.

Table 2
Descriptive statistics.

Variable	Count	Mean	Standard Deviation	Minimum	Maximum	Skewness	Kurtosis
EI	570	1.7893	0.8767	0.8776	5.8823	3.5174	15.5911
RE	519	1.1641	2.4573	−7.6009	4.4500	−1.0957	3.8976
Y	559	9.3770	3.4649	6.6502	23.9084	−0.8238	4.6654
EC	576	−0.4244	0.6538	−2.0815	1.3146	0.1631	3.3540
PO	588	1.2797	0.1733	0.9822	1.5262	0.0197	1.5561
AG	549	2.8102	4.5817	−2.3623	22.0058	3.5036	14.9140
IN	523	3.3951	0.5010	1.7442	4.4750	−0.4407	3.4501
SE	490	4.9453	4.3744	3.0798	23.1961	3.8040	15.5224

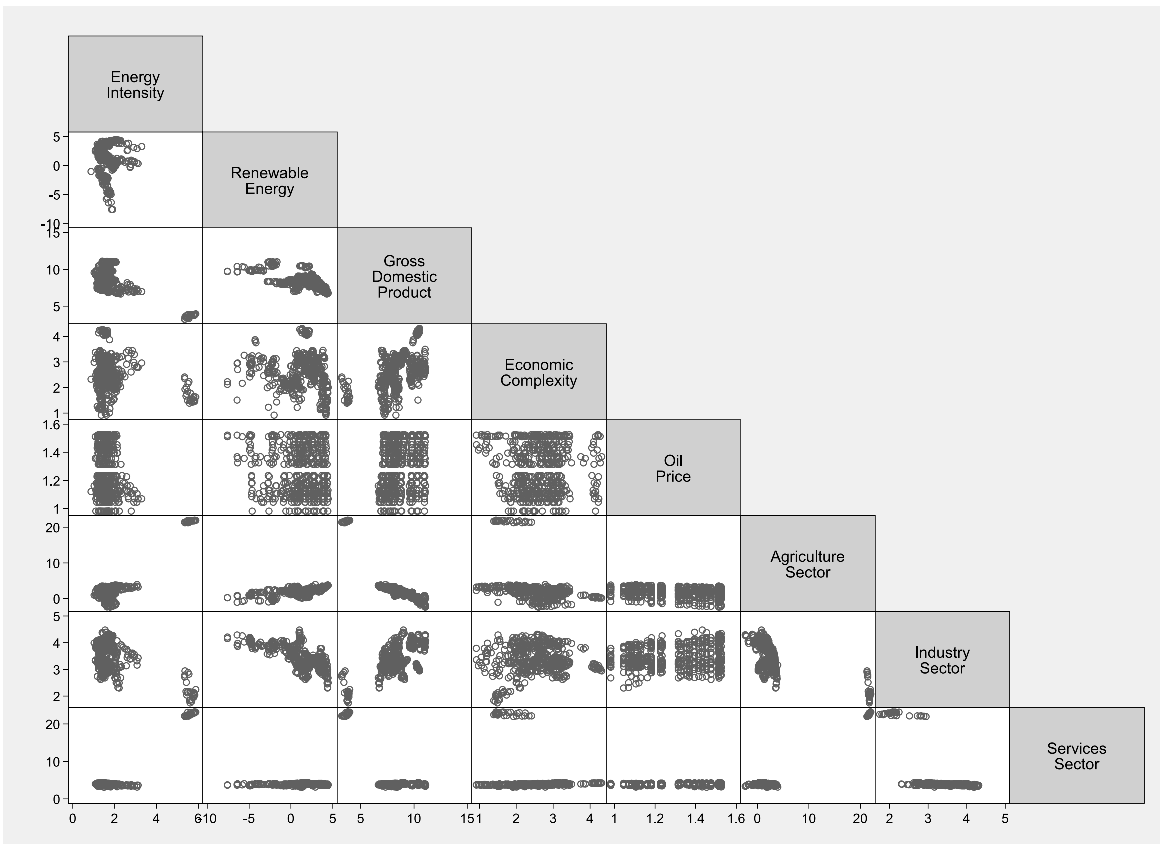

Fig. 1. Scatterplot matrix.

Table 3
Cross-sectional dependence test results.

Variable	Pesaran CD	Power enhanced CD+	Bias corrected CD*
EI	2.39** (0.01)	537.36*** (0.00)	4.40*** (0.00)
RE	10.14*** (0.00)	365.16*** (0.00)	−3.70*** (0.00)
Y	36.87*** (0.00)	716.44*** (0.00)	−3.72*** (0.00)
EC	−3.83*** (0.00)	1218.51*** (0.00)	−3.73*** (0.00)
PO	73.11*** (0.00)	1107.73*** (0.00)	60.82*** (0.00)
AG	33.23*** (0.00)	852.54*** (0.00)	−0.37 (0.71)
IN	11.45*** (0.00)	390.88*** (0.00)	−3.63*** (0.00)
SE	48.46*** (0.00)	352.95*** (0.00)	−3.74*** (0.00)

Notes: ***$p < 0.01$, **$p < 0.05$, *$p < 0.10$. P-values in parentheses.

Table 4
Second generation unit root test results.

Variable	Level	First difference
EI	−0.115 (0.45)	−3.973*** (0.00)
RE	0.845 (0.80)	5.209*** (0.00)
Y	−0.196 (0.42)	−1.189** (0.02)
EC	−0.146 (0.49)	−2.289*** (0.00)
PO	−0.201 (0.43)	−1.202** (0.03
AG	1.705 (0.95)	−1.899** (0.02)
IN	2.200 (0.98)	−5.087*** (0.00)
SE	3.561 (1.00)	4.584*** (0.00)

Notes: ***$p < 0.01$, **$p < 0.05$, *$p < 0.10$. P-values in parentheses.

Table 7 confirms the positive effect of economic complexity and oil price and the negative effect of economic growth on renewable energy consumption as a factor of environmental sustainability. The coefficient of economic complexity is positive and statistically significant at a 1 % level. This result implies the positive effect of economic complexity on renewable energy consumption. In addition, the coefficient of oil price is positive and statistically significant at a 1 % level, implying a positive effect of oil price on renewable energy consumption as the price of a substitution good, but also the high elasticity of this effect. Renewable energy consumption is elastic in response to oil price since an increase in oil price can raise the level of renewable energy consumption. In contrast, the coefficient of GDP is negative and statistically significant at

Table 5
Kao cointegration test results.

Equation	DF	ADF	UMDF	UDF
1	−2.8667*** (0.00)	−1.3567* (0.08)	−1.7321** (0.04)	−3.3876*** (0.00)
2	−2.3377*** (0.00)	−1.7867*** (0.00)	−1.3661*** (0.00)	−3.8526*** (0.00)
3	−1.3566* (0.08)	−1.0840 (0.13)	−3.5860*** (0.00)	−3.1670*** (0.00)
4	−1.8526*** (0.00)	−1.7867*** (0.00)	−2.1540*** (0.00)	−2.3865*** (0.00)

Notes: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$. P-values in parentheses. DF: Dickey-Fuller; ADF: Augmented Dickey-Fuller; UMDF: Unadjusted Modified Dickey-Fuller; UDF: Unadjusted Dickey-Fuller.

Table 6
Estimated results of model 1 (dependent variable: energy intensity).

Variable	PCSE	SCC	GLS
EC	0.0640** (0.03)	0.0640 (0.32)	0.0640** (0.02)
PO	−0.2693*** (0.00)	−0.2693*** (0.00)	−0.2693*** (0.00)
Y	−0.0393** (0.03)	−0.0393 (0.36)	−0.0393*** (0.00)
Constant	2.0985*** (0.00)	2.0985*** (0.00)	2.0985*** (0.00)
Wald χ^2/F	200.13*** (0.00)	15.36*** (0.00)	23.19*** (0.00)
R-squared	0.0475	0.0475	
RMSE		0.3391	

Notes: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$. P-values in parentheses.

Table 7
Estimated results of model 2 (dependent variable: renewable energy consumption).

Variable	PCSE	SCC	GLS
EC	1.2833*** (0.00)	1.2833*** (0.00)	1.2833*** (0.00)
PO	1.6303*** (0.00)	1.6303*** (0.00)	1.6303*** (0.00)
Y	−2.0828*** (0.00)	−2.0828*** (0.00)	−2.0828*** (0.00)
Constant	17.1405*** (0.00)	13.2906*** (0.00)	13.2906*** (0.00)
Wald χ^2/F	714.15*** (0.00)	63.88*** (0.00)	546.54*** (0.00)
R-squared	0.5506	0.5506	
RMSE		1.7533	

Notes: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$. P-values in parentheses.

a 1 % level. This result indicates not only the negative effect of economic growth on renewable energy consumption but also its high elasticity. Therefore, economic complexity and oil price increase renewable energy consumption in favor of energy security of sustainability; on the other hand, economic growth can decrease renewable energy consumption.

Table 8 shows the significant and negative effects of all economic sectors of industry, services, and agriculture on energy intensity as an economic efficiency indicator. The coefficient of industry, services, and agriculture value added are all negative and statistically significant at a 1 % level, except for agriculture value added in the SCC and GLS estimates. These results have two main implications. The first one is the relevance of the services sector's role in this model, as the most effective sector in economic efficiency. The second implication concerns the estimations of this disaggregated model are consistent with the results of Table 6 about the negative effect of aggregated economic growth on energy intensity. This finding implies that energy intensity is negatively affected by each single economic sector. These estimations confirm the economically efficient structure. In addition, the other estimations regarding economic complexity and oil price are consistent with previous results Thus, the economic structure, specifically the services sector, is economically efficient in developing countries, in line with the economic pillar of sustainability.

Table 8
Estimated results of model 3 (dependent variable: energy intensity).

Variable	PCSE	SCC	GLS
EC	0.1158*** (0.00)	0.1158 (0.11)	0.1158*** (0.00)
PO	−0.3404*** (0.00)	−0.3404*** (0.00)	−0.3404*** (0.00)
IN	−0.2732*** (0.00)	−0.2732*** (0.00)	−0.2732*** (0.00)
SE	−0.9111*** (0.00)	−0.9111*** (0.00)	−0.9111*** (0.00)
AG	−0.0361*** (0.00)	−0.0361 (0.18)	−0.0361* (0.09)
Constant	6.5962*** (0.00)	6.5962*** (0.00)	6.5962*** (0.00)
Wald χ^2/F	1508.93*** (0.00)	40.26*** (0.00)	92.34*** (0.00)
R-squared	0.1820	0.1820	
RMSE		0.3019	

Notes: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$. P-values in parentheses.

The results in Table 9 clarify that industry and services sectors have negative effects on renewable energy consumption, while the opposite is found for the agriculture sector. The coefficients of industry and services value added are negative and statistically significant at a 1 % level. These results in the disaggregated model are consistent with those of the aggregated model in Table 7. This consistency implies that renewable energy consumption receives a negative effect not only from the aggregated economic growth as a whole but also from each of the disaggregated sectors. In sharp contrast, the coefficient of the agriculture sector is positive and statistically significant at a 1 % level. This result shows the unique and exceptional role of the agriculture sector in renewable energy promotion. The estimated coefficients of the other variables of economic complexity and oil price are consistent with previous results of the aggregated mode, which support the robustness and reliability of the estimations. Therefore, economic structure impedes the promotion of renewable energy, while the agriculture sector is the only one to enhance renewable energy, consistent with the energy security of sustainability (see Table 10).

Finally, the results of the Granger causality tests are reported in Table 10. It emerges that energy intensity is caused by economic complexity, oil price, services sector, and agriculture sector; while renewable energy is only caused by GDP (see Table 11).

8. Discussion

This research shows that economic complexity decreases energy efficiency (i.e., energy-intensive complexity) but increases renewable energy (i.e., green complexity) in MENA. In contrast, economic growth increases energy efficiency (i.e., energy-saving growth) while decreasing renewable energy (i.e., brown growth[1]). Nonetheless, the total effect of the economic pillar is negative on the energy security of sustainability. Table 10 summarizes the results of models 1–4. It shows how economic complexity and growth affect energy intensity and renewable energy consumption over the sample. It indicates economic complexity and economic growth as indicators for the economic pillar of

Table 9
Estimated results of model 4 (dependent variable: renewable energy consumption).

Variable	PCSE	SCC	GLS
EC	0.1570 (0.19)	0.1570 (0.35)	0.1570 (0.24)
PO	1.9622*** (0.00)	1.9622*** (0.00)	1.9622*** (0.00)
IN	−4.3001*** (0.00)	−4.3001*** (0.00)	−4.3001*** (0.00)
SE	−1.3565*** (0.00)	−1.3565 (0.14)	−1.3565** (0.01)
AG	1.1243*** (0.00)	1.1243*** (0.00)	1.1243*** (0.00)
Constant	16.3665*** (0.00)	16.3665*** (0.00)	16.3665*** (0.00)
Wald χ^2/F	18648.48*** (0.00)	1494.66*** (0.00)	1280.45*** (0.00)
R-squared	0.7504	0.7504	
RMSE		1.3204	

Notes: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.10$. P-values in parentheses.

[1] Brown growth is adopted following Shirazi et al. [71], who used this term to indicate the polluting nature of economic development at the primary stages of the growth process in oil-exporting countries.

Table 10
Pairwise Granger Panel Causality test results.

Null Hypothesis	F Stat.	P-Value
EI ⇎ EC	0.5014	0.4792
EC ⇎ EI	3.2888	0.0703*
EI ⇎ PO	0.0108	0.9171
PO ⇎ EI	3.1946	0.0745*
EI ⇎ Y	7.4698	0.0065***
Y ⇎ EI	1.6122	0.2048
EI ⇎ IN	3.4883	0.0624*
IN ⇎ EI	0.8618	0.3537
EI ⇎ SE	0.5317	0.4663
SE ⇎ EI	11.8731	0.0006***
EI ⇎ AG	0.1779	0.6734
AG ⇎ EI	3.7556	0.0532*
RE ⇎ EC	11.2300	0.0009***
EC ⇎ RE	0.1027	0.7487
RE ⇎ PO	0.6112	0.4347
PO ⇎ RE	0.0003	0.9856
RE ⇎ Y	1.5318	0.2165
Y ⇎ RE	5.5018	0.0194**
RE ⇎ IN	0.6855	0.4081
IN ⇎ RE	2.0807	0.1499
RE ⇎ SE	1.6303	0.2024
SE ⇎ RE	0.0691	0.7927
RE ⇎ AG	0.1122	0.7378
AG ⇎ RE	0.0987	0.7535

Notes: 2 lags. ***$p < 0.01$, **$p < 0.05$, *$p < 0.10$.

Table 11
Estimated effects of economic pillar of sustainability on energy security.

Energy security	Sustainability Variables	Economic pillar Economic complexity	Comparison	Economic growth
	Energy intensity	Energy-intensive complexity	>	Energy-saving growth
	Renewable energy	Green complexity	<	Brown growth

sustainable development. It also defines energy intensity and renewable energy as indicators for the energy security aspect of sustainability. In this way, it concisely displays the estimated effects of economic complexity and economic growth on energy intensity and renewable energy including a comparative representation. In this table, energy-intensive complexity and energy-saving growth imply that economic complexity and economic growth increase and decrease energy intensity, respectively. Economic complexity is energy-intensive but growth is energy-saving, whereas economic complexity is green but growth is brown. This finding shows that economic complexity and growth have two different and conflicting effects on the energy security of sustainability, while each one can be mitigated and complemented by the other. To consider this aspect, this table compares the estimated coefficients to provide a comparative analysis. It adds a comparative signal by the unequal symbols to compare the estimated effects in the middle column. According to the estimated comparison, the effect of energy-intensive complexity and brown growth is greater than the energy-saving growth and green growth, respectively.

The results show that economic complexity increases energy intensity due to the "energy-intensive complexity" of the MENA region with energy-rich countries. This result implies that economic complexity reduces energy efficiency, rejecting Hypothesis 1, in line with Kahia et al. [19] but contrary to Khezri et al. [61] and Abbate et al. [62]. Although this result might seem contradictory at first, this research explains it with the idea of energy-intensive complexity. It is expected that economic complexity, as a proxy for economic technological progress, would decrease the level of energy intensity and increase energy efficiency. However, the results contrast this statement. The explanation lies in the energy-intensive complexity of the region.

The concept of energy-intensive complexity suggests that the economic complexity of MENA countries focuses on energy-intensive diversification and exportation due to the high availability of energy resources in the region. With abundant energy sources at relatively low prices, entrepreneurs and exporters are motivated to produce and export energy-intensive goods. This leads to an increase in the diversity and exportation of energy-intensive goods, contributing to the overall economic complexity. Based on this analysis, economic complexity and energy intensity show a positive relationship in this sample.

Another piece of evidence supporting the idea of energy-intensive complexity is the negative relationship between oil price and energy intensity in the results. The estimations demonstrate a reverse relationship between oil price and energy intensity, as the price negatively relies on the supply of energy. Due to the high availability of energy resources in this area, the energy price is relatively low, motivating producers and exporters to focus on energy-intensive goods. This analysis further supports the phenomenon of energy-intensive complexity, indicating that the low price of energy resources is a key variable.

In contrast to economic complexity, economic growth shows a negative relationship with energy intensity, in contrast with results by Chu [39], Doğan et al. [38], Romero & Gramkow [40], and Ali et al. [43]. This result points to the case of "energy-saving growth". This relationship holds not only for economic growth as a whole but also for its disaggregated sectors (industry and services). Thus, the economic structure in MENA countries reduces the share of energy in production by redistributing the share of production inputs in an equal way. According to this finding, economic growth and economic complexity have different effects on the energy sector, resulting in energy-intensive complexity and energy-saving growth.

Furthermore, economic complexity supports the energy security of sustainability by displaying a positive relationship with renewable energy consumption, confirming that complexity is green in the region. This result confirms Hypothesis 2, and is consistent with Khezri et al. [61], Abbate et al. [62], and Kahia et al. [16], but inconsistent with Kahia and Ben Jebli [25] and Kahia et al. [19]. A reason for that resides in the "inertia effect" of energy-intensive complexity. According to this phenomenon, complexity increases energy intensity, which not only leads to an overall increase in energy demand but also specifically drives up the demand for renewable energy. Therefore, the positive relationship between economic complexity and renewable energy consumption confirms that the inertia effect of energy-intensive complexity influences renewable energy consumption, contributing to a green complexity in the region.

On the other hand, economic growth goes against the energy security of sustainability by showing a negative relationship with renewable energy consumption, confirming that growth is brown rather than green in these countries. The brown growth is evident both in the aggregate economic structure and the disaggregated economic sectors.

In a comparative analysis, the harmful effects of economic complexity and growth on the energy security of sustainability are larger than their positive effects. The energy-intensive effect of complexity and the green nature of growth are greater than the energy-saving effect of growth and the brown nature of complexity. This finding shows that the current economic structure of developing countries is insufficiently capable for the achievement of sustainable development. In this way, the more the economy grows and develops in these countries, the more they diverge from a sustainable economy and clean environment.

Furthermore, the findings confirm that all economic sectors improve energy efficiency, implying an energy-efficient structure of the economy in the analyzed countries. Comparatively, the services sector shows the most beneficial role, highlighting the potential of the sector for environmental protection policies. Moreover, the industry and services sectors reduce renewable energy consumption. Nonetheless, the agriculture sector increases renewable energy consumption, stressing its beneficial role in the energy transition process.

9. Conclusions and policy implications

This paper investigates how economic complexity affects renewable energy and energy efficiency in the MENA region. Specifically, we aim to inspect the impact of economic growth, economic complexity, and oil prices on renewable energy and energy efficiency in the MENA countries for the 1990–2017 years, using PCSE, SCC, and GLS estimators.

The results show that economic complexity increases energy intensity, which implies that it contributes to environmental degradation by decreasing energy efficiency in the MENA countries. This result introduces the energy-intensive nature of economic complexity. However, economic complexity increases renewable energy consumption, which means that it improves the environment through the promotion of clean energies, highlighting the green nature of economic complexity. Moreover, it was found that the impacts of economic growth are diverse. Economic growth decreases energy intensity, showing a beneficial impact on the environment by increasing energy efficiency. This result notifies the energy-saving character of economic growth. Nonetheless, economic growth negatively affects the environment by decreasing renewable energy consumption, pinpointing the brown nature of economic growth. Overall, the economic complexity of these countries is energy-intensive but green, while their economic growth is energy-saving but brown. The negative effects surpass the positive ones, implying that the economy of developing countries needs restructuring to become more environmentally friendly.

Based on these findings, policymakers should adopt new policies to improve the structure of economic sectors in an environmentally friendly way. To achieve this end, they should formulate some plans to encourage economic activities increasing the share of other inputs compared to the energy in the productions, which helps reach an energy-saving complexity [90]. In addition, they should promote consumption and production of renewable energy to have a greener economy. In this way, the structure of the economy would be in line with the energy security of sustainable development. Moreover, a strategic approach to addressing shared energy and environmental challenges among the MENA countries may be to encourage collaboration and knowledge-sharing among them. To address common issues related to energy security and sustainable development, countries can pool their resources and expertise by working together through regional initiatives.

MENA countries should diversify their economy to create new job opportunities, foster innovation, and reduce their reliance on oil and gas exports. Moreover, they should carefully consider the transition towards renewable and clean energy sources in their structural transformation to reduce their dependence on fossil fuels and promote sustainable economic growth [91]. To this end, they should significantly invest in technology and infrastructure to create new jobs and support the development of new industries. By combining energy efficiency measures with a focus on economic complexity and renewable energy adoption, MENA countries can pave the way for a more sustainable and resilient economic future.

Concerning the limitations of the study, here we focused only on developing and emerging economies. For this reason, the innovative results of energy-intensive complexity and green growth are acceptable only for this type of country and they remain questionable for developed countries. Therefore, future studies may inspect this topic for the developed countries, to find a more comprehensive insight into the energy-saving and green characteristics of the economic complexity and growth.

CRediT authorship contribution statement

Vahid Mohamad Taghvaee: Conceptualization, Data curation, Methodology, Software, Writing – original draft, Writing – review & editing. **Behnaz Saboori:** Data curation, Methodology, Resources, Supervision, Validation, Writing – original draft. **Susanne Soretz:** Supervision, Validation, Visualization. **Cosimo Magazzino:** Data curation, Methodology, Software, Writing – review & editing. **Moosa Tatar:** Supervision, Validation.

Declaration of competing interest

None.

Data availability

Data will be made available on request.

Abbreviations

CADF	Cross-section Augmented Dickey–Fuller
CO_2	carbon dioxide
GDP	Gross Domestic Product
GHG	greenhouse gas
GLS	Generalized Least Squares
MENA	Middle East and North Africa
OLS	Ordinary Least Squares
PCSE	Panel-Corrected Standard Errors
SCC	Spatial Correlation Consistent
SDGs	Sustainable Development Goals
UAE	United Arab Emirates
WDI	World Development Indicators

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