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Original Research Articles

The Role of Aquaculture and Fisheries in EU27 Food Security: A Comparative Analysis of EU13 and EU14 States

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Ocean-sourced foods are essential for providing food security, putting an end to starvation, and building healthy, environmentally friendly, and resilient food systems. Still, it is important to keep these in mind while discussing food. More money was made for developing countries by exporting blue foods than by exporting any other agricultural products combined. The European Union Region (EU27) has countries with diverse economic structures, from highly developed industrial economies in older members to those in Central and Eastern Europe still catching up. Splitting them allows for in-depth study of economic structures, models, and growth mechanisms, and can inform targeted policy recommendations for growth and convergence. The core objective of this study is to analyse how aquaculture and fisheries production impact food security in the EU2 members based on their economic structure development; European Union Developing State (EU13) and European Union Developed State (EU14) countries from 1990 to 2023. To address potential endogeneity issues, robust least squares (RLS), two-stage least squares (2SLS), and ordinary least squares (OLS) estimators were employed, leading to significant findings. The findings confirm the existing knowledge and indicate that the role of aquaculture and fisheries production in ensuring food security is more pronounced in developing EU13 countries compared to wealthier EU14 countries. Aligning with existing knowledge, the analysis reveals that factors such as gross domestic product (GDP) and governance play a more crucial role in ensuring sustainable food security in developing EU13 countries relative to their wealthier EU14 counterparts. The reliance on fossil fuels has a more pronounced impact on food insecurity in developed EU14 nations compared to developing EU13 countries. This study suggests that policymakers in the EU14 developed countries provide policies targeted at promoting the growth of aquaculture production and fisheries production top priority based on the research conclusions. Additionally, this study suggests that policymakers in the industrialized EU14 countries improve governance, aquaculture economics, fisheries economics, and the efficiency of fossil fuel usage.

1. INTRODUCTION

The EU27 consists of countries with a wide range of economic structures. For example, the old - member states such as Germany, France, and Italy have highly developed industrial economies, while some new - member states in Central and Eastern Europe, like Poland and Hungary, have been catching up in recent years but still have differences in economic development levels and industrial characteristics. By splitting the EU27 into two groups, it is possible to conduct in-depth research on the economic structures, development models, and growth mechanisms of different groups, to provide targeted policy recommendations for promoting economic growth and convergence within the EU. From another perspective, the member states within the EU have different political systems and political cultures. Some countries are federal states, while others are unitary states. There are also differences in the foreign policies and strategic interests of each member state. For example, countries such as France and Germany play a leading role in promoting European integration, while some smaller member states may focus more on safeguard-

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ing their own national sovereignty and specific interests. Splitting the EU27 into two parts can help analyze the impact of different political systems and interest demands on the process of European integration, and provide a basis for promoting the further development of the EU's political integration.

The European Union (EU27) is actively exploring the potential of "blue food" to enhance food security by 2030. Blue food refers to aquatic foods like fish, shellfish, and algae, which are sourced from oceans, lakes, and rivers. The EU27 faces significant challenges in ensuring food security by 2030, particularly concerning "blue foods" - those from oceans and aquaculture. For example; Overfishing and Depleted Stocks; Traditional Aquaculture Practices; Climate Change Impacts; Ensuring Access and Affordability; Meeting Nutritional Needs; Balancing Economic and Environmental Concerns; Policy and Governance; Consumer Awareness and Demand. While the EU members generally enjoy a high level of food security, some countries and population groups are more vulnerable than others. For example; (1) Southern and Eastern European countries, countries may face obstacles due to factors like lower average incomes, higher reliance on food imports, and vulnerability to climate change impacts on agriculture. (2) Countries with specific economic vulnerabilities, countries facing economic difficulties or high unemployment rates may have a higher proportion of the population struggling to afford adequate food.

To ensure global food security in 2030 and the forthcoming years, there is a necessity for the sustained development of both aquaculture and fisheries, but they contribute in different ways and face distinct complications. Global fisheries production dropped to 90.3 million tonnes in 2020.[1] It is projected to recover and increase by 6 percent from 2020 to reach 96 million tonnes in 2030. In Europe, the reformed Common Fisheries Policy (CFP) has introduced the concept of maximum sustainable yield (MSY). Although MSY is not yet applied in all European sea basins, it has shown positive effects in some regions, such as the Northeast Atlantic.[1] The fisheries sector, provides a significant source of protein and essential nutrients, especially for communities with limited access to other protein sources. It also supports livelihoods for millions of people worldwide, particularly in developing countries.[2] The EU faces several restrictions in ensuring its fisheries sector contributes to food security by 2030. Here's a breakdown of the key problems [3]:

(1) Traditional fishing methods often result in the unintentional catch of non-target species (bycatch), including endangered or protected ones, (2) Destructive fishing practices can damage sensitive marine habitats, further impacting fish populations and the overall health of the ecosystem, (3) Many fish populations in European waters are still overfished or not managed sustainably, (4) Rising water temperatures and ocean acidification are altering the distribution and abundance of fish stocks, making it harder for fishers to catch them and potentially disrupting entire marine ecosystems, (5) Warmer waters can increase the risk of diseases in both wild and farmed fish, impacting production levels, (6) The fisheries sector increasingly competes for space with other maritime activities, (7) Ensuring fair and equitable access to fishing grounds and resources is crucial, especially for small-scale fishers, (8) The EU relies heavily on seafood imports to meet its consumption demands, (9) Ensuring that imported seafood is also produced sustainably is a key challenge, requiring international cooperation and traceability throughout the supply chain.

Globally, aquaculture has been growing rapidly and is projected to continue to do so. In 2020, global animal aquaculture production reached 87.5 million tonnes.[4] It is forecast that aquaculture production will reach 106 million tonnes in 2030. In Europe, with the implementation of policies such as the EU's "Food 2030" framework, there is more support and space for the development of aquaculture, and production is expected to increase.[4] The aquaculture sector increases seafood production to meet the growing demand from a rising global population. Also, it can be located closer to consumers, reducing transportation costs and environmental impact. More so, it can be more efficient than capture fisheries in terms of resource use and production. However, the EU's aquaculture sector faces several challenges in meeting the EU food security objectives for 2030.[5]

These include: (1) Potential for environmental impacts, including pollution from fish waste and feed, and the spread of diseases, (2) The use of fish that have been harvested from the wild as a nutritional source in specific aquaculture systems can put pressure on wild stocks, (3) Social concerns related to labor conditions, land use, and community impacts, (4) Public concerns about environmental impacts, animal welfare, and food safety need to be addressed to ensure the sector's social license to operate, (5) Outbreaks of diseases can cause significant losses in aquaculture production, (6) Aquaculture needs to be economically competitive to attract investment and ensure long-term sustainability, (7) A clear and supportive regulatory framework is needed to foster sustainable growth and innovation in the sector, (8) The sector needs to adapt to the impacts of climate change, such as rising water temperatures and ocean acidification, (9) Increasing consumer demand for sustainable and healthy seafood is crucial for the sector's growth.

To fill up the gap of previous research, the main questions of this research are as follows: (1) Can the aquaculture sector in the EU13 members versus EU14 members fulfil a main function in food security by 2030? (2) What is the development status of the aquaculture sector versus the fisheries sector toward food security in the EU13 members versus the EU14 members? (3) How is the economic structure of EU13 nations versus EU14 nations' responses in the aquaculture sector and fisheries sector towards food security? This study undertakes an in-depth exploration of food security within the European Union (EU) from 1990 to 2023, focusing specifically on the burgeoning aquaculture sector versus the fisheries sector. The main aims of this research are: (1) to economically analyse the level of contribution of the aquaculture sector in the EU13 members versus the EU14 members to achieve the food security targets by 2030. (2) to explore the level of contribution of the fish farming industry versus fisheries in the EU-27 members to achieve the food security objectives by 2030. (3) to economically analyse the level of contribution of the fisheries sector in the EU13 nations versus the EU14 nations to achieve the food security targets by 2030.

The novelty, innovation, and empirical contribution of this paper unfold through three distinct phases. First, the paper examines how the aquaculture industry affects food security in the EU27, applying the two-stage least squares (2SLS) techniques. Using the same 2SLS methodology, the study then expands its analysis to contrast the growth impacts on food security of the aquaculture sector in EU13 developing nations with those in EU14 developed nations. Lastly, utilizing the 2SLS technique, the researchers explore the contribution level of the fisheries sector versus the aquaculture sector on food security in EU13 developing countries and EU14 developed countries. These three analytical frameworks aim to furnish clear insights into the contribution level of the fisheries sector and the aquaculture sector towards food security in the EU14, EU13, and EU27 overall. The economic contribution of these sectors is substantial, encompassing not only the direct value of production but also the broader impacts on employment, trade, and regional development. Economic analysis plays a crucial role in informing policy decisions and promoting sustainable development in the fisheries and aquaculture sectors, using various tools and methodologies.

Searching the contribution level of fisheries and aquaculture toward attaining food security in the EU is significant for several reasons: (1) It helps to assess the current role of these two sectors in providing food for the EU population. (2) Analysing the contribution level can reveal the potential for these two sectors to further contribute to food security, as well as any limitations or challenges they face. (3) The findings can inform the development of policies and strategies that aim to enhance the contribution of fisheries and aquaculture to food security. (4) Tracking the contribution level over time allows for monitoring the effectiveness of policies and interventions aimed at improving food security. (5) This research can help to identify and address challenges that may hinder the contribution of fisheries and aquaculture to food security. (6) It is crucial to ensure that fisheries and aquaculture sustainably contribute to food security, without compromising the health of ecosystems or the livelihoods of future generations.

2. METHODOLOGY

2.1. ECONOMIC THEORY OF BLUE FOOD SECURITY

The economic theory of blue food security is an evolving field that draws on various disciplines, including fisheries economics, aquaculture economics, environmental economics, and development economics. It seeks to understand the complex interactions between human activities, natural resources, and economic outcomes in blue food systems. This research relies on the bioeconomic model, this model integrates biological and economic factors to analyze the interactions between fisheries, aquaculture, and other marine resources with human activities. They help assess the economic impacts of different management strategies and policies on blue food production and sustainability. Here's a breakdown of its key components and considerations: Biological components, economic components, integration and analysis, and food security considerations. A bioeconomic model for blue food security would likely involve a system of equations that link biological and economic factors. Here's a simplified type of equation this research needs:

(1) Biological components: $dN/dt = rN(1 - N/K) - h$;

(2) Economic components: $FSI = f(\pi, N, N\_n, \ldots)$

Where; N = population of the crop, t = time, r = intrinsic growth rate of the crop, K = carrying capacity (maximum sustainable population), h = harvesting rate, and lastly FSI = a measure of food security that depends on factors like profit, crop population, nutrient levels, and potentially other variables like income, access to resources, etc. Consequently, recent research conducted by Wang et al.,[6] Alsaleh et al.[2,3], and Bjørndal et al.[4] has culminated in the genesis of the subsequent model.

$FS_{it} = f(AQ_{it}, FSH_{it}, FF_{it}, GDP_{it}, GVR_{it})$

2.2. ECONOMETRIC METHODOLOGY

Exploring the period from 1990 to 2023, this research investigates how aspects driving the expansion of the maricultural sector and fisheries contribution level on food security across the European Union member governments (EU27). Utilizing the bioeconomic model as an analytical framework, the study analyses data provided by the European Union Commission database (EUROSTAT) and the World Development Indicators (WDI). Employing the two-stage least squares (2SLS) techniques, the research economic analysis of the contribution level of the aquaculture sector versus the fisheries sector to food security. Additionally, the research aims to classify the nations in the region into two categories: developed members (EU14) and developing members (EU13) a comparative analysis. Specifically, the study focuses on the European Union as a whole (EU27), distinguishing between. Using information from a bioeconomic model customized for the EU, a dynamic panel regression model is performed to investigate the relationship between control variables pertinent to the fisheries and aquaculture sectors and food security between 1990 and 2023.

This period marks a significant transformation, beginning in 1990 with only a few European countries engaging in the aquaculture sector and fisheries sector, and culminating in 2023 with widespread adoption across all EU countries, driven by the need to enhance food security and promote sustainable development. Concurrently, the EU pursued efforts to foster economic outgrowth and development, including establishing the euro as the official currency. Hence, the model underlying this study is outlined as follows:Top of Form

$$Y_{it} = \beta_0 + \beta_1 X_{it} + \varepsilon_{it} \quad (1)$$

When X are possible food security determinants represented by vectors, Y represents the aquaculture sector, and

Ɛ is the error term. Conversely, the subscripts i and t represent the corresponding countries and times. Given the findings of Wang and Alsaleh[7] and Wang et al.,[8,9] the developed equation (2) is improved and amended in the following ways in this study:

$$FS_{it} = \beta_0 + \beta_1 AQ_{it} + \beta_2 FP_{it} + \beta_3 GVR_{it} + \beta_4 GDP_{it} + \beta_5 FF_{it} + \varepsilon_{it} \quad (2)$$

As per Table 1, the availability of trustworthy data is required for an appropriate evaluation of the food production level in the equation, and the food and nutrition production level will be estimated using the average value. Thus, (FS) refers to food production index covers food crops that are considered edible and that contain nutrients. Coffee and tea are excluded because, although edible, they have no nutritive value. The study incorporates several independent biological, economic, environmental, and integrated variables. (AQ) stands for aquaculture, which is the term used to describe the harvesting of marine species, for example, fish and other marine species. The outcome of maricultural activities aimed at final harvesting for human demand. (FP) Fisheries' total production from human activities and operations, which are quantified in metric tonnes. Governance (GVR), sourced by the official European data and reflects perceptions of the quality of public services in the EU27 members, the quality of the civil service and the degree of its independence from political pressures in the EU13 versus EU14, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies in the EU27 members.

Data spanning from 1990 to 2023 for EU economies are utilized, with each metric considered on a per capita basis. Economic growth (GDP), derived from the European Commission's database and computed in constant US dollars, is a key economic indicator and proxy for gross domestic product. Fossil fuel consumption (FF), expressed in metric tonnes of oil equivalent, sourced from a European Commission database, serves as a proxy for energy consumption. The World Bank's World Development Indicators database (WDI), the European Commission's database (Eurostat), and Europa, the official site for European statistics, are the primary sources of yearly data for the countries analyzed in this research, compiled to fulfill its objectives. Table 1 offers a thorough summary of the database, comprising sources, transformations, and measure units.

Table 1 shows that all measurements used in the current paper are logged in logarithmic form. Within the applied structured model, in the model, Ɛ stands for the error term and β0 for the intercept. The coefficient β1, β2, β3, β4, and β5 are the coefficient vectors. Additionally, subscripts i and t correspond to time and country, respectively.

In this paper, a cross-sectional bioeconomic framework for food security is evaluated, taking into consideration as many of the independent variables influencing food security as feasible. The following is the formulation of the bioeconomic model of food security across multiple economic structure levels:

$$Y_{it} = \beta_0 + \beta_1 Y_{it-1} + \beta_2 X_{it} + \mu_{it} + \varepsilon_{it} \quad (3)$$

Where, i = 1, ...N, t = 1,...T.

The dependent variable (Y it) is regressed on exogenous independent variables (X_it) in the regression model, together with the lagged dependent variable. The error term is comprised of two distinct components: the individual-specific effect (μ_it) and the white noise error term (Ɛ_it). In this study, we employ a bioeconomic model to scrutinize the correlation between components within the fish farming industry versus the fisheries sector and food security. Specifically, the hypothesis is tested using a panel data regression model that utilizes data from a sample of nations. Regression models based on panel data are appropriate for the current research since they permit the inclusion of cross-sectional and time-series data changes. This method captures the variation among nations while allowing for the assessment of possible time- and country-specific impacts. Consequently, the empirical examination of the contribution level of the aquaculture sector versus the fisheries sector toward food security is conducted, drawing on literature employing similar panel data econometric methodologies.

H1: Aquaculture significantly enhances global food security by increasing the availability of nutritious food

H2: The fisheries sector plays a crucial role in global food security by providing a significant source of protein

Fisheries and aquaculture production are the variables related to human activities, elucidating its role as an explanatory factor in this investigation. Meanwhile, the development of the aquaculture sector embodies the blue growth factor for member i in period t. The standard analysis, Ordinary Least Squares (OLS) regression is employed, including both year-based and country-based fixed effects analysis. This methodological approach effectively addresses time-specific impacts and unobserved variability across countries, thereby shedding light on the interaction between the aquaculture sector versus the fisheries sector toward food security.Top of Form To enhance the accuracy of estimating the contribution level of the aquaculture sector versus the fisheries sector toward food security, the authors introduce time- and country-specific effects to mitigate potential biases. Additionally, this study employs the Robust Least Square (RLS) method for additional examination, aiming to determine endogenous models with reliability, and the Two-Stage Least Squares (2SLS) analysis to take care of possible endogeneity issues and demonstrate causal relationships among the aquaculture sector and fisheries sector toward food security.

Drawing on instrumental variables from previous literature, such as Greene[10] and Kennedy,[11] as utilized in works by previous work, both the 2SLS and RLS approaches are widely used and efficient mathematical tools to address endogeneity concerns.[12,13] While directly linked to food security, instrumental factors must correlate with the macroeconomic level, such as governance, fossil fuel consumption, and economic growth. In the first step, this research regresses the aquaculture sector versus the fisheries sector on instrumental factors to ascertain expected values for food security in the EU27 region overall. Subsequently, in the second step, this study explores the relationship between the instrumented blue growth and blue

Table 1. Dependent and independent factors details

Variable	Abbreviated	Data Source	Measurement Unit
Food Security	FS	WDI	(2004-2006 = 100)
Aquaculture Sector	AQ	WDI	metric tons
Fisheries Sector	FP	WDI	metric tons
Governance	GVR	Eurostat	% of confidence in government effectiveness
Fossil Fuel	FF	Eurostat	metric tons of oil equivalent
Economic Growth	GDP	Eurostat	Gross domestic product (constant $)

economy toward food security in the EU14 members versus EU13 members. Regarding the second phase, the researchers rely on data gathered via the EUROSTAT database as a stand-in for the state of economic development.Top of Form Evaluating a nation's blue economy and blue growth depends heavily on this framework, which defines the likelihood of two levels of development: developing and developed [3].

Moreover, thirdly, the contribution level of the controller variable and magnitude effect of blue growth, blue economy, and blue food on food security is deemed negligible, rendering this structure a reliable and trustworthy tool.[14] Additionally, the framework developed for this study clusters standard errors at the national level and includes year and country-fixed effects. In summary, to enhance the robustness of the analysis, this research integrates 2SLS and RLS techniques to address endogeneity issues. This inclusion increases the likelihood that conclusions regarding the contribution level of the fisheries sector and aquaculture sector on food security reflect genuine causal relationships rather than spurious correlations.

3. RESULTS

3.1. ESTIMATION OUTCOMES

A crucial step in reducing variance among variables and making it easier to derive trustworthy estimators is applying natural logarithm transformations to all of the variables in Table 2. Table 2 presents a comprehensive overview of summary statistics and descriptive metrics, illustrating the variables' adherence to a normal distribution. Meanwhile, the correlation analysis results are displayed in Table 3. Notably, the results, which show no significant correlations between the explanatory components, highlight the lack of multicollinearity issues. Thus, the probability of multicollinearity emerging within the same model during variable estimation is mitigated. Moreover, a statistically significant positive correlation (0.063) is shown in Table 3 within the correlation matrix between aquaculture parameters and food security. Similarly, Table 3 demonstrates that the correlation matrix between food security and fishery characteristics is positive and statistically significant (0.117). These coefficients' positive values suggest that greater engagement in fisheries production is reflected concurrently with the outgrowth of the aquaculture field in EU members. Positive relationships exist for all variables and the development of fisheries; these correlations are comparatively larger for the aquaculture industry's expansion.

Before estimating the unknown parameters, it is essential to conduct a series of standard preliminary tests to assess the time series characteristics of the variables. The primary aim of this study is to identify and address any cross-sectional dependency (CD) present among the panel data, as neglecting this issue may result in inaccurate coefficient estimations. CD, arising from unobserved common factors, has the potential to significantly undermine the efficiency improvements linked to panel data analysis.[15] Therefore, fixing this issue is essential to ensure the reliability of coefficient estimations. To evaluate cross-sectional dependency within the panel, we employ the Pesaran[16] CD test, which reveals considerable inter-country dependency across various quantitative measures, as depicted in Table 4. Panel estimation techniques must incorporate methods resilient to the effects of cross-sectional dependency, alongside unit root and cointegration tests, to mitigate the risk of size distortions.

Therefore, we employ panel non-stationarity tests, such as Im-Pesaran-Shin (IPS) (2003),[17] Breitung and Das,[18] and Breitung,[19] to unbiasedly assess the integration properties of the variables in question (see Table 5). The panel unit root tests proposed by Breitung[19] and Breitung and Das[18] operate under the assumption that each panel member possesses a consistent autoregressive value, whereas the IPS (2003) test allows for distinct autoregressive values within the analysis. Table 5 shows that for relatively large panel data sets, such as the one used in this work, the Breitung[19] panel unit root test has higher power than other similar unit root tests. In addition, we use the cross-sectional dependence accounting panel unit root test developed by Breitung and Das[18] to assess how cross-sectional dependence affects the results of the unit root test. The results in Table 5 show that for each unit root test specification, all variables exhibit stationarity in first differences but non-stationarity in levels. This means that all variables used in the estimation have first-order integrals (I(1)).

Employing both Westerlun's [20] Bootstrapped panel cointegration test and Pedroni's[21] panel cointegration test, the authors confirm the presence of a non-spurious long-term relationship between the variables, as outlined in Table A (see Appendix). Pedroni[21] offers a comprehensive framework for panel cointegration testing, similar to the 2-step Engle and Granger technique. This methodology addresses heterogeneity by eliminating individual-specific determin-

Table 2. Results of Descriptive-Statistics

Variable	Observations	Mean	Std. Dev.	Min	Max
FS	918	2.001	0.044	1.848	2.227
AQ	918	4.123	0.858	1.643	5.638
FP	918	4.929	0.825	3.211	6.310
GDP	918	4.377	0.395	3.129	5.253
FF	918	2.753	0.761	0.011	4.600
GVR	918	1.867	0.070	1.482	1.979

Table 3. Panel Data Matrix Analysis

Factors	FS	AQ	FP	GDP	FF	GVR
FS	1.000					
AQ	0.063	1.000				
FP	0.117	0.668	1.000			
GDP	0.074	0.130	0.256	1.000		
FF	0.020	0.337	0.365	0.217	1.000	
GVR	0.032	0.203	0.9366	0.643	0.443	1000

Table 4. Diagnostic test of cross-sectional independence of nonlinear panel data

Factor	FS	AQ	FP	GDP	FF	GVR
Pesaran[16]	(3.12)***	(5.95)***	(18.82)***	(83.55)***	(65.35)***	(31.30)***

Remark: *** refer importance at the 1%, scale.

Table 5. The interpretation of panel unit root tests

Factor	Difference		First Difference	
	LLC	IPS	LLC	IPS
FS	0.609***	5.000	37.388***	29.637***
AQ	3.884***	10.385	15.406***	28.510***
FP	5.560***	3.649***	10.480***	12.528***
FF	21.53***	15.59***	60.12***	61.75***
GDP	8.696***	5.224***	14.380***	16.814***
GVR	10.911**	18.011***	13.687***	21.324***

Remark: *** refer importance at the 1%, scale.
Levin, Lin & Chu test (LLC), and Im, Pesaran, and Shin W-stat test (IPS).
Source: Author calculations

istic trends and short-term characteristics in the initial phase of the analysis. Pedroni's method provides seven different test statistics based on the estimated residuals, which are classified according to whether a single process is assumed (called "grouped" or "between-dimensional" tests) or whether a common process is assumed (called "pooled" or "within-dimensional" tests). In addition, Westerlun's (2007) method proposes four additional tests in which the null hypothesis of no cointegration is present.

Unlike residual-based tests, Westerlun's approach focuses on structural dynamics rather than residual dynamics. This relaxes the common factor restrictions imposed by residual-based tests. This alleviates potential efficacy reductions encountered by residual-based cointegration tests due to common factor limitations.[22] With the removal of this constraint, long-term and short-term adjustment procedures need not be identical. By utilizing Westerlun's [20] bootstrap technique, this study establishes robust critical values to minimize cross-sectional dependence bias. This approach enhances the reliability of the cointegration test results. The findings in Table A, see Appendix, furnish substantial evidence supporting cointegration from both Pedroni's[21] and Westerlun's [20] bootstrapped cointegration tests.

Table 6 presents the findings of a variance inflation factor (VIF) regression, which is of pivotal significance for

Table 6. Variance Inflation Factor Estimation (VIF)

Factor	Co-efficient	Probability	Variance Inflation Factor
AQ	0.070***	0.000	1.88
FP	0.057***	0.000	1.68
FF	0.022***	0.004	1.29
GDP	0.177**	0.019	1.01
GVR	0.126***	0.002	1.07
C	2.420***	0.000	

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels respectively.

identifying potential interrelationships or multicollinearity between the independent variables. This step is essential to ensure unbiased conclusions from the regression analysis. Before embarking on the VIF analysis. This study initially conducted a technique of linear regression estimation, whose outcomes are additionally presented in Table 6. As demonstrated in the above table, it is evident that multicollinearity is absent from the given dataset. The absence of multicollinearity is indicated by a VIF value lower than 5, according to a widely accepted convention. As a result, Table 6 shows no discernible relationship between governance, economic growth, fisheries, and aquaculture production, and fossil fuels.

3.2. REGRESSION ANALYSIS OLS, 2SLS, AND RLS

This study employs a hierarchical approach to analysis, delving into three distinct levels. Firstly, it delves into the correlations between variables, emphasizing their interplay. Secondly, it conducts an Ordinary Least Squares (OLS) regression analysis, incorporating the aquaculture sector and fisheries sector toward food security. This regression methodology assumes the exogeneity of the aquaculture component and the fisheries component, enabling the estimation of the findings below. Notably, variables such as aquaculture production and fisheries production may be jointly determined, as highlighted by various authors, thereby potentially introducing endogeneity issues. To address this, the study utilizes 2SLS and RLS estimators to mitigate endogeneity concerns. The study's timeframe encompassing all EU27 members from 1990 to 2023 is delineated in Tables 8, 9, and 7. Furthermore, Tables 9 and 8 extend their analysis to encompass both developed and developing members, along with considering the economic development structure in their 2SLS and RLS regressions, respectively.

The EU27 region's standard analysis results employing OLS, 2SLS, and RLS regression in Model 1 are shown in Table 7. While the results from OLS generally align with those from 2SLS and RLS, the coefficients often exhibit greater magnitudes in the 2SLS or RLS regressions employing the estimator. Notably, the aquaculture production variable demonstrates a positive and significant influence across 2SLS, RLS, and OLS estimation specifications. A 1% boost in aquaculture production has a favourable influence on food security of 0.06% for OLS, 0.02% for 2SLS, and 0.05% for RLS. The food security hypothesis is strongly supported by statistically significant data from both the RLS analysis specification and the 2SLS analysis. In line with previous studies, aquaculture directly increases the availability of seafood within the EU and provides a source of protein and essential nutrients, supplementing traditional fisheries.[23-25] This is crucial in a context where global demand for seafood is rising, and many wild fish stocks are overexploited.

Based on these three criteria, fisheries production is among the most dependable. The OLS estimate, the 2SLS estimator, and the RLS estimator all have positive effects on food security of 0.05%, 0.03%, and 0.07%, respectively, when fisheries production is increased in the EU27 region. The outcome of the previous paper by Okeke-Ogbuafor et al.,[1] Bjørndal et al.,[4] and Shelton et al.[26] are in line with this result, showing that fisheries are important for food security in European nations, although the specific contribution can vary depending on factors like the type of fishery, the region, and the specific food security indicators being considered.

A rise in economic growth has an advantageous consequence on food sufficiency in the EU27 region of between 0.01% and 0.41% for OLS and 2SLS, respectively. The economic growth specification does not demonstrate the requisite robustness of the three specifications in terms of statistical significance and coefficient size, suggesting limited statistical support for the RLS test. This outcome is in line with what earlier papers conducted by Panghal et al.,[27] Cheng et al.,[28] and Yaqoob et al.,[29-31]

The degree of food security is greatly improved by good governance, the OLS estimator contributes 0.13%, the 2SLS estimator 0.09%, and the RLS estimator 0.02% to the percentage gain in good governance toward food sufficiency in the EU-27 region. This supports the economic theory of blue food security for the members that generate blue food output. This result confirms the primary conclusion of Collins,[32] Jones et al.,[33] and Adelle and Dekeyser et al.,[34] stating that food security is implicitly recognized in the EU treaties, particularly in the context of the Common Agricultural Policy (CAP) and consumer protection.

Model 2's standard analysis results using OLS, 2SLS, and RLS tests for the EU14 developed nations are shown in Table 8. While OLS results provide initial insights, the findings are reinforced by both 2SLS and RLS. Interestingly, coefficients in 2SLS or RLS tests often exhibit greater magnitudes. Consistently, a positive and statistically significant correlation between the aquaculture sector and food se-

Table 7. Data Analysis for the European Union Member from 1990 to 2022

Factor	OLS		2SLS		RLS	
	Coeff.	Standard Err.	Coeff.	Standard Err.	Coeff.	Standard Err.
AQ	0.060	0.078***	0.046	0.064***	0.053	0.020**
FP	0.051	0.081***	0.037	0.065***	0.079	0.021***
FF	-0.0164	0.051***	-0.012	0.049***	-0.052	0.018***
GDP	0.015	0.065**	0.416	0.054**	0.021	0.013
GVR	0.131	0.048***	0.093	0.039**	0.025	0.012**
Constant	2.416	0.098***	2.688	0.015***	1.945	0.029***
R^2	0.089		0.028		0.023	
Adjusted-R^2	0.084		0.022		0.057	

Note: ***, ** and * indicate significance at the 1%, 5%, and 10% levels respectively.

curity is observed. The strength of this association varies amongst specifications, though. In this way, a boost in aquaculture production is associated with a 0.01%, 0.01%, and 0.02% increase in food security in the OLS, 2SLS, and RLS tests, respectively. This pattern is in line with research by Elzaki,[35] Muallil et al.,[36] and Chapagai et al.,[37] suggesting that by increasing domestic production, aquaculture can help reduce the dependence on seafood imports. This can enhance food security by making the EU region less vulnerable to fluctuations in global markets and supply chains.

Among the three specified criteria, the fishing industry has consistently demonstrated the highest levels of statistical significance and coefficient size, thus indicating its notable resilience. In the EU14 developed countries, increasing fisheries production has positive benefits on food sufficiency of 0.04%, 0.04%, and 0.02%, respectively, according to the OLS estimate, the 2SLS regressors, and the RLS regressors. This work's outcomes are in line with earlier papers, which indicate that the sustainable fisheries sector can reduce the EU's dependence on seafood imports, enhancing its food sovereignty. While old fisheries methods cause fish stocks to decline, endangering food security in the long run and the health of marine ecosystems[38-40]

Furthermore, economic growth has the strongest effect among the three parameters for the EU-14 in terms of statistical significance and coefficient size. According to OLS, 2SLS, and RLS estimates, an increase in economic growth percentage of 0.03%, 0.02%, and 0.02%, respectively, has a positive impact on food security. This result is consistent with the conclusions of three previous studies that pointed out that economic growth can lead to increased investment in the blue economy, including the fisheries and aquaculture sectors, which can improve productivity and increase food supply.

Surprisingly, concerning coefficient size and statistical significance, the data set provided on fossil fuels has a consistently negative impact across all three criteria, with a coefficient that appears to remain constant across specifications for the developed EU14 countries. For the OLS, 2SLS, and RLS regressors, a rise in fossil fuels as a percentage harms food security is 0.01%, 0.02%, and 0.06%, respectively. This finding aligns with other studies that demonstrate increased carbon dioxide in the atmosphere, partly due to fossil fuel combustion, is absorbed by the ocean, making it more acidic which is called ocean acidification's can harm shellfish, corals, and other marine organisms, impacting aquaculture and wild fisheries.[41-43]

The outcomes of the standard analysis in Model 3 are shown in Table 9, employing a range of estimators including OLS, 2SLS, and RLS. Although the results of the OLS regressor are in line with those of the 2SLS and RLS regressions, the coefficients in the 2SLS or RLS regressor that use the analysis for the EU13 developing countries frequently show larger magnitudes. The aquaculture industry shows a notable improvement in all estimation criteria. A rise in the percentage of aquaculture production specifically translates into improvements in food security of 0.10%, 0.08%, and 0.03% in OLS, 2SLS, and RLS, respectively. Moreover, strong, statistically significant evidence for the food security economic hypothesis is provided by the 2SLS and RLS estimate specifications. This finding aligns with several studies, concluding that the aquaculture sector is an important component of the food system and can contribute a greater role in enhancing food security,[44-46] by increasing the availability of nutritious seafood, reducing reliance on imports, and stimulating economic growth.

A rise in the percentage of fisheries production benefits food security for the EU13 developing nations by 0.09%, 0.07%, and 0.03% under the OLS, 2SLS, and RLS scenarios, respectively. There is strong statistical support for the food security economic hypothesis from both the 2SLS and RLS estimations. This result resonates with the findings from other papers, suggesting that the emphasis on sustainable fisheries management is highly needed to guarantee the long-term well-being of fish stocks and the marine environment that helps fulfill demand and provide food security.[2,47,48]

Of the three criteria, economic growth (GDP) has the greatest statistical significance and coefficient size, with coefficients showing variability depending on the specification. A 0.25%, 0.70%, and 0.05% rise in GDP, respectively, has a beneficial effect on food security for the EU13 developing countries according to the OLS, 2SLS, and RLS regressor. This observation is in line with outputs from

Table 8. Data Analysis for the Developed European Union Member from 1990 to 2022

Factor	OLS		2SLS		RLS	
	Coeff.	Standard Err.	Coeff.	Std. Error	Coeff.	Standard Err.
AQ	0.011***	0.033	0.012***	0.039	0.023***	0.021
FP	0.041***	0.072	0.043***	0.094	0.022***	0.026
FF	-0.017***	0.036	-0.020***	0.043	-0.062***	0.018
GDP	0.036***	0.058	0.029***	0.060	0.021***	0.061
GVR	0.032	0.028	0.055	0.036	0.077***	0.021
Constant	1.873***	0.080	1.854	0.103	1.716	0.046
R^2	0.340		0.390		0.596	
Adjusted-R^2	0.310		0.340		0.971	

Remark: ***, ** and * indicate significance at the 1%, 5%, and 10% levels respectively.

Table 9. Data Analysis for the Developing European Union Member from 1990 to 2022

Factor	OLS		2SLS		RLS	
	Coeff.	Standard Err.	Coeff.	Std. Error	Coeff.	Standard Err.
AQ	0.102***	0.020	0.082***	0.018	0.031***	0.068
FP	0.098***	0.015	0.075***	0.012	0.038***	0.049
FF	-0.034***	0.011	-0.029***	0.098	-0.093**	0.037
GDP	0.256***	0.083	0.700***	0.019	0.059**	0.027
GVR	0.079	0.010	0.097	0.087	0.036	0.032
Constant	2.039***	0.024	2.610***	0.037	1.930***	0.078
R^2	0.143		0.137		0.842	
Adjusted-R^2	0.132		0.270		0.179	

Remark: ***, ** and * indicate significance at the 1%, 5%, and 10% levels respectively.

studies, suggesting that economic growth can lead to technological and infrastructure advancements in fisheries and aquaculture sectors, which can improve efficiency and reduce costs to ensure food security.[27,28,49]

On the other hand, regarding coefficient size and statistical significance, fossil fuel input consistently emerges across all three specifications, although its coefficient varies among specifications for the EU13 developing countries. There is a 0.03%, 0.02%, and 0.09% decrease in food security for every percentage rise in fossil fuels. This result is in line with earlier studies by Bhave et al.,[50] Shupler et al.,[51] and Rasul et al.,[52] stating that the extraction and transport of fossil fuels can disrupt marine habitats and ecosystems, affecting fish populations, fish immigration and the overall health of the marine environment.

4. DISCUSSION

Panel 2SLS and RLS techniques have both confirmed the results of the OLS panel study, indicating consistency in the sign and significance level of coefficients across the models. This consistency underscores the accuracy and usefulness of data produced by the panel 2SLS and ROLS approaches for making insightful deductions. The directional consistency of the OLS coefficients remains unaltered, notwithstanding potential minor discrepancies in the significant thresholds between them and those from panel 2SLS and RLS. In light of the varying degrees of their economic development, the 27 countries within the European Union were classified into two distinct groups to examine how the expansion of the aquaculture sector might affect food security: the EU14 members and the EU13 members. This segmentation allows for an assessment of the contribution level of the aquaculture sector versus the fisheries sector toward food security within each subgroup of EU14 members versus EU13 members.

Table 8 offers insights into the expected effects of the growing aquaculture sector and fisheries sector in EU14 developed countries on food security, while Table 9 presents the impacts of the growing aquaculture sector and fisheries sector on food security in EU13 members. According to the results shown in Tables 7, 8, and 9, the aquaculture's level of contribution significantly enhances food security across the studied three regions. The findings indicate that the burden of fisheries and aquaculture production on food security is greater for EU13 nations than for EU14 nations. Specifically, the effects of aquaculture output measure at 0.08 for EU13 and 0.01 for EU14, while, EU13 members and EU14 members have 0.07 and 0.04 impacts, respectively, from fisheries production. This suggests that EU13 developing countries have greater potential to enhance food security through the expansion of the fisheries sector and aquaculture sector compared to EU14 developed countries.

Taking an alternative perspective, the findings suggest that EU14 developed countries are significantly more affected by the fisheries sector in terms of food security than by the aquaculture sector. In the EU14 nations, the exact impact degree for the aquaculture and fisheries sectors is 0.01 and 0.04, respectively. This suggests that the fishing industry might substantially enhance food security more rapidly than the aquaculture sector by embracing green fisheries policy and fisheries sustainable development concepts within the food-producing industry. Alternatively, the findings show that the aquaculture sector has a greater and more meaningful influence on food security than the fisheries sector in EU13 developing nations. The specific impact magnitudes for the fisheries and aquaculture sectors in the EU13 developing nations are 0.07 and 0.08, respectively. Such findings suggest the potential for the aquaculture sector to experience a substantial increase to boost food security faster than the fisheries sector by using green aquafarming policies and blue farming green development methodologies toward food security.

Regarding economic growth (GDP), food security is more positively and significantly impacted by EU13 developing nations than by EU14 developed nations. For EU13 members and EU14 members, the exact impact magnitudes are 0.70 and 0.02 respectively, indicating that EU13 members could significantly accelerate improvements in food security compared to EU14 members by leveraging fisheries economies and aquaculture economies techniques toward food security. Moreover, according to the results obtained from the RLS estimator, governance has a more adverse impact on food security in EU13 developing countries than in EU14 developed countries. Top of FormFor EU14 developed countries, no significant impact on food security is observed, contrasting with a precise and notable magnitude of 0.03 identified for EU13 developing countries. This discrepancy suggests that EU13 developing countries could markedly improve food security compared to their EU14 developed countries by implementing blue governance methodologies for the aquaculture and fisheries sectors toward food security.

Conversely, the results indicate a more detrimental and significant influence of fossil fuel usage on food security for EU14 developed countries in contrast to the EU13 developing nations. Specifically, the exact magnitudes of the effects are -0.020 for EU14 nations and -0.029 for EU13 countries, indicating a potential for EU14 developed countries to exacerbate food insecurity faster than their EU13 developing nations through the utilization of conventional energy practices toward food security.

5. CONCLUSION AND IMPLICATIONS

This article documents that EU13 developing countries are more dependent on fisheries production and aquaculture production than EU14 developed countries in achieving food security aims by 2030. This demonstrates how crucial it is to increase the efficiency of aquaculture and fisheries components as well as green development in various settings across the EU13 developing countries to attain better levels of food security. Similarly, the researchers demonstrate that EU13 developing nations have greater food security due to the importance and high level of governance and economic growth in contrast to EU14 nations. This shows that to increase levels of food security resulting from the aquaculture sector and fisheries sector, it is critical to boost economic growth and governance initiatives throughout various settings in the EU13 developing nations. Nevertheless, the researchers uncovered that the use of fossil fuels contributes significantly to food insecurity in EU14 countries compared with EU13 developing nations.

This emphasizes how crucial it is to support green energy and renewable energy initiatives in all relevant situations within the EU14 developed countries to increase food security resulting from the fisheries and aquaculture sectors. The findings of this investigation bolster the notion that the aquaculture sector plays a critical role in advancing the effectiveness and efficacy of sustainable blue aquaculture and blue food security. Even after doing many robustness tests with extra controls, different instruments, other measures of aquaculture sector growth, and examination of separated samples, these findings hold. This research presents an alternative viewpoint and concludes that, among EU14 developed countries, the fisheries sector contributes level more significantly and at a higher level to the achievement of food security than the aquaculture sector. This emphasizes how crucial it is to boost the productivity of the fisheries sector in all of the EU14 developed countries' various settings to attain greater levels of food security.

However, recent data indicate that among EU13 developing countries, the aquaculture sector contributes more to food security than the fisheries sector does. To attain better levels of food security, aquaculture sector aspects of productivity and sustainable development must be strengthened in several situations across EU13 developing nations. According to the authors' conclusion, authorities ought to prioritize policies that will boost the aquaculture sector's growth effectiveness and fisheries sector growth, especially in the EU14 developed countries with inefficient aquaculture sector expansion and unproductive fisheries sector growth. To achieve a high level of food security, the authors may accomplish this by creating an atmosphere that supports the blue economic growth aspects of the fisheries and aquaculture sectors. Additionally, to sustain and further the expansion of green maricultural techniques and underwater life conservation for better blue food security, EU14 nations' authorities with insufficient fossil fuel usage and ineffective blue governance should give priority to improving the aquaculture sector.

From a different angle, the authors advise policymakers in EU13 developing nations and EU14 nations to strengthen marine policies that aim to raise the fish farming industry's low output relative to the high output of the fisheries sector, thereby promoting blue growth and food security in general. The focal point for EU-27 governments and regulators should center predominantly on particular dimensions of the aquaculture sector, encompassing eco-friendly blue farming methods, aquaculture efficiency, productivity, and blue governance, which hold particular significance for ensuring food security. Furthermore, policymakers must consider the potential of green technological innovations to augment the sustainability of the aquaculture sector. Accelerating the recovery of aquaculture ecosystems, enhancing convenience, and fortifying security can pave the way for food security in the future through the adoption of green digitalization, environmentally conscious technological advancements, and eco-friendly solutions.

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AUTHORS' CONTRIBUTIONS

M.A. (Mohd Alsaleh) gathered the data and estimated the panel cointegration model and the competitive advantage of the external factors on the aquaculture in the EU27 region; A.S.A.-R. (Abdul Samad Abdul-Rahim) Revised the work based on the reviewing report; M.A. contributed with conclusions and recommendations and the study's limitations and further research; M.A. conducted the literature review; and A.S.A.-R. was responsible for the overall rewriting and review process.

COMPETING OF INTEREST

No competing interests were disclosed.

ETHICAL CONDUCT APPROVAL

The authors declare that the manuscript does not report studies involving human participants, human data, or human tissue.

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REFERENCES

1. Okeke-Ogbuafor N, Gray T, Kamara S, et al. Climate-smart fisheries: CO2 emissions reduction and food security are complementary. *Marine Policy*. 2024;159:105926. doi:10.1016/j.marpol.2023.105926

2. Alsaleh M, Wang X, Nan Z. Evaluating the Potential of Information and Communication Technologies to Increase Aquaculture Sustainability. *Sustainable Development*. Published online 2024. doi:10.1002/sd.3281

3. Alsaleh M, Abdul-Rahim AS. What are the influence of fishery activities and their implication on marine water pollution? an empirical analysis. *Environment Development and Sustainability*. Published online 2024:1-32. doi:10.1007/s10668-024-05561-x

4. Bjørndal T, Dey M, Tusvik A. Economic analysis of the contributions of aquaculture to future food security. *Aquaculture*. 2024;578:740071. doi:10.1016/j.aquaculture.2023.740071

5. Alsaleh M, Abdul-Rahim AS, Yuan Y, Longqi S. Evolution through intellectual property rights in the aquaculture sector: reshaping aquaculture production networks. *Environment Development and Sustainability*. Published online 2024:1-28. doi:10.1007/s10668-024-05242-9

6. Wang X, Alsaleh M, Abdul-Rahim AS. The role of information and communication technologies in achieving hydropower sustainability: evidence from EU economies. *Energy & Environment*. 2022;35(3):1550-1572. doi:10.1177/0958305X221137566

7. Wang X, Alsaleh M. Determinants of Geothermal Power Sustainability Development: Do Global Competitiveness Markets Matter? *Sustainability*. 2023;15(4):3747. doi:10.3390/su15043747

8. Wang X, Alsaleh M, Nan Z. Measuring the Impact of Innovation Ecosystem and Enabling Environment on Fisheries System Performance. *Journal of the Knowledge Economy*. Published online 2024:1-35. doi:10.1007/s13132-024-02330-z

9. Wang X, Alsaleh M, Nan Z. Rapid Growth in Greenhouse Gas Emissions from the Adoption of Industrial-Scale Aquaculture: The Pathway Towards a Blue Economy. *Journal of the Knowledge Economy*. Published online 2024:1-26. doi:10.1007/s13132-024-02318-9

10. Greene W. Reconsidering heterogeneity in panel data estimators of the stochastic frontier model. *Journal of Econometrics*. 2005;126(2):269-303. doi:10.1016/j.jeconom.2004.05.003

11. Kennedy P. *A Guide to Econometrics*. The MIT Press; 2003.

12. Cooray A. The role of the government in financial sector development. *Economic Modelling*. 2011;28(3):928-938. doi:10.1016/j.econmod.2010.11.001

13. Khan MA, Kong D, Xiang J, Zhang J. Impact of institutional quality on financial development: cross-country evidence based on emerging and growth-leading economies. *Emerging Markets Finance and Trade*. 2020;56(15):3829-3845. doi:10.1080/1540496X.2019.1588725

14. Alsaleh M. The criticality role of industrial disaster to blue farming sustainability: insights from the aquaculture sector. *Environment Development and Sustainability*. Published online 2024:1-29. doi:10.1007/s10668-024-05669-0

15. Phillips PC, Sul D. Dynamic panel estimation and homogeneity testing under cross-section dependence. *The Econometrics Journal*. 2003;6(1):217-259. doi:10.1111/1368-423X.00108

16. Pesaran MH. General diagnostic tests for cross-sectional dependence in panels. *Empirical Economics*. 2004;60:13-50. doi:10.1007/s00181-020-01875-7

17. Im KS, Pesaran MH, Shin Y. Testing for unit roots in heterogeneous panels. *Journal of econometrics*. 2003;115(1):53-74. doi:10.1016/S0304-4076(03)00092-7

18. Breitung J, Das S. Panel unit root tests under cross-sectional dependence. *Statistical Neerlandica*. 2005;59(4):414-433. doi:10.1111/j.1467-9574.2005.00299.x

19. Breitung J. The local power of some unit root tests for panel data. In: *Nonstationary Panels, Panel Cointegration, and Dynamic Panels*. Group Publishing Limited, Emerald; 2001:161-177.

20. Westerluns J. Testing for error correction in panel data. *Oxford Bulletin of Economics and Statistics*. 2007;69(6):709-748. doi:10.1111/j.1468-0084.2007.00477.x

21. Pedroni P. Panel cointegration: asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. *Econometric Theory*. 2004;20(3):597-625. doi:10.1017/S0266466604203073

22. Kremers JJ, Ericsson NR, Dolado JJ. The power of cointegration tests. *Oxford Bulletin of Economics and Statistics*. 1992;54(3):325-348. doi:10.1111/j.1468-0084.1992.tb00005.x

23. Garlock T, Asche F, Anderson J, et al. Aquaculture: The missing contributor in the food security agenda. *Global Food Security*. 2022;32:100620. doi:10.1016/j.gfs.2022.100620

24. Canty SW, Deichmann JL. Do small-scale fisheries have the capacity to provide food security to coastal populations? *Fish and Fisheries*. 2022;23(3):708-718. doi:10.1111/faf.12643

25. Akbari M, Foroudi P, Shahmoradi M, et al. The evolution of food security: where are we now, where should we go next? *Sustainability*. 2022;14(6):3634. doi:10.3390/su14063634

26. Shelton C, White CS, Forster J, Conlon S, Engelhard GH, Pinnegar JK. Disaster risk in Caribbean fisheries: How vulnerability is shaped and how it can be reduced in Dominica and Antigua and Barbuda. *Marine Policy*. 2024;160:105951. doi:10.1016/j.marpol.2023.105951

27. Panghal A, Mor RS, Kamble SS, Khan SAR, Kumar D, Soni G. Global food security post-COVID-19: Dearth or dwell in the developing world? *Agronomy Journal*. 2022;114(1):878-884. doi:10.1002/agj2.20932

28. Cheng P, Tang H, Lin F, Kong X. Bibliometrics of the nexus between food security and carbon emissions: Hotspots and trends. *Environmental Science and Pollution Research*. Published online 2022:1-18. doi:10.1007/s11356-022-23970-1

29. Hunter P. Harnessing the sun's power: Hybrid photosynthesis might become a key technology to address the energy crisis and food security challenges. *EMBO reports*. 2022;23(11):e56149. doi:10.15252/embr.202256149

30. Luqman M, Al-Ansari T. Energy, water and food security through a waste-driven polygeneration system for sustainable dairy production. *International Journal of Hydrogen Energy*. 2022;47(5):3185-3210. doi:10.1016/j.ijhydene.2021.10.214

31. Granit I. Microgrids through the Energy-Water-Food Security Nexus in La Guajira, Colombia: Increasing water and food security or jeopardizing groundwater levels? *Energy Research & Social Science*. 2022;93:102814. doi:10.1016/j.erss.2022.102814

32. Collins AM. Empowerment, rights, and global food governance: gender in the UN Committee for World Food Security. *Globalizations*. 2022;19(2):220-237. doi:10.1080/14747731.2021.1877006

33. Jones EC, Ong C, Haynes J. Disaster-Related Food Security and Past General Governance Strategies in a Worldwide Sample. *Weather, Climate, and Society*. 2022;14(1):3-18. doi:10.1175/WCAS-D-20-0138.1

34. Adelle C, Dekeyser K. Food and sustainable development governance. In: *Handbook on the Governance of Sustainable Development*. Edward Elgar Publishing; 2022:14-29. doi:10.4337/9781789904321.00009

35. Elzaki RM. Does fish production influence the GDP and food security in Gulf Cooperation Council countries? Evidence from the dynamic panel data analysis. *Aquaculture*. 2024;578:740058. doi:10.1016/j.aquaculture.2023.740058

36. Muallil RN, Irilis RA, Habibuddin AA, Nur-aisa SA, Ajik JO, Ancheta RA. A rapid assessment of the status, trends and challenges in small-scale commercial sardine fisheries in the Sulu Archipelago, southern Philippines. *Marine Policy*. 2024;160:105965. doi:10.1016/j.marpol.2023.105965

37. Chapagai PP, Katel O, Penjor P. Relationships Between Food Systems, Agricultural Practices, and Food Security Amidst Climate Change in Western Bhutan. *American Journal of Food Science and Technology*. 2024;3(1):1-12. doi:10.54536/ajfst.v3i1.2295

38. Tidd AN, Rousseau Y, Ojea E, Watson RA, Blanchard JL. Food security challenged by declining efficiencies of artisanal fishing fleets: A global country-level analysis. *Global Food Security*. 2022;32:100598. doi:10.1016/j.gfs.2021.100598

39. Olaifa ES, Osabuohien ES, Issahaku H. Enhancing fish production for food security in Nigeria. *Materials Today: Proceedings*. 2022;65:2208-2214. doi:10.1016/j.matpr.2022.06.243

40. Onyenekwe CS, Okpara UT, Opata PI, Egyir IS, Sarpong DB. The Triple Challenge: Food Security and Vulnerabilities of Fishing and Farming Households in Situations Characterized by Increasing Conflict, Climate Shock, and Environmental Degradation. *Land*. 2022;11(11):1982. doi:10.3390/land11111982

41. Guo J, Tanaka T. Energy security versus food security: An analysis of fuel ethanol-related markets using the spillover index and partial wavelet coherence approaches. *Energy Economics*. 2022;112:106142. doi:10.1016/j.eneco.2022.106142

42. Muhirwa F, Shen L, Elshkaki A, et al. Ecological balance emerges in implementing the water-energy-food security nexus in well-developed countries in Africa. *Science of The Total Environment*. 2022;833:154999. doi:10.1016/j.scitotenv.2022.154999

43. Kipkoech R, Takase M, Amankwa Afrifa EK. Renewable Energies in Ghana about Market Condition, the Environment, and Food Security. *Journal of Renewable Energy*. 2022;2022. doi:10.1155/2022/8243904

44. Aura CM, Owiti H, Nyamweya C, et al. Aligning small indigenous fish species (SIS) in policy and management for enhanced food security and nutrition: The case of the Kenyan Lake Victoria Omena fishery. *Lakes & Reservoirs: Research & Management*. 2022;27(1):e12399. doi:10.1111/lre.12399

45. March A, Failler P. Small-scale fisheries development in Africa: Lessons learned and best practices for enhancing food security and livelihoods. *Marine Policy*. 2022;136:104925. doi:10.1016/j.marpol.2021.104925

46. Rahman MS, Huang WC, Toiba H, Efani A. Does adaptation to climate change promote household food security? Insights from Indonesian fishermen. *International Journal of Sustainable Development & World Ecology*. Published online 2022:1-14. doi:10.1080/13504509.2022.2063433

47. Brockington M, Beale D, Gaupholm J, et al. Identifying barriers and pathways linking fish and seafood to food security in Inuit Nunangat: A scoping review. *International Journal of Environmental Research and Public Health*. 2023;20(3):2629. doi:10.3390/ijerph20032629

48. Roberts N, Mengge B, Oaks B, Sari N, Irsan, Humphries A. Fish consumption pathways and food security in an Indonesian fishing community. *Food Security*. 2023;15(1):1-19. doi:10.1007/s12571-022-01323-7

49. Yaqoob N, Ali SA, Kannaiah D, et al. The effects of agriculture productivity, land intensification, on sustainable economic growth: a panel analysis from Bangladesh, India, and Pakistan Economies. *Environmental Science and Pollution Research*. Published online 2022:1-9. doi:10.1007/s11356-021-18471-6

50. Bhave AG, Conway D, Dessai S, Dougill AJ, Mkwambisi D. Stress-testing development pathways under a changing climate: water-energy-food security in the lake Malawi-Shire river system. *Philosophical Transactions of the Royal Society A*. 2022;380(2221):20210134. doi:10.1098/rsta.2021.0134

51. Shupler M, Mwitari J, Gohole A, et al. COVID-19 impacts on household energy & food security in a Kenyan informal settlement: The need for integrated approaches to the SDGs. *Renewable and Sustainable Energy Reviews*. 2021;144:111018. doi:10.1016/j.rser.2021.111018

52. Rasul G, Neupane N, Hussain A, Pasakhala B. Beyond hydropower: towards an integrated solution for water, energy and food security in South Asia. *International Journal of Water Resources Development*. 2021;37(3):466-490. doi:10.1080/07900627.2019.1579705

APPENDIX

Table A. Panel Cointegration Test in EU countries

Test	Without Trend	With Trend
A. Pedroni Residual Cointegration Test:		
Alternative hypothesis: common AR coefficients (within dimension):		
Panel v-Statistic	2.978 (0.998)	4.781 (0.996)
Panel rho-Statistic	2.291 (0.989)	2.288 (0.898)
Panel PP-Statistic	1.102*** (0.000)	1.646*** (0.000)
Panel ADF-Statistic	3.1299*** (0.000)	6.150*** (0.000)
Alternative hypothesis: common AR coefficients (between dimensions)		
Group rho-Statistic	4.083	0.978
Group PP-Statistic	2.011***	(0.000)
Group ADF-Statistic	4.8166***	(0.000)

Remark: ***, ** and * refer importance at the 1%, 5%, and 10% scales respectively.
Values in parentheses are p-values.
Source: Alsaleh[14]