



Research article

Ecological security and agricultural production in the Arab League: Is financial development moderating the interaction?

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ABSTRACT

The jeopardizing of ecological security due to the detrimental effects of human activities necessitates the adoption of various actions to reduce ecological intensity. Though some studies have explored the moderating impact of financial development (FND) towards achieving ecological security, in Arab World it has not been thoroughly investigated. Against this backdrop, we investigate combined role of agricultural production (AFP), gross domestic product (GDP), energy consumption, population, direct and moderating impacts of FND on ecological intensity for a panel of 12 Arab League member states from 1995 to 2021. The empirical outcomes unveiled that AFP and GDP have U-shaped nexus with ecological intensity. It posits that at early stages of AFP, ecological intensity is reduced to a certain level, beyond which higher AFP hinders ecological security supporting the evidence against the Borlaug hypothesis. Our findings further unfolded that environmental Kuznets curve (EKC) hypothesis does not hold for the selected Arab League member states, denoting that real GDP has a U-shaped relationship with ecological intensity. Further findings confirm that energy consumption induces ecological deterioration in the absence of its interaction with FND, along with the interaction term. The causality results largely support these outcomes. Based on these findings, Arab League's climate-related policies should further explore FND to drive energy transition and environmentally friendly measures.

1. Introduction

The economic growth within the Arab League nations is marked by rapid technological advancement and a substantial influx of migrant workers and more recently expanding agricultural production. These developments, although drive economic prosperity in diverse ways also pose substantial ecological challenges. This rapid expansion in populations over the years has largely contributed to intensifying ecological challenges, including pollutant emissions, climate change, food, and water scarcity in the region. Carbon dioxide (CO₂) emissions in the Middle East nearly doubled from 1987 to 2017, reaching 6.1 tons per person, exceeding the global average (The World Bank, 2023). Although the Arab League vividly illustrates prospects of economic growth, as evidenced by impressive gross domestic product (GDP) and per capita energy consumption, surpassing those of many developing nations, this

remarkable prospect is predominantly underpinned by a growing dependence on fossil fuels, which inevitably continue to increase most of the countries' ecological footprint (Fig. 1, see appendix). Evidently, the region's susceptibility to climate change underscores critical climate change mitigation and adaptation measures, thus possibly necessitating the Egypt's hosting of COP27 in 2022 and the United Arab Emirates' hosting of COP28 in 2023.

Therefore, understanding the region's diverse characteristics is essential for assessing the economic gatekeepers of ecological security. In many Arab nations, agriculture is predominantly rural-based such that insufficient services hinder productivity during both droughts and heavy rainfall years, necessitating simultaneous investment in infrastructure such as roads, transportation, storage, and marketing channels. This need is most acute in least developed countries like Sudan, Somalia, and Mauritania (Almulhim and Cobbinah, 2023). The region exhibits a dual agricultural structure, with a modern export-oriented

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Abbreviation

AFP	Agricultural production
GDP	Real gross domestic product
EKC	Environmental Kuznets curve
FND	Financial development
UAE	United Arab Emirates
GHG	Greenhouse gas
MENA	(Middle East and North Africa)
MMQR	(Method of Moments Quantile Regression)
OLS	(The ordinary least squares regression with Driscoll-Kraay standard errors)

sector and a vast traditional subsector ([McLachlan, 2023](#)). While the modern sector (such as the service industry) benefits from research and development, modern technology, and imports, the traditional sector i. e. agricultural struggles with limited technological influence. Moreover, prolonged conflicts, economic challenges, political disparities, and inadequate extension services and credit facilities further hamper agricultural productivity ([Salem, 2023](#)). Thus, understanding this complex interplay of factors is essential for mitigating threats to food security and ecological stability in the region.

In light of this, this examination seeks to scrutinize an extension of the environmental Kuznets curve (EKC) hypothesis via an application of the Borlaug hypothesis ([Borlaug, 2007](#)). Researchers frequently employ the EKC hypothesis to explore the connection between economic development and land use change ([Selcuk et al., 2021](#); [Boluk and Karaman, 2024](#); [Shakoor et al., 2023](#); [Cetin et al., 2022](#)). The EKC applied to land use suggests that at lower levels of per capita income, land use tends to favor agriculture. As income per capita increases, however, the allocation of land to agricultural activities typically decreases. Nevertheless, the expansion of agricultural land during development is contingent upon the intricate interplay of agricultural technology and various factors crucial for agricultural production. However, [Borlaug \(2007\)](#) hypothesized that agricultural productivity correlates with income growth, but there are concerns that agricultural productivity may contribute to environmental degradation by encouraging cropland expansion. This dual perspective underscores the complex relationship between agricultural productivity and environmental outcomes. A report by the [FAO \(2017\)](#) supports that these detrimental environmental effects of agricultural expansion include deforestation, groundwater depletion, and biodiversity loss. Empirical studies ([Gokmenoglu and Taspinar, 2018](#)) have yielded conflicting results regarding this relationship, with some opposing while others align with Borlaug's view. In light of these, an extension of the EKC incorporating the Borlaug's hypothesis is employed. Agricultural production is employed in this examination as it accounts for value added from agricultural activities including food, forestry and fishing in the Arab region. By addressing this knowledge gap, this research aims to inform more nuanced and effective sustainable agriculture policies. It further investigates the potential moderating role of FD and energy consumption amid increasing agricultural production and economic growth with ecological intensity in the Arab League.

The rest of this paper follows this structure: In Section 2, a thorough review of the literature is presented to place the study in context. Section 3 gives a detailed account of the data, theoretical foundations, and methodology used. Section 4 displays the findings and subsequent discussions. Finally, Section 5 wraps up the paper and provides policy suggestions.

2. Literature review**2.1. Economic prosperity and ecological security**

The concerns about environmental degradation have driven the need to continuously probe the influencing factors of ecological security within the framework of the EKC hypothesis, originally formulated by [Grossman and Krueger \(1991\)](#). The EKC theory suggests that ecological security tends to suffer during the early stages of growth but begins to improve after some threshold ([Al-Mulali et al., 2019](#); [Verbič et al., 2022](#); [Ahmad & Satrovic, 2023b, 2024](#)). In continuing the exploration of this growth-environmental quality relationship, other factors including energy utilization, population, economic growth and similar, have been widely studied for several cases including the Arab League members.

For instance, [Al-Mulali et al. \(2019\)](#) investigated how electricity consumption and economic growth impacted the environmental degradation challenge within the GCC countries. Their study controlled for local investment, active labor, and net exports. Hence, using the panel cointegration technique (Pedroni) on data from 1980 to 2014, they observed a short-term, unidirectional causality running from GDP to environmental quality, lending support to the conservation hypothesis. Shifting focus to the broader MENA region, [Gorus and Aydin \(2019\)](#) explored the complex interplay between economic expansion, energy demand, and carbon emissions across 8 Middle East countries, including, Oman, the UAE and Saudi Arabia. Employing both time domain and frequency domain analyses, their investigation covered the period from 1975 to 2014. Their results highlighted diverse outcomes across the countries. Saudi Arabia exhibited evidence of a reciprocal relationship between economic expansion and carbon emission. In contrast, Oman aligned with the neutrality hypothesis, implying that GDP did not exert a substantial influence on CO₂ emissions. Lastly, the UAE's case supported the conservation hypothesis, indicating that GDP was associated with ecological security.

Additionally, [Charfeddine and Kahia \(2019\)](#) delved into the multifaceted relationships within the MENA region by examining the influence of economic growth, capital, clean energy utilization, labor, carbon emissions, and financial development across twenty-four (24) countries across the Middle East. Their analysis employed a Westerlund panel cointegration technique and covered data spanning from 1980 to 2015. Notably, their results lent support to the growth hypothesis, signifying a positive correlation between GDP and the other variables and CO₂ emissions. [Xu et al. \(2018\)](#) explored the interconnections among GDP growth, electricity consumption, CO₂ emissions, globalization, urbanization, and financial development in Saudi Arabia from 1971 to 2016, employing the ARDL technique. Their findings suggested that GDP growth and electricity consumption positively affect CO₂ emission. These diverse findings including several others not mentioned here highlight the nuanced nature of the relationships between energy, economic growth, and ecological factors across the MENA region, highlighting the need for context-specific approaches in policy formulation and decision-making.

2.2. Energy consumption and ecological security

Relative to the energy-environment relationships, several studies have sought to investigate the intricate regarding energy utilization, GDP, and environmental consequences. [Hasanov et al. \(2017\)](#) conducted a comprehensive examination of this nexus in a select group of 10 oil-exporting Eurasian nations, which notably included the six Gulf Cooperation Council (GCC) countries. Employing two distinct models—one based on primary energy consumption and the other on residential electricity consumption—their investigation yielded intriguing insights. The primary energy consumption model adopted in the study affirmed the growth hypothesis, suggesting that growing energy demand directly influences growth economically ([Hasanov et al., 2017](#)). In contrast, the residential electricity consumption model revealed

evidence in favor of the neutrality hypothesis, implying that electricity consumption did not significantly influence economic growth.

Further extending the scope of inquiry, Antonakakis et al. (2017) embarked on an expansive analysis encompassing 106 states, including GCC member nations, during the period spanning 1971 to 2011. Their investigation comprised six distinct models, each dedicated to analyzing a specific category of energy consumption: coal, crude oil, green energies, natural gas, electricity, and total energy. The results revealed significant variations among these models. The models for total energy and oil consumption provided support for the feedback hypothesis, implying a mutually reinforcing the energy demand-economic growth nexus. In contrast, the models for electricity consumption and green energy utilization endorsed the conservation hypothesis, indicating that these energy types had a more neutral impact on economic growth. The model for natural gas consumption aligned with the growth hypothesis, signifying a positive correlation with economic growth, while the model for coal energy consumption upheld the neutrality hypothesis, suggesting a limited influence on economic expansion.

Turning attention to the MENA countries, Charfeddine and Mrabet (2017) explored the factors affecting economic growth. Their study encompassed 15 Middle Eastern countries, which included Kuwait, Qatar, Saudi Arabia, Qatar, and Oman, and scrutinized various determinants, including demand for energy, rural-urban movements, political institutional index, rate of fertility, life expectancy and ecological footprint. Employing a panel cointegration procedure, their investigation yielded compelling results, notably in support of the feedback hypothesis, suggesting a bi-directional relationship among the factors examined. Lastly, while focusing on electricity utilization's influence on economic growth, Al-Mulali and Che Sab (2018) studied twelve Middle Eastern countries, including the six Gulf Cooperation Countries, over the period spanning from 1990 to 2008. Employing the Pedroni panel cointegration technique, their analysis supported the feedback hypothesis, signifying a bidirectional relationship between electricity consumption and economic growth. These findings collectively validate the broader understanding of the intricate interplay between energy, economic growth, and environmental factors, offering valuable insights for policymakers and researchers alike.

However, recent studies present contrasting viewpoints. Muazu et al. (2023) found a significant negative effect of clean energy utilization on the economic expansion of selected African countries. Mumuni and Mwimba (2023) revealed that demand for energy initially hinders short-term growth among certain African states, with reliance on unclean energy sources negatively affecting growth in both long and short terms. Their results indicate that clean energy utilization exerts short-term limiting effects on growth as well as long-term enhancements on growth. Moreover, pollutant emissions like CO₂ exhibit significant impacts on economic growth in the short and long terms, while fossil fuel combustion negatively affects growth over the same time frames. Additionally, Mohsin et al. (2023) examined the links between CO₂ emission, crypto volume, GDP, and energy utilization. Utilizing various estimation techniques, their study confirmed bi-directional causality between ecological security and crypto volume in both the short and long terms, as well as unidirectional causality between energy utilization and GDP.

2.3. Agricultural production and ecological security

Reynolds (2015) studied the connection among AFP and CO₂ emissions, particularly in regions like South Asia and sub-Saharan Africa. Their model-based estimations provide further evidence of a connection between agriculture output and carbon emissions. Similarly, Wang et al. (2020) conducted a study investigating the impact of different aspects of crop production on greenhouse gas emissions. Their research posits that harvest residues increase greenhouse gases like CO₂, thus negatively impacting ecological security. Furthermore, investigations into the broader implications of CO₂ emissions from agricultural and economic

activities have been explored in other studies (Farooq et al., 2023). The agricultural sector relies on industrial equipment and transportation, both of which consume biofuels and release carbon emissions (Sardar and Rehman, 2022). Agricultural activities, such as crop harvesting, animal husbandry, forestry, and fishing, intensify CO₂ emissions (Sansika et al., 2023). Agricultural machinery, used for tasks like land cultivation, crop harvesting, and underground water extraction, increase emissions (Rahman et al., 2021; Ganie et al., 2024). The transportation of agricultural output, forest timber, and other goods predominantly employs biofuel-based modes, resulting in pollution from carbon emissions (Trofimov, 2024). It can be equally noticed from (Khurshid et al., 2022) that agricultural production inhibits ecological security of Pakistan. Similarly, Shah et al. (2022) portrayed that agriculture is significant in putting pressure on environmental sustainability of emerging countries. This is since agricultural sector boosts energy consumption and land conversion leading to soil degradation and deforestation.

Agricultural production processes contribute to two distinct categories of CO₂ emissions: direct and indirect. Direct emissions stem from the utilization of fossil fuels in a range of agricultural and transportation tasks (Al-Naemi and Al-Otoom, 2023). On the other hand, indirect emissions are a consequence of the various procedures inherent to agricultural activities. It is worth noting that embodied carbon emissions often surpass the emissions produced during the actual agricultural production (Sansika et al., 2023). Furthermore, according to Wang et al. (2023), a substantial proportion of overall CO₂ emissions originate from the release of CO₂ during the transportation of agricultural products, both domestically and internationally.

2.4. Interplay between financial development, population and ecological security

Khan et al. (2019) explored the intricate interplay between energy usage, financial development, population, globalization, and ecological security in Pakistan from 1971 to 2016. Their research highlighted the positive influence of population on carbon emissions, while an adverse effect is exhibited by globalization, energy utilization, and financial development. Additionally, Shahbaz et al. (2020) delved into the dynamics of exports within China's consumption-driven CO₂ emissions context from 1984 to 2018. Their findings revealed a reverse effect of exports and energy utilization on the environment, while highlighting the positive contribution of financial development. The dynamic interplay between financial growth and environmental degradation within BRICS nations was also studied by Chishti and Sinha (2022). Their utilization of time series data techniques revealed positive shocks in financial development were effective in reducing environmental degradation, particularly in terms of CO₂ emissions, while adverse shocks amplified emissions. Furthermore, their study substantiated the presence of the EKC within BRICS. Hu et al. (2024) opted for urbanization to determine the impact of population on ecological intensity. The findings of this study divulged that population hinders ecological security of ecologically less efficient countries. Moreover, Scholtens (2017) conducted a study focusing on China, spanning from 1982 to 2017, to discern the effects of industrialization, financial development, and energy utilization on carbon emissions. The findings indicated a substantial reduction in CO₂ emissions associated with heightened financial development.

Turning attention to the Gulf Cooperation Council (GCC) countries, Bekhet et al. (2017) embarked on a comprehensive exploration of the multifaceted relationships involving economic expansion, energy utilization, carbon emissions, and financial development. Employing the Auto Regressive Distributed Lag (ARDL) technique, their analysis spanned from 1980 to 2011 and yielded diverse findings. Different GCC nations exhibited varying levels of support for different hypotheses. Two member states (Saudi Arabia and Qatar) leaned towards the growth hypothesis, indicating a positive correlation between economic

expansion and energy utilization in these economies. Conversely, the UAE and Oman show results supporting the feedback hypothesis, suggesting a mutually reinforcing relationship between these variables. Meanwhile, Bahrain and Kuwait aligned with the neutrality hypothesis, implying that energy utilization had no substantial influence on economic expansion in the panels studied. Likewise, Sharif et al., 2022 ventured into exploring green finance's role in ensuring quality environment among G7 states from 1995 to 2019. Their findings revealed that such financial innovations substantially reduced CO₂ emissions, while also highlighting the moderating effect of social globalization on the economic growth and carbon emissions nexus. In tandem, Ahmad and Satrovic (2024) provided verification that financial development with technology played crucial roles in improving ecological security.

2.5. Knowledge gap

Previous studies overlooked the impact of agricultural production on ecological security of Arab League members under the umbrella of Borlaug hypothesis. Considering this, the present study introduces AFP as an emerging phenomenon in the region and seeks to examine its impact on the region's ecological security via extending the EKC to include the Borlaug hypothesis. In addition, it combines financial development as a moderating factor to assess shifts in economic trends. This implies that a highly developing financial sector can contribute significantly to the agricultural sector's ability to reduce ecological intensity in the presence of growing energy consumption in the region. In addition, contrary to previous works that solely used mean estimators, this study employs Method of Moments Quantile Regression to assess the heterogenous impacts across diverse quantiles of ecological security. This paper also checks the regularity of baseline findings by employing the alternative measures of financial development. Past works mostly rely on traditional proxies for ecological security while neglecting the ecological intensity. Against this backdrop, this study incorporates ecological intensity as the more comprehensive indicator of ecological security to assess not only ecological but also economic activity scope of sustainability. The conceptual framework for this research is grounded in the environmental Kuznets curve (EKC), a choice informed by the extensive application in previous empirical studies and their validation by numerous studies (Verbić et al., 2022; Jena et al., 2022; Dalwai et al., 2024; Satrovic et al., 2024a). Drawing upon the EKC, this research posits that agricultural production has an impact on ecological intensity, and this relationship has only been fairly studied among few individual states within the Arabian region. Further, few studies have validated the EKC from the lens.

3. Data, empirical model, and methods

3.1. Data

The World Bank, 2023 provided the balanced dataset on real GDP per capita, agricultural production, and population. Additionally, the data on energy consumption were retrieved from Our World in Data, 2023 while International Monetary Fund, (2023) provided the data on financial development. Global Footprint Network, 2022 reported data on ecological footprint that are used to compute ecological intensity. Table 1 exhibits the list of our study variables, along with the description, sources and unit of measurement. The sample comprises 12 member states of the Arab League (Table 2). Secondary data were collected from the dataset spanning from 1995 to 2021. The selection of the investigative laboratory and the time period is determined by the availability of AFP and ecological footprint data.

Based on our dataset, Mauritania evidences the maximum ecological intensity in 2004 whereas Saudi Arabia reports the minimum value in 1999. Escalating ecological intensity (Fig. 1) in Arab League is substantially associated with the high energy consumption per capita (Fig. 2), and dynamic population growth. There is also greater

Table 1
Synopsis of the variables.

Variable	Description	Source
AFP	Agricultural production - agriculture, forestry, and fishing, value added (% of GDP)	The World Bank, (2023)
GDP	GDP per capita (constant 2015 US\$)	The World Bank, (2023)
ENC	Primary energy consumption per capita, in kilowatt-hours per year	Our World in Data, (2023)
POP	Percentage of a country's population 15+ that is employed	The World Bank, (2023)
FNI	Financial development 1: Depth, access, and efficiency of financial institutions	IMF (2023)
FNIM	Financial development 2: Depth, access, and efficiency of financial markets and institutions	IMF (2023)
ES	Ecological footprint consumption (global hectare - gha per person)/GDP	Global Footprint Network, (2022)

ecosystem impairment in the Arab League member states caused by water and soil pollution. Given that water and soil have been intensively used in the agricultural production, there are various ecological issues faced by inspected countries attributable to agricultural activity such as desertification and biodiversity loss (Villanthenkodath et al., 2023).

In Table 2, the study reveals varying average values across the considered variables. Notably, the highest average is associated with the energy consumption, while the lowest pertains to ecological intensity. United Arab Emirates stand out with the largest energy consumption, with Comoros reporting the smallest ENC in 1997. Relative to agricultural production, Sudan reported the highest value in 1997, while United Arab Emirates recorded the lowest value in 2012. Shifting to the GDP, United Arab Emirates spotlighted the highest value in 1997, whereas Syria documents the lowest in 2021. The data presented in Table 2 indicated an average POP of 45.52%. United Arab Emirates reported the maximum employment to population rate in 2019, while Jordan showed the lowest POP in 2021. Concerning financial development, Jordan records the highest value of FNI in 2005, while Comoros reports the minimum in 1998. As far as the alternative proxy for financial development is gauged, the maximum value of FNIM is highlighted for Jordan in 2008 and United Arab Emirates in 2014, whereas the minimum value is divulged for Comoros in 1996, 1998, and 1999. It's important to note that the high standard deviation values across all the variables signify substantial variation in these variables compared to their mean values.

3.2. Model specifications

Our study investigates the linkage amid income, agricultural production, energy consumption, population, financial development, and ecological intensity. We establish on the EKC theoretical postulation to unriddle the ecological pressures of FND and economic output at initial and higher stages of economic development. Although carbon dioxide emission is mostly used to proxy the quality of the environment, the current approach utilizes ecological intensity because it a wider representation of the biosphere. Thus, bearing in mind the literature, (Musah, 2022; Haldar and Sethi, 2022; Satrovic et al., 2024b), the adopted EKC baseline model is presented below (Eq. (1)):

$$ES_{it} = f(AFP_{it}, AFP_{it}^2, GDP_{it}, GDP_{it}^2, ENC_{it}, POP_{it}, FND_{it}) \quad (1)$$

where, ES_{it} denotes ecological security proxied by ecological intensity, AFP_{it} is agricultural production and AFP_{it}^2 is its squared term, ENC_{it} is energy consumption, POP_{it} stands for employment to population ratio. This study utilizes the twin measures of financial development (FND) namely: depth, access, and efficiency of financial institutions (FNI) and depth, access, and efficiency of financial markets and institutions (FNIM). Real GDP per capita (GDP_{it}) is introduced along with its quadratic term (GDP_{it}^2). Cross sections are signified by i , whereas t ex-

Table 2
The descriptive statistics.

Stat./Var.	AFP	GDP	ENC	FNI	FNIM	POP	ES	Country
Mean	30.63	1251.28	1014.41	0.08	0.04	40.87	0.00122	Comoros
Stan. dev.	2.08	90.07	346.34	0.02	0.01	0.94	0.00029	
Maximum	35.80	1383.38	1685.73	0.11	0.06	42.35	0.00201	
Minimum	28.96	1096.61	509.27	0.04	0.02	39.49	0.00091	
Mean	13.37	2997.87	9136.37	0.27	0.31	41.53	0.00053	Egypt
Stan. dev.	1.93	534.47	1214.31	0.02	0.05	1.80	0.00007	
Maximum	16.12	3896.84	10,688.42	0.32	0.43	45.05	0.00062	
Minimum	10.70	2122.88	6823.15	0.23	0.23	38.30	0.00037	
Mean	3.29	4115.65	12,532.67	0.45	0.46	33.18	0.00047	Jordan
Stan. dev.	0.90	484.17	1299.89	0.02	0.08	1.00	0.00006	
Maximum	4.79	4920.87	15,157.30	0.51	0.58	34.93	0.00056	
Minimum	1.95	3477.17	9183.15	0.42	0.35	31.00	0.00035	
Mean	4.43	7218.71	15,444.54	0.47	0.29	41.03	0.00045	Lebanon
Stan. dev.	1.41	1142.25	1967.55	0.03	0.03	1.36	0.00007	
Maximum	6.79	9037.09	18,831.66	0.50	0.34	43.37	0.00059	
Minimum	1.40	5543.76	10,675.19	0.38	0.22	38.36	0.00037	
Mean	21.33	1448.61	3330.61	0.18	0.10	39.53	0.00170	Mauritania
Stan. dev.	3.80	126.51	1327.25	0.03	0.02	1.92	0.00021	
Maximum	28.13	1635.84	5873.27	0.26	0.14	41.75	0.00214	
Minimum	14.52	1215.25	1872.36	0.13	0.07	35.80	0.00142	
Mean	12.01	2583.15	5473.02	0.35	0.29	43.82	0.00062	Morocco
Stan. dev.	1.72	535.37	1089.32	0.07	0.05	1.74	0.00008	
Maximum	18.44	3355.61	7267.46	0.44	0.35	45.77	0.00079	
Minimum	9.88	1692.85	3851.71	0.25	0.18	39.44	0.00048	
Mean	1.92	19,465.33	64,060.35	0.41	0.36	59.02	0.00028	Oman
Stan. dev.	0.62	1285.67	19,582.69	0.02	0.04	6.16	0.00008	
Maximum	3.21	22,879.50	87,160.52	0.47	0.43	69.08	0.00038	
Minimum	1.02	17,662.20	29,375.08	0.37	0.27	52.88	0.00015	
Mean	3.57	18,330.36	76,357.25	0.31	0.41	50.86	0.00026	Saudi Arabia
Stan. dev.	1.34	1356.96	11,812.37	0.04	0.07	2.71	0.00005	
Maximum	6.14	20,508.10	95,158.55	0.36	0.52	57.48	0.00034	
Minimum	2.07	15,561.50	59,696.38	0.22	0.27	47.37	0.00014	
Mean	32.21	2061.79	1892.68	0.20	0.10	41.59	0.00074	Sudan
Stan. dev.	8.87	239.55	672.19	0.03	0.02	1.45	0.00015	
Maximum	45.04	2381.36	2684.06	0.28	0.14	43.71	0.00115	
Minimum	6.36	1507.84	797.84	0.16	0.08	38.84	0.00055	
Mean	26.96	1177.43	11,075.04	0.20	0.10	39.16	0.00135	Syria
Stan. dev.	6.47	279.58	3579.38	0.02	0.01	5.60	0.00013	
Maximum	40.74	1552.87	15,298.66	0.24	0.12	46.48	0.00167	
Minimum	18.76	744.67	5507.22	0.13	0.07	31.08	0.00108	
Mean	9.41	3410.19	9035.98	0.33	0.20	39.76	0.00049	Tunisia
Stan. dev.	1.40	577.08	946.15	0.05	0.03	1.10	0.00008	
Maximum	13.71	4094.88	10,276.66	0.41	0.25	40.88	0.00071	
Minimum	6.85	2289.40	6736.64	0.28	0.17	36.44	0.00036	
Mean	1.28	49,644.26	149,162.30	0.36	0.40	75.88	0.00022	United Arab Emirates
Stan. dev.	0.63	10,448.34	24,608.33	0.03	0.11	2.66	0.00003	
Maximum	2.33	63,791.60	199,207.40	0.41	0.58	80.55	0.00028	
Minimum	0.63	34,541.00	114,656.60	0.31	0.23	72.68	0.00019	
Mean	13.37	9475.39	29,876.27	0.30	0.26	45.52	0.00069	Total
Stan. dev.	11.64	13,922.02	44,143.54	0.12	0.15	11.45	0.00048	
Maximum	45.04	63,791.60	199,207.40	0.51	0.58	80.55	0.00214	
Minimum	0.63	744.67	509.27	0.04	0.02	31.00	0.00014	

emphasizes the investigated time-period, so as $i = 1, \dots, N, t = 1, \dots, T$. Eq. (1) is modified by bringing in the natural logarithms of variables spotlighted in Tables 1 and is further expressed as (Eq. (2)):

$$LES_{it} = \alpha_{it} + \beta_{1i}LAFP_{it} + \beta_{2i}LAFP_{it}^2 + \beta_{3i}LGDP_{it} + \beta_{4i}LGDP_{it}^2 + \beta_{5i}LENC_{it} + \beta_{6i}LPOP_{it} + \beta_{7i}LFND_{it} + \varepsilon_{it} \tag{2}$$

where, α_{it} and ε_{it} denote country effects, and disturbance term respectively. L signals the natural logarithm while $\beta_{1i} - \beta_{7i}$ depict long-run elasticities.

The dependent variable is ecological intensity which is calculated as ecological footprint per unit of economic activity (GDP). This variable is adopted to assess the ecological security catalyzed by the demand on materials from nature concerning the areas such as: fisheries, forest, cropland, carbon footprint, and build-up land per unit of GDP. High ecological intensity implicates a high cost of converting ecological assets into economic output, while low ES gauges a lower cost of converting

ecological footprint to GDP. The selection of ecological intensity as a proxy for ecological security is justifiable on the ground that it represents a comprehensive ecological indicator (Hu et al., 2024). Notably, contrasted with the traditional proxies like anthropogenic emissions (carbon, methane, sulfur), ES portrays the deterioration of ecological quality in respect to the economic blessings of using materials from nature. The EKC phenomenon proves true if $\beta_{3i} > 0$ and $\beta_{4i} < 0$ (Satrovic et al., 2024b). Precisely, the signs of these coefficients imply that the nexus between ecological intensity and income has a cap shape (\cap). In other words, as country starts the economic sophistication, a rise in income amplifies pollutant emission and curtails ecological security. When $\beta_{3i} = \beta_{4i} = 0$, the ecological security-income nexus is not confirmed. There are several other possibilities, for instance when $\beta_{3i} < 0$ and $\beta_{4i} > 0$, there may be a U-shaped relationship between income and ecological security while when $\beta_{3i} > 0$ and $\beta_{4i} = 0$, an increasing monotonic function is verified. In the light of conceptual framework of the EKC hypothesis, the expected sign of the parameter β_{3i} is positive and β_{4i} is negative (i.e., $\beta_3 = \frac{\partial ES}{\partial GDP} > 0$; $\beta_4 = \frac{\partial^2 ES}{\partial GDP^2} < 0$).

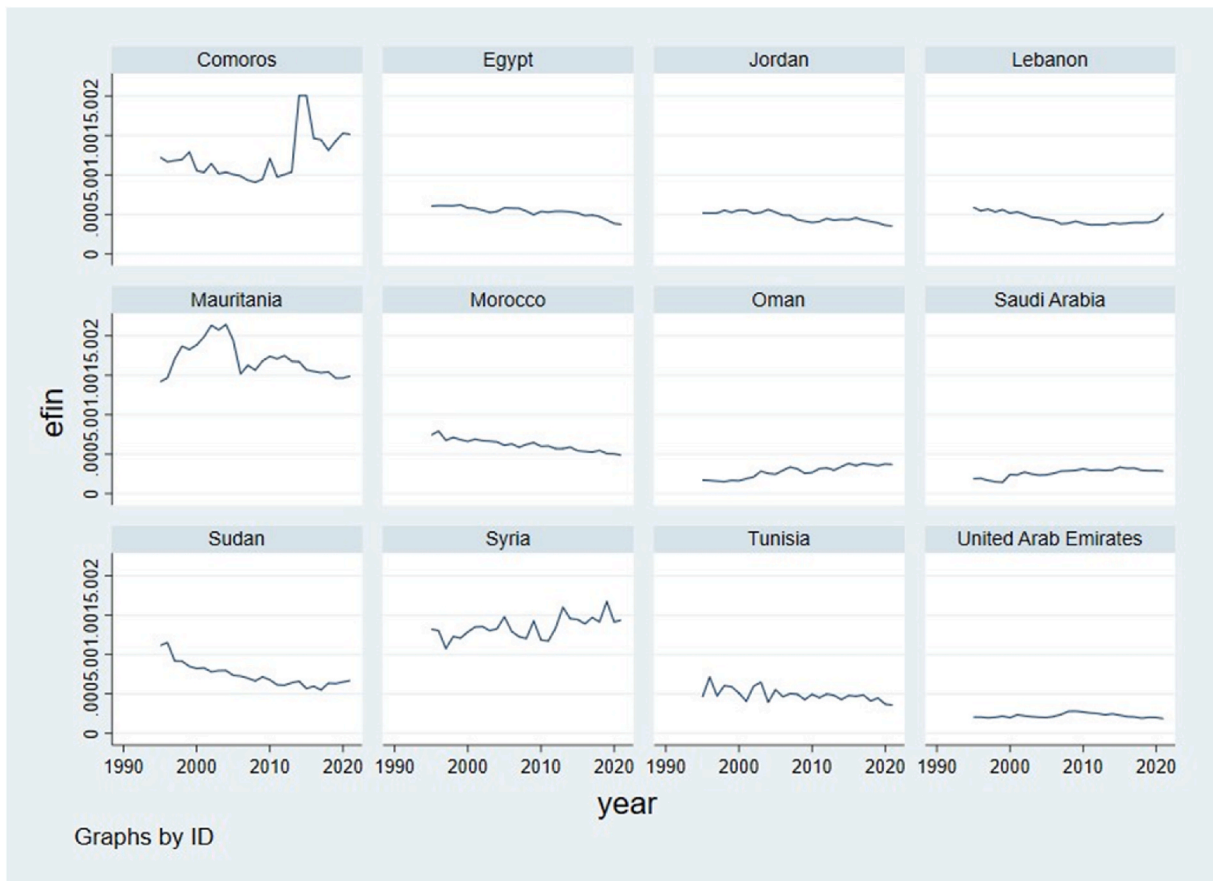


Fig. 1. Ecological intensity – Arab League.

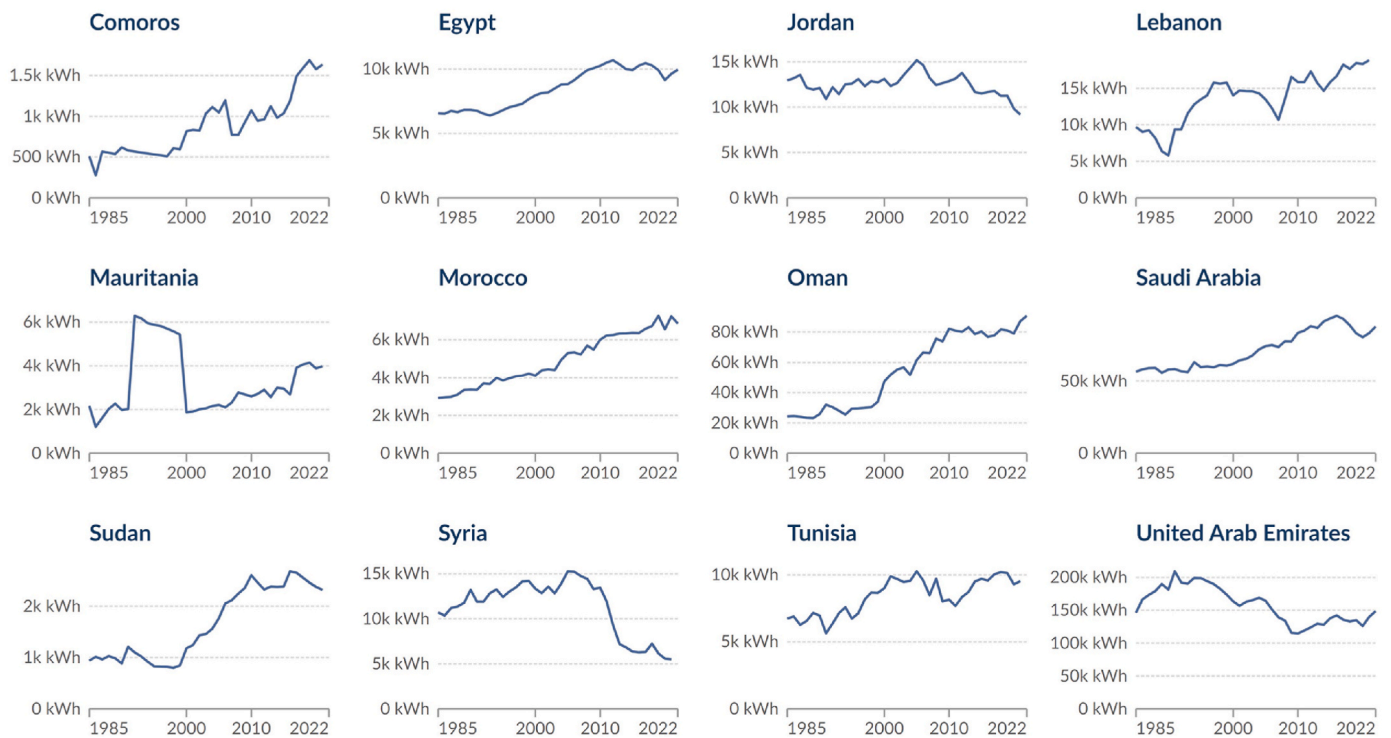


Fig. 2. Energy consumption – Arab League.

Growth in the agricultural sector has gained pervasive attention among research community in the recent decades. This was driven by the substantial population explosion that challenged the ability of governments to produce enough food for all. Following previous the literature (Sansika et al., 2023; Shah et al., 2022; Khurshid et al., 2022), the present research opts for agriculture, forestry, and fishing, value added (% of GDP) - AFP to assess the agricultural production. Agricultural sector is a primary source of food and thus serves out as an important yardstick to ensure the food sufficiency (Fuglie and Wang, 2012). Consequently, the agricultural activity has experienced a substantial growth around the globe accompanied by adverse ecological impact (Ganie et al., 2024). This is attributed to the fact that agriculture induces the deforestation, thus generating substantial emission of methane and other greenhouse gasses that bring about ecological deterioration, inhibition of biodiversity. More so, agriculture uses considerable amount of energy directly (cultivation; heating; harvesting) and indirectly (buildings; agrochemicals production) propelling the energy-related pollutant emissions (Trofimov, 2024). The intensification of agricultural activity is attributable to irrigation being among the key ecological impacting activities as it leads to erosion and water pollution. In addition, agriculture sector uses fertilizers to increase the soil fertility and crop yield. However, an intensive use of fertilizers encourages a corresponding increase in pollutants inhibiting the accomplishment of ecological security (Khurshid et al., 2022).

In the light of conceptual framework of the Borlaug hypothesis, the expected sign of the parameter β_{1i} is positive and β_{2i} is negative (i.e., $\beta_1 = \frac{\partial ES}{\partial AFP} > 0$; $\beta_2 = \frac{\partial ES}{\partial AFP^2} < 0$).

Moreover, combating fossils fuels releases substantial amounts of greenhouse gases causing a worsening of environmental performance. Herein, energy consumption is expected to promote ecological intensity i.e. ($\beta_5 = \frac{\partial ES}{\partial ENC} > 0$). We also account for population and financial development. Population growth is associated with intensified energy consumption, and is just expected to induce adverse impact on ecological security. Then, it is theorized that ecological intensity is ought to be boosted by population i.e. ($\beta_6 = \frac{\partial ES}{\partial POP} > 0$). Further, financial development may culminate in damaging or advancing impact on ecological security ($\beta_7 = \frac{\partial ES}{\partial FND} > 0$ or < 0). FND will be beneficial for ecological security, if affordable loans are used to support eco-friendly activities. However, if financial development motivates individuals and business sector to engage with unsustainable production and consumption, FND will impair ecological security (Ehigiamusoe et al., 2022).

To ascertain the indirect impact of financial development on ecological intensity, our study introduces the combined impact of FNI and ENC and employs the following model (Eq. (3)):

$$LES_{it} = \alpha_{it} + \beta_{1i}LAFP_{it} + \beta_{2i}LAFP_{it}^2 + \beta_{3i}LGDP_{it} + \beta_{4i}LGDP_{it}^2 + \beta_{5i}LENC_{it} + \beta_{6i}LPOP_{it} + \beta_{7i}LMod 1_{it} + \epsilon_{it} \tag{3}$$

where $Mod 1 = FNI * ENC$. The combined effect of FNI and ENC is projected to furnish the disadvantageous impacts on the proxy for ecological security i.e. ($\frac{\partial ES}{\partial FNI * ENC} > 0$). Finally, Eq. (3) is modified to capture the impact of ENC given the alternative proxy for financial development and can be formalized as (Eq. (4)):

$$LES_{it} = \alpha_{it} + \beta_{1i}LAFP_{it} + \beta_{2i}LAFP_{it}^2 + \beta_{3i}LGDP_{it} + \beta_{4i}LGDP_{it}^2 + \beta_{5i}LENC_{it} + \beta_{6i}LPOP_{it} + \beta_{7i}LMod 2_{it} + \epsilon_{it} \tag{4}$$

where $Mod 2 = FNIM * ENC$. The coefficient of moderator is ought to promote ecological intensity i.e. ($\frac{\partial ES}{\partial FNIM * ENC} > 0$).

3.3. Methodology

In the first stage, the authors used the two cross-sectional de-

pendency (CD) tests, namely Pesaran (2007) CD and Pesaran (2015) scaled Lagrange multiplier (LM) test to identify the right econometric techniques to employ. These tests are utilized because the presence of cross-sectional dependence may produce unreliable and biased estimates. Arab League member states have become more economic interdependent since the mid-1990s. The move towards increased economic interdependence has been part of the globalization move. Economic interdependence corroborates the cross-sectional dependence in agricultural production, energy use, and real GDP among the Arab League member states. To address this issue, our study examines the panel cross-sectional dependence. Pesaran (2015) scaled LM test equation is formalized as (Eq. (5)):

$$CD = \left(\frac{TN(N-1)^{\frac{1}{2}} - P}{2} \right) \tag{5}$$

where $P = \left(\frac{2}{N(N-1)} \right) \sum_{i=1}^{N-1} \sum_{j=i+1}^N P_{ij}$, P_{ij} denote the correlation coefficients.

This study also employs the Pesaran (2007) CD test, out of which the test equation is shown in Eq. (6) as:

$$CD = \sqrt{\frac{2T}{N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^N \hat{\rho}_{ij}} \tag{6}$$

where $\hat{\rho}_{ij}$ signals the residual correlation.

Additionally, the study utilizes the Pesaran and Yamagata (2008) slope homogeneity test to examine the heterogeneity of slope coefficients. This test provides both ordinary and adjusted measures of slope coefficient heterogeneity. To address concerns related to slope coefficient heterogeneity and cross-sectional dependence, the study employs a stationarity test with panel data. In particular, the research applies the cross-sectionally augmented (CIPS) panel unit root test introduced by Im et al., 2003 and proposed by Pesaran (2007). The null hypothesis is $H_0 : \beta_i = 0$ for all cross-sections versus the alternatives $H_1 : \beta_i < 0$. Westerlund (2005) cointegration test is used in our study to evaluate long-run equilibrium linkages amid the selected variables.

To evaluate the mean impacts of independent variables on ecological intensity, the ordinary least squares (OLS) regression with Driscoll-Kraay standard errors is applied. Since this estimator may provide underestimated or overestimated results, suggested by Ahmad and Satrovic, 2023a, our study opted for the panel Method of Moments Quantile Regression (MMQR) with fixed effects devised by Machado and Silva (2019). The MMQR estimates the parameters addressing the dependent variable's different levels (quantiles). Particularly, it estimates the impact of agricultural production, real GDP per capita, their squared terms, energy consumption, population, and financial development on ecological security of Arab League member states with low, intermediate, and high levels of ecological intensity. Eq. (7) provides the panel quantile regression specification, as presented below:

$$Q_{Y_{it}}(\tau|X_{it}) = \alpha(\tau)'X_{it} + \beta_i, i = 1, \dots, N, t = 1, \dots, T \tag{7}$$

Here, Y_{it} stands for the ecological intensity, X_{it} signals the regressors, $\alpha(\tau)$ represents the unknown coefficients, β_i divulges the unobserved individual effects. Our models in Table 6 are formalized as (Eqs. (8)–(11)):

$$Q_{LES}(\tau|X_{it}) = a_{1\tau}LAFP_{it} + a_{2\tau}LAFP_{it}^2 + a_{3\tau}LGDP_{it} + a_{4\tau}LGDP_{it}^2 + a_{5\tau}LENC_{it} + a_{6\tau}LPOP_{it} + a_{7\tau}LFNI_{it} + \beta_i \tag{8}$$

$$Q_{LES}(\tau|X_{it}) = a_{1\tau}LAFP_{it} + a_{2\tau}LAFP_{it}^2 + a_{3\tau}LGDP_{it} + a_{4\tau}LGDP_{it}^2 + a_{5\tau}LENC_{it} + a_{6\tau}LPOP_{it} + a_{7\tau}LFNIM_{it} + \beta_i \tag{9}$$

$$Q_{LES}(\tau|X_{it}) = a_{1\tau}LAFP_{it} + a_{2\tau}LAFP_{it}^2 + a_{3\tau}LGDP_{it} + a_{4\tau}LGDP_{it}^2 + a_{5\tau}LENC_{it} + a_{6\tau}LPOP_{it} + a_{7\tau}LMod1_{it} + \beta_i \tag{10}$$

$$Q_{LES}(\tau|X_{it}) = a_{1\tau}LAFP_{it} + a_{2\tau}LAFP_{it}^2 + a_{3\tau}LGDP_{it} + a_{4\tau}LGDP_{it}^2 + a_{5\tau}LENC_{it} + a_{6\tau}LPOP_{it} + a_{7\tau}LMod2_{it} + \beta_i \tag{11}$$

Based on Eqs. (10) and (11), Mod1 = FNI*ENC, Mod2 = FNIM*ENC. In the final stage, we identify the causal nexus between the dependent variable and regressors. In this vein, our study uses causality test proposed by Dumitrescu and Hurlin (2012).

4. Discussion of results

4.1. Pre-estimation diagnostics

As a first step, this study analyses the potential cross-sectional dependence and slope heterogeneity. The estimated results for Pesaran (2007) CD, Pesaran (2015) and Pesaran and Yamagata (2008) tests are provided in Table 3.

According to the results presented in Table 3, the outcomes of the analysis support the rejection of the null hypothesis of cross-sectional independence. This suggests that the variables examined in the study are not independent across different sections. As previously discussed, economic interdependence within the Arab League member states leads to increased cross-border movement of goods and strengthens the links among these states. Consequently, it implies that a shock in agricultural production, real GDP per capita, energy consumption, population, financial development, and ecological intensity in one Arab League member state is likely to have spillover effects on other member states.

Regarding slope heterogeneity, the results indicate that the values of Δ and Δ adj. are statistically significant at a 1% significance level. This suggests that the null hypothesis of homogenous slope coefficients can be rejected, indicating that the slope coefficients are not uniform. As a result, the analysis allows for the estimation of a heterogeneous panel. Therefore, to address the issues of cross-sectional dependence and slope heterogeneity, the study employs a second-generation panel unit root test, specifically the cross-sectionally augmented (CIPS) panel unit test with constant and trend proposed by Im et al., 2003. The results of this test are presented in Table 4.

According to the results in Tables 4 and it is evident that all the variables do not meet the criteria for the null hypothesis of being non-stationary at their levels. Further examination involved testing the variables on their first differences. In this case, the findings show that all variables are significant in rejecting the null hypothesis of a unit root. Since the variables do not exhibit the unit root problem when differenced, then the long-run equilibrium relationships among the study variables is examined. Table 5 presents the results from the panel cointegration tests.

From Table 5, the associated values of Westerlund (2005) cointegration test are significant at 1% and 5% level, respectively rejecting the

Table 3
Results of cross-sectional dependence (CD) and the slope homogeneity tests.

Model/Test	Pesaran (2007) CD	Pesaran (2015) LM	Pesaran and Yamagata (2008) Δ	Pesaran and Yamagata (2008) Δ adj
LES = f(LAFP, LAFP ² , LGDP, LGDP ² , LENC, LPOP, LFNI)	-3.253 ^a	28.851 ^a	10.498 ^a	12.858 ^a
LES = f(LAFP, LAFP ² , LGDP, LGDP ² , LENC, LPOP, LFNIM)	-3.045 ^a	29.300 ^a	10.406 ^a	12.744 ^a

Note: p values in parentheses, ^a p < 0.01, ^b p < 0.05, ^c p < 0.10, L-natural logarithm.

Table 4
CIPS unit root tests.

Var.	Levels	1st Diff
LAFP	-2.876 ^b	-4.589 ^a
LAFP ²	-2.942 ^b	-4.638 ^a
LGDP	-2.161	-3.916 ^a
LGDP ²	-2.158	-3.851 ^a
LENC	-1.841	-4.460 ^a
LPOP	-2.165	-3.513 ^a
LFNI	-3.228 ^a	-5.468 ^a
LFNIM	-3.194 ^a	-5.367 ^a
LES	-2.640	-5.322 ^a

Note: ^a p < 0.01, ^b p < 0.05, ^c p < 0.10.

Table 5
Cointegration tests.

Model/Statistic	Westerlund (2005) Stat.
LES = f(LAFP, LAFP ² , LGDP, LGDP ² , LENC, LPOP, LFNI)	-2.361 ^a
LES = f(LAFP, LAFP ² , LGDP, LGDP ² , LENC, LPOP, LFNIM)	-2.303 ^b

Note: ^a p < 0.01, ^b p < 0.05, ^c p < 0.10.

null hypothesis of no cointegration. Such significant values confirm the existence of long-run equilibrium connection between the study variables. Specifically, agricultural production, real GDP per capita, energy consumption, population, financial development, and ecological security are cointegrated in the long run. Herein, the presence of cointegration among the study variables for the Arab League member states is accurate and efficient.

4.2. Coefficient results

4.2.1. MMQR result

Based on Table 6 and Fig. 2 (Appendix), MMQR approach that considers slope heterogeneity shows U-shaped relationship between agricultural production and ecological intensity and between GDP and ecological intensity. This translates that in the early stages of agricultural production and economic growth, ecological intensity decreases, but beyond a certain threshold the trend reverses, so that higher agricultural production and economic growth lead to higher ecological intensity, thus jeopardizing ecological security. Specifically, the results confirm that higher agricultural production and economic growth are associated with higher ecological intensity in the later stages of economic emancipation, thus failing to prove the existence of the Borlaug and EKC hypothesis respectively. This is attributed to the fact that agricultural production emits substantial amounts of methane and other pollutants bringing about ecological concerns. It is equally noticeable from our findings that agricultural production is inefficient in minimizing soil degradation and mitigating deforestation of Arab League member states. Intuitively, it can be inferred that the initial advantageous ecological impact of agricultural production is shifted to harmful as intensified food production culminates in ecological challenges such as pollution and irrigation issues. Another reason for adverse ecological impact of agricultural production at the later stages of growth could be attributed to the substantive use of energy in cultivation and heating process furnishing the release of carbon emissions from fossil fuels which create damaging ecological impacts inhibiting biodiversity. In addition, agricultural production exerts negative impact on ecological security through land conversion that modifies the purpose of land from non-agricultural to agricultural. The non-conformity of Borlaug hypothesis uncovers that the selected Arab League members use energy inefficient methods of agricultural production, a result consistent with (Ganie et al., 2024). In other words, farming systems of the investigative laboratory are high energy-intensive and substantially rely on irrigation

Table 6
Panel quantile regression model and ordinary least square (OLS).

Model	Var./QR	OLS		0.1 QR		0.3 QR		0.5 QR		0.7 QR		0.9 QR	
		Coef.	P > z	Coef.	P > z	Coef.	P > z	Coef.	P > z	Coef.	P > z	Coef.	P > z
Model 1: LES = f(LAFP, LAFP ² , LGDP, LGDP ² , LENC, LPOP, LFN)	LAFP	-0.225 ^a	0.001	-0.453 ^a	0.001	-0.306 ^a	0.000	-0.211 ^a	0.001	-0.127 ^c	0.095	-0.017	0.884
	LAFP ²	0.049 ^a	0.001	0.085 ^a	0.007	0.062 ^a	0.001	0.047 ^a	0.003	0.033 ^c	0.069	0.015	0.568
	LGDP	-2.787 ^a	0.000	-3.964 ^a	0.000	-3.202 ^a	0.000	-2.711 ^a	0.000	-2.275 ^a	0.000	-1.705 ^b	0.034
	LGDP ²	0.132 ^a	0.000	0.216 ^a	0.000	0.162 ^a	0.000	0.127 ^a	0.000	0.096 ^a	0.004	0.055	0.260
	LENC	0.141 ^a	0.000	0.114	0.221	0.132 ^b	0.019	0.143 ^a	0.002	0.153 ^a	0.004	0.166 ^b	0.035
	LPOP	1.131 ^a	0.000	1.010 ^a	0.003	1.088 ^a	0.000	1.138 ^a	0.000	1.183 ^a	0.000	1.242 ^a	0.000
	LFNI	0.128 ^c	0.067	0.026	0.857	0.092	0.287	0.135 ^c	0.057	0.173 ^b	0.035	0.222 ^c	0.067
Model 2: LES = f(LAFP, LAFP ² , LGDP, LGDP ² , LENC, LPOP, LFNIM)	LAFP	-0.171 ^b	0.011	-0.406 ^a	0.003	-0.255 ^a	0.003	-0.150 ^b	0.037	-0.070	0.402	0.056	0.671
	LAFP ²	0.041 ^a	0.003	0.077 ^b	0.014	0.054 ^a	0.005	0.037 ^b	0.022	0.025	0.194	0.005	0.864
	LGDP	-2.854 ^a	0.000	-4.088 ^a	0.000	-3.295 ^a	0.000	-2.742 ^a	0.000	-2.323 ^a	0.000	-1.661 ^c	0.050
	LGDP ²	0.137 ^a	0.000	0.220 ^a	0.000	0.167 ^a	0.000	0.129 ^a	0.000	0.101 ^a	0.002	0.056	0.282
	LENC	0.138 ^a	0.000	0.130	0.153	0.135 ^b	0.014	0.139 ^a	0.003	0.142 ^b	0.010	0.146 ^c	0.081
	LPOP	1.119 ^a	0.000	1.028 ^a	0.001	1.087 ^a	0.000	1.128 ^a	0.000	1.159 ^a	0.000	1.207 ^a	0.000
	LFNIM	0.162 ^a	0.001	0.100	0.363	0.140 ^b	0.036	0.167a	0.003	0.188 ^a	0.005	0.221 ^b	0.031
Model 3: LES = f(LAFP, LAFP ² , LGDP, LGDP ² , LENC, LPOP, LMod1)	LAFP	-0.225 ^a	0.001	-0.453 ^a	0.001	-0.306 ^a	0.000	-0.211 ^a	0.001	-0.127 ^c	0.095	-0.017	0.884
	LAFP ²	0.049 ^a	0.001	0.085 ^a	0.007	0.062 ^a	0.001	0.047 ^a	0.003	0.033 ^c	0.069	0.015	0.568
	LGDP	-2.787 ^a	0.000	-3.964 ^a	0.000	-3.202 ^a	0.000	-2.711 ^a	0.000	-2.275 ^a	0.000	-1.705 ^b	0.034
	LGDP ²	0.132 ^a	0.000	0.216 ^a	0.000	0.162a	0.000	0.127 ^a	0.000	0.096 ^a	0.004	0.055	0.260
	LENC	0.013	0.874	0.089	0.576	0.040	0.677	0.008	0.916	-0.020	0.828	-0.056	0.674
	LPOP	1.131 ^a	0.000	1.010 ^a	0.003	1.088 ^a	0.000	1.138 ^a	0.000	1.183 ^a	0.000	1.242 ^a	0.000
	LMod1	0.128 ^c	0.067	0.026	0.857	0.092	0.287	0.135 ^c	0.057	0.173 ^b	0.035	0.222 ^c	0.067
Model 2: LES = f(LAFP, LAFP ² , LGDP, LGDP ² , LENC, LPOP, LMod2)	LAFP	-0.171 ^b	0.011	-0.406 ^a	0.003	-0.255 ^a	0.003	-0.150 ^b	0.037	-0.070	0.402	0.056	0.671
	LAFP ²	0.041 ^a	0.003	0.077 ^b	0.014	0.054 ^a	0.005	0.037 ^b	0.022	0.025	0.194	0.005	0.864
	LGDP	-2.854 ^a	0.000	-4.088 ^a	0.000	-3.295 ^a	0.000	-2.742 ^a	0.000	-2.323 ^a	0.000	-1.661 ^c	0.050
	LGDP ²	0.137 ^a	0.000	0.220 ^a	0.000	0.167 ^a	0.000	0.129 ^a	0.000	0.101 ^a	0.002	0.056	0.282
	LENC	-0.023	0.671	0.029	0.832	-0.005	0.956	-0.028	0.689	-0.046	0.581	-0.074	0.561
	LPOP	1.119 ^a	0.000	1.028 ^a	0.001	1.087 ^a	0.000	1.128 ^a	0.000	1.159 ^a	0.000	1.207 ^a	0.000
	LMod2	0.162 ^a	0.001	0.100	0.363	0.140 ^b	0.036	0.167 ^a	0.003	0.188 ^a	0.005	0.221 ^b	0.031

Note: ^a p < 0.01, ^b p < 0.05, ^c p < 0.10, Mod1 = FNI*ENC, Mod2 = FNIM*ENC, QR = Quantile regression.

and fertilizers that do not only contribute to soil fertility but also to ecological challenges such as water pollution and erosion. These findings are in line with (Shah et al., 2022; Trofimov, 2024) portraying that an increase in agricultural activity inhibits the biodiversity and induces the deforestation and waste generation affecting environmental quality of developing countries. The adverse environmental impact of agricultural production is also found by (Sansika et al., 2023) uncovering that eco-unfriendly fertilizers and traditional farming methods support the climate change and environmental deterioration. Moreover, for income growth and environmental degradation nexus, these findings align with the research of Villanthenkodath et al. (2023) and Alhassan (2021) but contradict the conclusions of Verbič et al. (2022).

Given the findings displayed in Table 6 and Fig. 2, it is pertinent to notify that EKC phenomenon cannot be substantiated for Arab League members. The results imply a U-shaped ecological intensity-economic expansion nexus unfolding the persistence of scale effect in the underlying sample of countries. In particular, the adverse ecological impact of economic expansion which is peculiar to scale effect surpasses the beneficial environmental impacts of factors related with composition effect at the higher stages of growth. This outcome is quite predictable in light of Arab League as it still endures initial growth stage where the economic expansion takes precedence over ecological resilience. These findings further insinuate only limited progress in economic transformation towards energy and carbon efficient sectors, which is justified by the fact that Arab League members are leading exporters of oil gauging that composition effect is ineffective in facing out the adverse consequences of scale effect at the higher stages of growth. Notably, scale effect uncovers that intensified energy use in the production will drive up pollutants and consequently give rise to ecological deterioration of analyzed countries. As far as the technique effect is observed, Arab League members are strongly reliant on advanced nations to secure the access to modern technologies and innovations (Organization of the Petroleum Exporting Countries OPEC, 2016). Herein, neither composition nor technique effects are in position to deepen the ecological security of the inspected Arab League members as these fail to abolish the

repercussions of scale effect.

Similarly, energy consumption is positively associated with ecological intensity. An increase in energy consumption worsens ecological security. The coefficients related to energy consumption demonstrate an increasing trend across different quantiles, indicating that the adverse ecological effects of energy consumption are more pronounced in Arab League member states with higher ecological intensity in model without moderation (Model 1). However, energy consumption exhibits a positive and statistically significant influence on ecological intensity between 20th and 90th quantiles in models without moderation. This environmental degradation associated with energy consumption can be attributed to several contributing factors. First, the production and consumption of energy have resulted in environmental pressures. Second, there is a limited access to environmentally friendly products that has considerably increased the concentration of anthropogenic emissions in the atmosphere. Next, the non-conformity of EKC hypothesis inflicts that the scale effect is the most prevalent channel to justify the link between economic expansion and environment in Arab League. Herein, the surge in production is attributed to an upswing in energy consumption being among the leading production inputs. Given that the majority of manufacturing methods are dependent on energy, a rise in economic output inevitably facilitates anthropogenic emissions. This result coincides with those reported by Jena et al. (2022) gauging that fossil fuels inhibit the accomplishment of sustainable development goals. Similarly, Mohsin et al. (2023) uncovered that energy exerts an adverse environmental impact portraying the necessity to shift to green technology for the accomplishment of net-zero objectives.

Additionally, the results indicate that financial development has a positive effect on the ecological intensity (see Table 6). Notably, the coefficients associated with depth, access, and efficiency of financial institutions exhibit an increasing trend across various quantiles, suggesting that the adverse impact of financial development is more pronounced in Arab League member states with higher ecological intensity in Model 1. It can be attributed to the fact that financial development may induce adverse ecological impacts, as the access to loans that fulfill

individuals' and business' financial need supports traditional production methods accompanied by an intensive use of energy that increases the anthropogenic emissions and reduces ecological security. Financial development hinders the achievement of ecological security in Arab League as outlined by the positive and statistically significant coefficient of LFNI in Model 1. The adverse ecological impact of FNI is justifiable in a sense that cheap and easy accessible loans will enable business sector to deepen their carbon intensive production that further challenges the ecological quality. In addition, individuals may also use these loans to purchase energy-intensive gadgets which in turn encourage environmental deterioration. The positive coefficient of financial development demonstrates that financial system of Arab League prioritizes projects that run economic expansion irrespective of their environmental impact, a result consistent with (Satrovic et al., 2024a). In addition, the countries of interest are lagging behind advanced nations in terms of financial performance with the lack of progress towards funding eco-friendly projects. However, these outcomes do not coincide with Ahmad and Satrovic (2024) who unfolded that financial development facilitates the realization of environmental quality objectives in OECD countries.

Similarly, the result posits adverse environmental impact of population in the Arab League member states. Although this outcome is naturally expected, the transformation of the natural environment into the built environment has become one of the most significant sources of anthropogenic environmental disturbance. Population expansion is one of the key determinants of environmental deterioration as it requests more natural resources to satisfy human needs, generates more waste from resources extraction, and accordingly generates more pollutants. The results confirm the findings of Jena et al. (2022), Sultana et al. (2022), and Iqbal et al. (2023).

4.2.2. Indirect effects of FND

To assess the indirect impact of financial development on ecological intensity, we introduced interaction terms, namely FNI and ENC (Model 3). The positive effect of energy consumption on ecological intensity is reduced compared to our baseline model, insinuating that financial development may inhibit the adverse ecological impact of energy consumption. This is since Arab League is working towards the improvement of financial system and imposing stringent regulations that will foster financial institutions to support greener projects. As such financial sector may be providing cheap loans to support modern technologies that will not only save energy but also contribute to the ecological security. As such, scale effect may be altered with composition and technique effects to explain the economic emancipation-environmental nexus. Financial sector may also be effective in boosting the capability of Arab League members to reach their own technological improvements that will indeed reduce their dependence on advanced nations' innovations. This finding aligns with the research of Ehigiamusoe (2020) noting that the joint impact of financial development and energy on environment is positive.

4.3. Robustness

The specific effects of regressors on ecological intensity using OLS serves as robustness to the panel quantile regression results in Table 6. Additionally, visual representation of the quantile regression analysis is also shown in Fig. 2 (see Appendix). The OLS estimator revealed that agricultural production and its square term have opposing effects on ecological intensity. Precisely, a 1% increase in agricultural production reduces ecological degradation by 0.225%, while an increase in the squared term enhances it by 0.049% (Model 1). The coefficients of LAFP and LAFP² in Table 6 indicate a U-shaped relationship between agricultural production and ecological intensity.

Concerning real GDP per capita and its squared term, the negative and positive coefficients, respectively, also suggest a U-shaped pattern. Specifically, a 1% increase in real GDP per capita reduces ecological intensity by 2.787%, while an increase in the squared term enhances it

by 0.132%. The results emphasize that energy consumption, population, and financial development significantly contribute to increased ecological intensity in the Arab League member states. These findings are consistent and statistically significant such that a 1% increase in energy consumption, population, and FNI leads to an ecological intensity increase of 0.141%, 1.131%, and 0.128%, respectively. We also examined the indirect impact of financial development on ecological intensity. Specifically, the interaction terms between financial development and energy consumption (in Model 3), are significantly positive.

To ensure the reliability of our base model, depth, access, and efficiency of financial markets and institutions was introduced as an additional proxy for FND. The results, as shown in Table 6 and Figure A2, reaffirm a U-shaped pattern in the relationship between ecological intensity and AFP, as well as between ecological intensity and GDP, in model without moderation (Model 2). These outcomes suggest that higher levels of agricultural production and income are linked to a compromise in ecological intensity from the angle of FNIM as an indicator of FND. The outcomes also underscore that energy consumption, population, and FNIM have adverse effects on the ecological security of our study group. The interaction term of FNIM and energy consumption in Model 4 unfolds that ENC enhances ecological intensity via the channel of FNIM. The coefficients in Models 2 and 4, align with those presented for Models 1 and 3, thereby strengthening the robustness of our initial findings.

Moreover, because neither the OLS regression nor the panel quantile regression can establish a causal relationship between the study variables, we conducted the Granger causality test to investigate this aspect. In this regard, our study adopted the causality test proposed by Dumitrescu and Hurlin (2012), the results of which are summarized in Table 7. From Table 7, agricultural production unilaterally causes ecological intensity. In addition, population and financial development unilaterally cause the indicator of ecological security. The estimated results also reveal bidirectional causality between real GDP per capita, energy, and ecological intensity. Here, the bidirectional causality affirms that real GDP per capita and energy consumption are among the key factors of ecological intensity in the present research that considers 12 Arab League members in the period from 1995 to 2021.

5. Conclusion and policy recommendation

The notion of a green economy, which integrates many aspects of economic development, energy systems, and ecological preservation, has unquestionably emerged as a prominent subject of study in both economic and environmental literature in recent decades. Extensive endeavours have been undertaken to investigate methods for enhancing green productivity growth, focusing on economic conditions, energy consumption, and ecological conditions. However, there exists a dearth of understanding regarding the impact of newly developed agricultural production on ecological intensity. This study aims to fill the existing gap in the academic literature by employing a comprehensive index that measures agricultural production, real GDP per capita, energy

Table 7
The DH Granger causality evidence.

Null hypothesis	Z-bar stat	Prob.
LAFP→LES	4.335 ^b	0.038
LES→LAFP	2.141	0.144
LGDP→LES	3.903 ^b	0.049
LES→LGDP	3.305 ^c	0.070
LENC→LES	3.723 ^c	0.054
LES→LENC	13.959 ^a	0.000
LPOP→LES	4.391 ^b	0.037
LES→LPOP	0.133	0.715
LFNI→LES	5.301 ^b	0.022
LES→LFNI	0.264	0.608

Note: ^a p < 0.01, ^b p < 0.05, ^c p < 0.10.

consumption, and the direct and moderating effects of financial development and population on ecological sustainability. The analysis focuses on the environmental Kuznets curve (EKC) hypothesis and examines a panel dataset consisting of 12 member states of the Arab League from 1995 to 2021.

The analysis findings suggest the presence of a U-shaped correlation between agricultural production and ecological intensity. The argument suggests that during the initial phases of agricultural development, there is a decrease in ecological intensity up to a specific threshold. However, after agricultural production exceeds this threshold, there is an increase in ecological intensity. This observation contradicts the Borlaug hypothesis. Moreover, this study does not support the inverted U-shaped EKC hypothesis. This suggests that there is U-shaped link between real GDP per capita and ecological intensity in these countries. Additionally, the study has substantiated the notion that energy use contributes to environmental degradation when not considered in conjunction with financial development, as well as their relationship. The favourable effects of energy usage are found to be diminished when considering interaction factors. The findings of the causality analysis indicate that there is a one-way causal relationship from agricultural production to ecological intensity. Moreover, a bidirectional relationship is observed between real GDP per capita, energy, and ecological intensity.

5.1. Policy recommendation

Based on the findings, subsequent policy implications are derived. To advance the cause of ecologically sustainable agricultural practices, it is recommended that Arab League nations persist in their efforts to advocate for the adoption of a zero-growth approach towards chemical fertilisers. Additionally, conducting experiments aimed at substituting chemical fertilisers with organic alternatives should be pursued, with the goal of enhancing cost-effectiveness and efficiency within the agricultural sector. Moreover, it is advisable for Arab League countries to initiate actions aimed at creating and improving a robust production oversight and monitoring system for the chemical fertilizer sector. This endeavour should be coupled with the rigorous enforcement of industry access management measures. Additionally, concerted efforts should be directed towards the establishment of a national agricultural sustainable development pilot demonstration area with the objective of minimizing emissions. Based on these premises, it is imperative for the Arab League countries to enhance its endeavours in regulating carbon emissions in the agricultural sector, implement measures to conserve agricultural fertilisers, attain a decline in fertiliser consumption, and foster sustainable practices in agricultural activities.

Furthermore, Arab League nations should prioritize several key actions to drive a sustainable agricultural sector. They need to actively promote the seamless integration of industrialization and agricultural modernization while fostering increased transparency in agriculture activities. It is essential for these countries to place a strong emphasis on encouraging agricultural land consolidation, facilitating large-scale agricultural operations, attracting industrial production elements into agriculture, and improving the efficiency of agricultural land transfers.

Moreover, Arabian states must prioritize the advancement of agricultural science and technology, integrate agricultural mechanization into production, enhance overall agricultural sector productivity, facilitate the transition to agricultural industrialization, establish a mutually beneficial relationship between industry and agriculture, and increase the value-added aspect of agricultural production. In addition, the Arab League nations should consider implementing fiscal and industrial policies to nurture the growth of their agricultural sector. These policies should be coupled with efforts to achieve a harmonious balance between industry and agriculture, promote collaboration in agriculture with

foreign nations, incentivize the export of competitive agricultural products, facilitate agricultural expansion abroad, promote the mutual recognition of agricultural product certifications, and increase the level of agricultural openness. These measures aim to enhance agricultural production and ultimately lead to the high-quality development of the agricultural economy within the Arab League countries.

Considering the rejection of the modified environmental Kuznets curve (EKC) theory, it is not tenable to regard economic progress as a panacea for environmental challenges. Hence, it is imperative for the Arab League nations to intensify their endeavours to foster enhanced economic growth, thereby creating a favourable climate for mitigating the adverse effects of the ecological crisis. This implies that the expansion of a nation could potentially be constrained as a means of managing and mitigating environmental damage. Furthermore, it is imperative to incorporate additional measures that enhance environmental sustainability, such as the implementation of afforestation/reforestation initiatives, the use of energy-saving technology, and the exploration of various growth choices that prioritize environmental preservation. Moreover, it is imperative to implement active policy interventions, such as stringent environmental legislation, to promote enhanced environmental sustainability alongside increased economic growth within the region.

5.2. Study limitations

In conclusion, this study addresses a significant research gap pertaining to the relationship between agricultural total factor output and ecological intensity. However, there are still unresolved inquiries that need to be identified, hence suggesting alternative avenues for future investigation. Initially, our basic research just focuses on empirically examining the relationship between agricultural production and ecological sustainability within a linear framework. In recent years, there has been a notable increase in scholarly interest regarding the non-linear dynamics characterising the interplay between the economy and the environment. To have a comprehensive understanding of agricultural production, it would be valuable to add variables like green finance, service value added, green technology, etc. to identify their impact on ecological sustainability across various market circumstances or states. Furthermore, sustainable development is a comprehensive concept that encompasses various aspects within the realms of economics, ecology, and society. Due to the inherent challenges associated with evaluating social impact, this study primarily concentrates on analysing economic and environmental outcomes. A future study should explore this dimension to enhance the existing literature on agricultural production.

CRediT authorship contribution statement

Elma Satrovic: Writing – original draft, Formal analysis, Conceptualization. **Bright Akwasi Gyamfi:** Writing – original draft, Formal analysis, Conceptualization. **Andrew Adewale Alola:** Writing – review & editing. **Divine Q. Agozie:** Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix

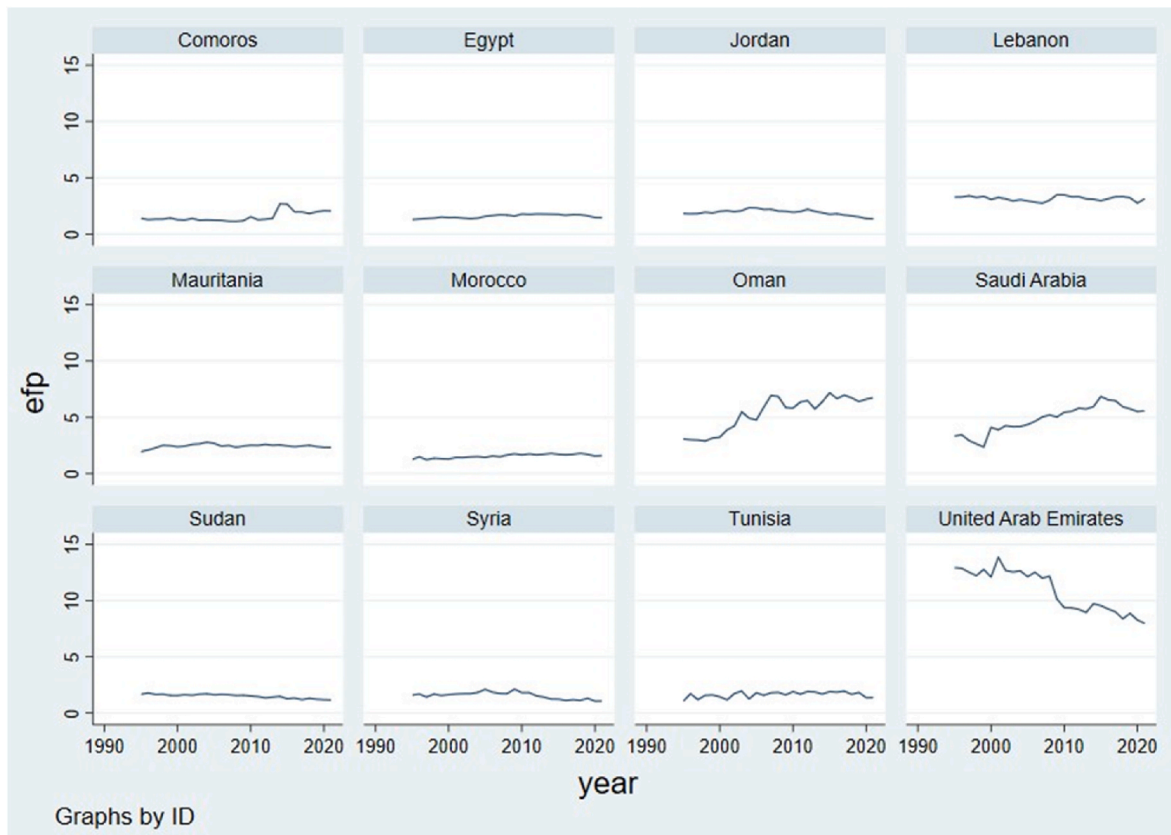
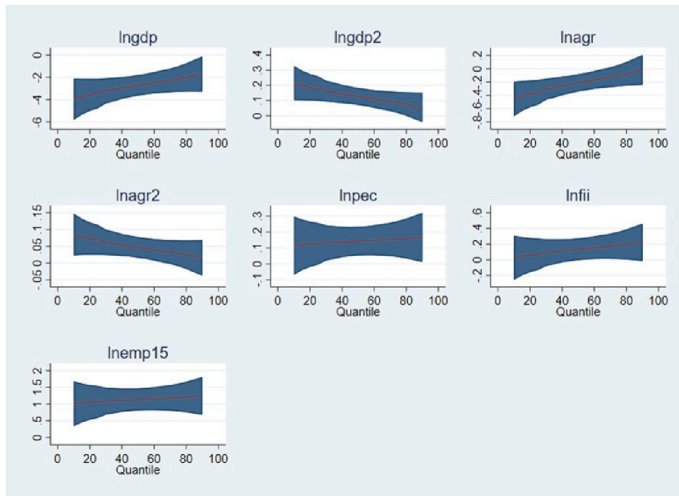
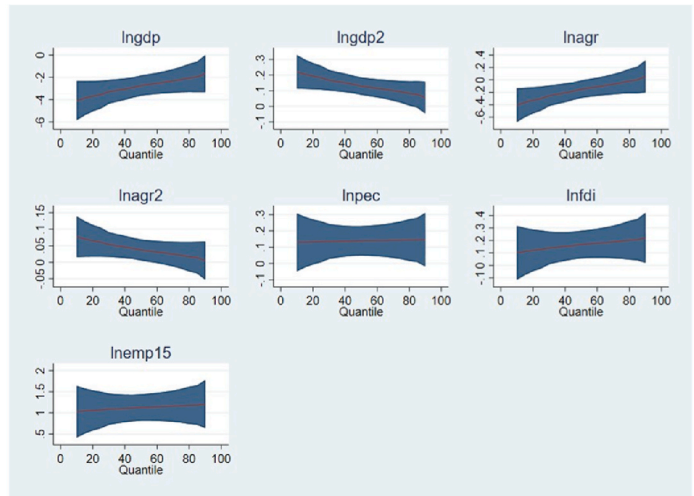


Fig. 1. Ecological footprint – Arab League.

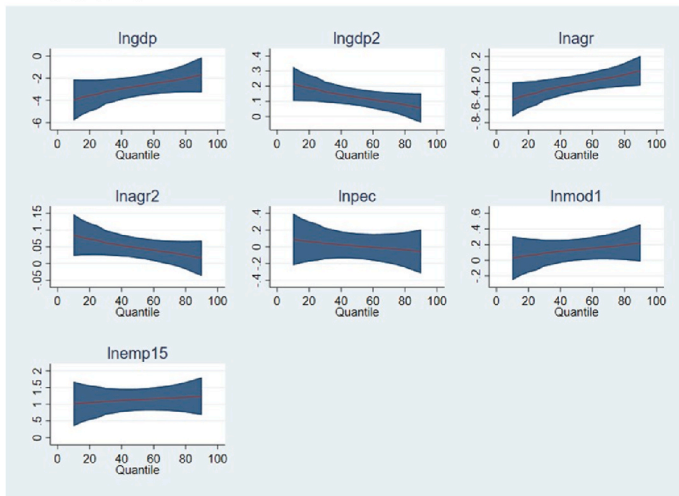
Model 1



Model 2



Model 3



Model 4

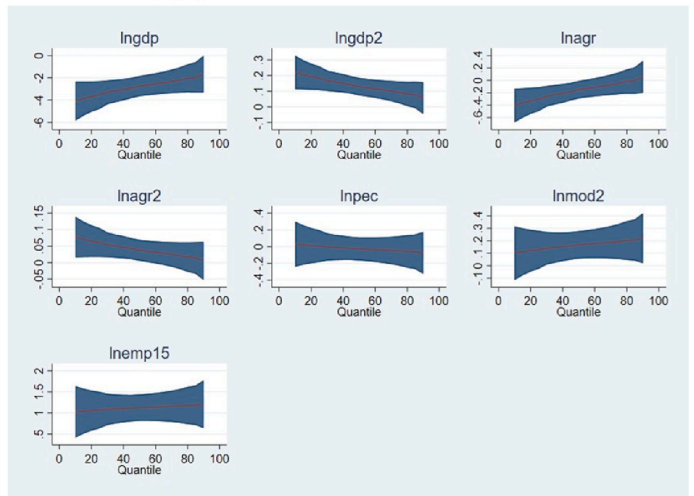


Fig. 2. Plotting coefficients of quantile regression

Note: lngdp = LGDP, lngdp2 = LGDP2, lnagr = LAFP, lnagr2 = LAFP2, lnpecc = LENC, lnemp15 = LPOP, lnffi = LFNI, lnfdi = LFNIM, lnmod1 = LMod1, lnmod2 = LMod2.

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