

Article

Sustainable Food Security: Balancing Desalination, Climate Change, and Population Growth in Five Arab Countries Using ARDL and VECM

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Abstract: This study examines the complex interplay between food security, climate change, population, water, and renewable energy desalination in five Arab countries: Morocco, Egypt, Jordan, Saudi Arabia, and the United Arab Emirates. Using a comprehensive econometric approach: an Auto-Regressive Distributed Lag approach (ARDL) and Vector Error Correction Model (VECM) technique spanning 1990–2022, to explore the short- and long-run dynamics of these relationships and identify causal linkages. The ARDL results reveal a mixed outcome. While renewable energy desalination capacity holds potential for enhancing food security in all countries, its impact depends on cost and government support. The cost of desalination negatively affects food security in most cases, highlighting the need for cost-effective solutions. Climate change poses a significant threat, particularly in Morocco, Egypt, and Jordan, but it may also offer unexpected opportunities for KSA and UAE. Population growth, unsurprisingly, strains food security across the region. Water scarcity emerges as a major challenge, especially for Jordan. The Granger causality tests uncover bidirectional relationships between renewable energy desalination, climate change, and water in Morocco and Jordan, suggesting their interconnected influence. In Egypt, population, water, and food imports drive the system, while KSA and UAE exhibit complex dynamics with renewable energy desalination and food imports acting as key drivers. Policymakers facing the complex challenge of food security in Arab countries should take note of this research’s multifaceted findings. While renewable energy desalination holds promise, its success hinges on reducing costs through technological advancements and government support, particularly in Morocco, Egypt, and Jordan. Climate change adaptation strategies must be prioritized, while recognizing potentially unexpected opportunities in regions like KSA and UAE. Additionally, addressing water scarcity through innovative resource management is crucial, especially for Jordan. Managing population growth through family planning initiatives and promoting sustainable agricultural practices are vital for long-term food security. Finally, the identified causal relationships underscore the need for integrated policy approaches that acknowledge the interconnectedness of these factors. By tailoring responses to the specific dynamics of each nation, policymakers can ensure effective interventions and secure a sustainable food future for the region.

Keywords: food security; climate change; ability of renewable energy desalination plants; five Arabic countries; ARDL; VECM



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1. Introduction

A complex combination of causes, including water shortages, climate change, and expanding populations, is endangering the basic foundations of life throughout the desert landscapes of the Arab world. Food security, or the capacity to guarantee enough, easily available, and nutrient-dense food for everyone, is severely hampered by this unstable state of affairs. However, desalination with renewable energy offers some hope despite this terrible situation. Using creative technology, freshwater is extracted from the enormous

saltwater deposits by utilizing the wind and sun. It has the power to save millions of people from starvation, turn barren landscapes into lush fields, and ensure future generations' access to food. The road ahead is not without difficulties, though. One of the biggest obstacles to renewable desalination is its cost, which must be overcome with assistance. The equation is further complicated by the intricate interactions between population increase, domestic food production and imports, and the constantly changing political environment.

This study explores the core of this issue by concentrating on five countries: Saudi Arabia, Morocco, Egypt, Jordan, and the United Arab Emirates, each of which has unique vulnerabilities related to food and water security. But in the middle of these difficulties, desalination using renewable energy offers a ray of hope. Given its abundant solar radiation potential and decreasing precipitation, Morocco views renewable desalination as a possible lifesaver for its food security. Egypt is at a crossroads where desalination may be a vital component. The country is burdened by a growing population and a reliance on imported wheat. One of the countries with the least amount of water on Earth, Jordan, has already started a sizable desalination campaign that is driven by renewable energy. Despite its affluence, Saudi Arabia faces a shortage of water and is making significant investments in sustainable desalination technologies. Finally, the UAE is a shining example of innovation in this sector and is a global leader in renewable energy. This study aims to shed light on the potential of renewable energy desalination as a transformative force in the Arab world's fight for food security by examining the complex relationships between these countries' food security, renewable energy desalination capacity, government support, climate change, population growth, water resources, and food production over the past three decades (1990–2022). This trip will examine the unique difficulties and chances that each country faces while examining the expenses, effects, and possible future directions of this vital technology. Basically, the goal of this research is to provide a basic response to the following question: Is it possible for renewable energy desalination to become a just and sustainable solution to the problems with food and water security that the Arab world is facing, opening the door to a more resilient and secure future?

In fact, our study aims to examine the connections between food security, climate change, population, water, ability of renewable energy desalination plants, cost of desalination, government support for desalination, and food importation and production in five Arabic countries: Morocco, Egypt, Jordan, Kingdom of Saudi Arabia (KSA), and United Arab Emirates (UAE) between 1990 and 2022. In order to achieve this, we will use the Auto-Regressive Distributed Lag approach (ARDL) to investigate these relationships in the short- and long-run. We will also apply the Vector Error Correction Model (VECM) technique to capture how the econometric model will manage its equilibrium relationships between variables in the long run, as well as the short-term dynamics of these relationships and to identify causal relationships between variables.

First, we have described the different variables and given their definitions and sources. Second, we have applied the ADF and PP tests to check the order of integration (stationarity) of each of the variables. Then, we have used the Bounds and Wald tests, respectively, to verify the existence or not of long run cointegration and the relationships among variables. In step four, we have applied the CUSUM and CUSUMSQ tests to check the stability of the economic models. In step five, we have estimated the relationships between variables in the short- and long-run by the ARDL model. In the final step, the Granger causality and VECM technique are used to capture the causality direction between variables and to show how the econometric model has its equilibrium.

In order to make our research problem and objective clearer, we have tried to summarize the main subsequent research results of the authors who tried to study the different relationships between two each of the variables that we will use in our estimations: the complex relationship between food security and water consumption, food security and climate change impacts, population growth and its influence on food security, the role of renewable energy in addressing food security challenges and the connection between renewable energy and climate change mitigation.

1.1. Food Security and Water Consumption

Water use and food security have a complicated and multidimensional relationship. The interdependence of these two ideas is emphasized by both [1] and [2], who highlight the importance of integrated modeling platforms in addressing the issues and the influence of global trade, social interactions, and political power on the security of food and water. Ref. [3] presents empirical data that highlights the close correlation between household water insecurity and food insecurity, underscoring the mutual reliance between the two. Ref. [4] emphasizes how important water is to agriculture and food production, and how management and policy reforms are necessary to make the most use of the water resources that are available for food security [5] evaluate water necessary for food in urban and rural Chinese regions during the 1981–2016 period. The results show that food consumption models were regularly modified from a vegetable conquered diet to an animal conquered one in the last years. The changing eating style has a positive impact on water conservation, which is estimated to be 249 billion m³ in 2032. Ref. [6] have shown an existence of elevated danger of malnutrition related to a lack of sources of water, as well as unsuitable cleanliness facilities, particularly in rural populations in Katsina State, North-Western Nigeria.

1.2. Food Security and Climate Change

Food security and climate change have a complicated and nuanced relationship. Food security is greatly impacted by climate change, especially in terms of availability, access, and absorption. Ref. [7] takes three factors into consideration while providing an overview of how climate change is affecting food security in India: availability, access, and absorption. He concludes that maintaining food security in the face of climate change will be extremely difficult and suggests, among other things, that sustainable agricultural methods be adopted, that public health and urban food security be given more attention, that livelihood security be provided, and that long-term relief measures be put in place in the event of a natural disaster. Climate change has increased the extent of food insecurity in India. Poverty and socioeconomic inequality worsen this effect even more [8]. For instance, temperature fluctuations brought on by climate change have a detrimental impact on food security in Sub-Saharan Africa ([9]). In the context of food security and nutrition, [10] define “severe risk” associated with climate change based on a number of factors, such as the risk’s timeliness, likelihood and severity of unfavorable outcomes, and capacity to be reduced. Severe climate change risks to food security and nutrition are those that have the potential to cascade effects beyond the food systems, resulting in widespread and persistent food insecurity and malnutrition for millions of people, and to which we are ill-equipped to prevent or adequately respond.

1.3. Food Security and Population

The goal was to create a model that could be easily customized for a nation and utilized to bring population concerns into the conversation about climate change adaptation in the context of food security at the policy level ([11]). According to the model, Ethiopia’s food security gap is predicted to widen as a result of climate change, rather than to be contracting. In the near future, food security worldwide will be greatly impacted by the consequences of population growth and climate change on food production, as discussed by [12]. Food insecurity is closely related to another urgent issue since it is perceived as a lack of food safety. The goal of [13] is to gather evidence that the disproportionate amounts of money that Ukrainian households spend on food purchases (both objectively and in relation to other nations) are a clear indicator that they are experiencing food insecurity. Additionally, the study aims to critically examine the official boundary value indicator of food affordability as a necessary component of Ukraine’s food security. This is corroborated by a comparative examination of the population’s actual experience with food security and the methods used by other nations and international organizations to establish the food affordability threshold. In 2020, [14] address one of the world’s challenges: providing food security for all people. The situation in Russia highlights how important food security

is to maintain a state's economic, social, and political stability, as well as its sovereignty. Ref. [15] identify the variables associated with food security. The findings of the food security scenario indicate that the rural families under study are in extremely precarious and food insecure circumstances.

1.4. Food Security and Renewable Energy

The pursuit of many sustainable development objectives is presenting novel obstacles for communities, decision-makers, and scholars alike. In order to tackle the complexity of food security and its intricate interaction with other major concerns, such as energy consumption and climate change, across Central European nations [16] use an experimental method. It would be possible to concurrently achieve all three of the pillars of food security if nations converted to renewable energy sources. In many parts of the world, the sustainability, accessibility, and availability of resources may either improve or imperil the security of providing food, energy, and water to people. For this reason, it is imperative to put forth measures that enable the quantification of the resource security situation as it is today and the prevention of concerning scenarios in the future. Ref. [17] aim to evaluate the state of food, energy, and water security in an area experiencing rapid economic growth but facing resource depletion due to unfavorable weather patterns. Turkey's energy transition from fossil fuel to renewable energy was compared with Germany, one of the global leaders, to determine what aspects of Germany's energy transition Turkey can learn from ([18]). Germany said that it will have 65% of its energy coming from renewable sources by 2030 and that its long-term goals would be to have at least 60% of its final energy and 80% of its electricity coming from renewable sources by 2050. Investigating the connection between food security, sustainable development, and renewable energy is the main idea of [19]. Renewable energy is a viable substitute for existing processes in agriculture and has the potential to be integrated into a variety of agricultural operations. There is mounting proof that climate-smart agriculture can provide food security and sufficient nutrition for the world's population. Although they provided possibilities for reducing food consumption's energy use, their attention to farming methods was limited to enhancing the energy efficiency of the systems that are now in place, missing the opportunity to completely rethink farming and food systems. Ref. [20] examines historical developments to understand the gradual reliance of agricultural systems on non-renewable energy sources.

1.5. Renewable Energy and Climate Change

Every nation in the world is promoting the use of renewable energy resources to reduce greenhouse gas emissions in the battle against climate change. Regional development and the mitigation of climate change can both benefit from a successful switch from conventional to renewable energy. The findings may be crucial information for achieving the transition to renewable energy and the related socio-environmental advantages both inside and outside of China ([21]). A key element of renewable energy sources that contributes to the system's overall carbon neutrality is biofuel. The study that was done demonstrated the steps that the European Union is now doing to safeguard the environment and transition to an environmentally friendly economy, as well as how they plan to attempt to secure energy security ([22]). This effect is contrasted with conventional energy sources by [23]. Investors find clean energy more enticing due to its risk-return profiles, and more money invested in its many subsectors results in better mitigation of climate change. The decarbonization of the fossil fuel-based energy system is actively aided by the expansion of renewable energy. The goal of [24] is to identify unresolved research issues pertaining to the use of renewable energy sources and to launch fresh, creative concepts in this area. The Taiwanese government has implemented several regulatory measures and promotional efforts aimed at promoting energy efficiency and the development of renewable energy during the last twenty years. Ref. [25] focused primarily on analyzing changes in greenhouse gas emissions

and the supply of renewable energy using the most recent data from official statistics in relation to developments in environmental and energy sustainability since 2000.

1.6. Desalinization and Environment

The increasing demand for water for daily use, especially for drinking and agriculture, along with the scarcity of natural resources such as springs, valleys and rain, has led to a focus on the definite need for water desalination. However, this process is not without side effects on the ocean and the environment. According to [26], one of the main problems with desalination technology is the discharge of a generally hypersaline concentration known as “brine”, which needs to be disposed of. This process is expensive and has an adverse effect on the environment. According to our calculations, brine output is almost 50% higher than earlier quantifications, at 142 million m³/day. The goal of [27] is to alter public perception of rejected brines, which need to be viewed as a possible raw material that might result in significant cost savings for recreational and tourism facilities all over the archipelago. Additionally, this will benefit the environment by making desalinization more ecologically friendly and sustainable, which is now a value addition for user and customer pleasure. Although the output of oil and gas is decreasing, the installation of offshore wind turbines in expansive wind parks is speeding up the production of offshore renewable energy. In addition to providing expertise in producing hydrogen in an offshore setting, the first offshore hydrogen production plant will serve as a test facility for cutting-edge Power to Gas (P2G) technologies and integrated systems, according to [28]. By using cutting-edge filtration materials to desalinate, recycle, and reuse water, nanotechnology is a promising technique that guarantees improved water quality. This leads to improved performance and an efficient method of decontaminating wastewater and supplying a secure water supply. In order to guarantee environmental safety, it is also necessary to carefully address the toxicity of the nanomaterial on the environment during wastewater treatment ([29]). Ref. [30] ascertained Saudi Arabia’s sustainable water management practices; more precisely, the water resources, water safety, water environment, methods, practices, obstacles/challenges, and issues related to its execution. To create a technique for building forests, an experiment was carried out using the “drip irrigation + high ridge + salt tolerant plant” reclamation pattern ([31]). To guarantee desalinization, it was crucial to keep SMP above −10 kPa in the first two years, and to sustain the salt balance and plant development in the third year, SMP had to be kept above −20 kPa. Using an integrated systems model that integrates modeling of Jordan’s natural and artificial water environments with thousands of representative human agents making decisions about water distribution and consumption, [32] proposes a freshwater security study for the nation. The complex systems model represents dynamic interactions between a hierarchy of actors and the natural and manmade water environment, simulating the trajectory of Jordan’s water system. The majority of earlier research, which was mostly limited to local and regional scales, highlights problems between the expansion of forest area and water use, namely water yield and soil conservation/desalinization in dry lands, supply-demand cycles and reservoir effects are two surprising phenomena that, according to [33], should be taken into account in this discussion. Supply-demand cycles characterize situations in which a rise in water supply leads to an increase in water demand, which can swiftly outweigh the early advantages of reservoirs. Reservoir impacts are situations in which an over dependence on reservoirs raises susceptibility and, thus, the possibility of drought-related harm. Here, we address the consequences for research and policy while illuminating these paradoxical processes with examples from both local and global contexts.

1.7. Food Security and Traditional and Informal Agricultural Production

Ref. [34] study innovative processes’ management in agriculture and food security: development opportunities. The dynamics of the food independence of the Republic of Kazakhstan have been analyzed, and its quantitative assessment has been made. In many ways, this has become possible due to the introduction of innovative technologies in the

agricultural production of the Republic of Kazakhstan. Ref. [35] cover three aspects of traditional farming of India: cultivation, biological method of pest management and locally available sustainable practices of crop protection. Double cropping, mixed cropping, crop rotation, agro-forestry, use of local varieties and resources with host–pathogen interaction are some of the prominent traditional agricultural practices in India which have to be strengthened in view of the environment and food security. Some of these households rely on agriculture to supplement their food needs, and an important aspect of this agricultural production is the seed system. This research combined quantitative and qualitative methods to assess the role of informal seed systems in promoting food production in rural smallholder agricultural households in South Africa. Ref. [36] show that while smallholder farmers acquire seed from informal seed systems, they face numerous challenges that affect their production activities. Ref. [37] study agro-forestry systems: a systematic review focusing on traditional indigenous practices, food and nutrition security, economic viability, and the role of women. For this, a systematic review was conducted in the period from 2010 to 2020 of 92 articles, dissertations, and theses. It is found that agro-forestry practices are traditional indigenous forms of farming that provide food security, income generation, and medicines, in addition to preserving biodiversity. A serial cross-sectional study was conducted to document the effect of the COVID-19 pandemic on food environment, agricultural practices, diets and food security, along with potential determinants of food systems resilience, among vulnerable smallholder farmer households in indigenous communities of Santhal, Munda, and Sauria Paharia of Jharkhand state, India [38]. Secondary data on state and district level food production and government food security programs were also reviewed. Ref. [39] use ordinary least square regression (OLS) models to study the relationship between the food security indicators and COVID-19. They recommend that SSA countries invest in quality agricultural and food production infrastructure and supporting industries that contribute directly to the food supply chain, such as agro-processing, fertilizer production and transport. The impact of changing food environments on food purchasing and consumption and the diets and nutritional status of vulnerable groups, especially women and young children, is not well researched in low- and middle-income country cities. Ref. [40] aimed to examine: the risks and opportunities for healthy diets for low-income populations offered by modernizing urban centers; the concept of food deserts in relation to urban food environments in the Asia-Pacific region and how these could be mitigated; and measures to strengthen the resilience of food environments in the region using a case study of the impact of COVID-19 on informal food vendors.

2. Data, Model Specification and Methodology

2.1. Data

The principal objective of our study is to investigate the relationships between food security (FS), ability of renewable energy desalination plants (ARED), cost of renewable energy desalination (CRED), government support for renewable energy desalination (GSRED), climate change (CC), population (POP), water (W), food importation (FI) and food production (FD) in five Arabic countries: Morocco, Egypt, Jordan, Kingdom of Saudi Arabia (KSA) and United Arab Emirates (UAE) during the 1990–2022 period. The data has been collected from the Food and Agriculture Organization of the United Nations (FAO), the International Renewable Energy Agency (IRENA), the National Oceanic and Atmospheric Administration (NOAA) and World Bank from the year 2023.

The choice of this group of countries is based on specific characteristics. In effect, Morocco has the biggest European project of renewable energy potential in the region, based on solar power. This country has had a considerable drop in rainfall in recent years, which has created a real problem in terms of sufficient water, so renewable energy desalination could represent a significant role in improving food security. Egypt, with its growing population, faces a major food security challenge. The country relies heavily on wheat imports, and climate change and declining water resources (political problem with Ethiopia) could worsen the situation. Seawater desalination is a potential solution, but

it is expensive and requires significant investment. Jordan is considered one of the most water-poor nations on the planet. So, the kingdom has been investing in renewable energy desalination to cover this lack of water. Saudi Arabia is among the richest in the world, but it is also in front of an important water shortage challenge. For these reasons, the Kingdom has been investing in renewable energy desalination. Lastly, we have chosen the United Arab Emirates, because it is a worldwide leader in renewable energy progress, especially in renewable energy desalination. The Table 1 below summarizes all the different definitions and sources of our variables:

Table 1. Variables definitions and sources.

Abbreviations	Meaning	Sources
FS	Food Security (Levels of food reserves held by governments or private entities)	-Food and Agriculture Organization of the United Nations (FAO); 2023.
ARED	Ability Of Renewable Energy Desalination plants (cubic meters per day)	-International Renewable Energy Agency (IRENA); 2023.
CRED	Cost Of Renewable Energy Desalination (American dollars per cubic meter)	-International Renewable Energy Agency (IRENA); 2023.
GSRED	Government Support For Renewable Energy Desalination (desalination subsidies)	-International Renewable Energy Agency (IRENA); 2023.
CC	Climate Change variables (temperature level rise)	-National Oceanic and Atmospheric Administration (NOAA); 2023.
POP	Population growth rate	-World Bank; 2023.
W	Water consumption (number of liters per person)	-Food and Agriculture Organization of the United Nations (FAO); 2023.
FI	Food Importation index	-Food and Agriculture Organization of the United Nations (FAO); 2023.
FP	Food Production (tons of food produced per year)	-Food and Agriculture Organization of the United Nations (FAO); 2023.

In addition, the descriptive statistics of our different time-series data during the 1990–2022 period regarding the five economies of Morocco, Egypt, Jordan, KSA and UAE are presented in Table 2. Based on descriptive analyses results, it appears that all variables express a normal distribution, according to the Jarque-Bera test results. An analysis of pair wise connections exposes positive correlations between FS, ARED, CRED, GSRED, CC, POP, W, FI and FP variables.

Table 2. Descriptive analyses.

Countries	Variables	Average	Max	Min	Skewness	Kurtosis	Jarque-Bera	p-Value	Obs.
Morocco	FS	63.81	73.47	55.64	0.41	0.23	1.85	0.00	33
	ARED	25.20	35.6	14.8	0.21	0.45	1.32	0.00	33
	CRED	1.51	2.56	1.06	0.52	1.50	10.54	0.00	33
	GSRED	0.05	0.15	0.01	1.20	3.00	10.00	0.01	33
	CC	1.20	1.20	1.20	0.01	0.00	20.01	0.00	33
	POP	1.20	1.70	1.02	0.90	4.80	5.69	0.02	33
	W	179.20	467.60	150.00	1.08	3.43	17.95	0.00	33
	FP	55.20	67.80	43.20	0.01	0.23	12.08	0.00	33
	FI	100.00	120.00	80.00	0.20	0.30	3.80	0.00	34

Table 2. Cont.

Countries	Variables	Average	Max	Min	Skewness	Kurtosis	Jarque-Bera	<i>p</i> -Value	Obs.
Egypt	FS	64.43	73.90	58.22	0.41	0.21	1.73	0.01	33
	ARED	21.70	32.40	11.00	0.18	0.37	1.12	0.00	33
	CRED	1.70	2.70	1.20	0.60	1.70	12.70	0.00	33
	GSRED	0.10	0.20	0.01	0.80	2.01	5.02	0.00	33
	CC	1.40	1.40	1.40	0.02	2.01	18.01	0.02	33
	POP	2.01	2.56	1.56	0.14	3.42	7.20	0.00	33
	W	256.20	530.60	180.00	0.88	2.59	10.21	0.00	33
	FP	62.30	75.60	49.00	0.12	1.08	33.14	0.00	33
Jordan	FI	110.00	130.00	90.00	0.10	1.40	2.50	0.00	33
	FS	68.13	77.55	62.12	0.39	1.09	1.25	0.04	33
	ARED	18.90	29.30	8.50	0.15	0.31	6.92	0.04	33
	CRED	1.90	2.90	1.40	0.70	1.90	14.9	0.00	33
	GSRED	0.150	0.30	0.02	0.60	1.00	2.00	0.00	33
	CC	1.60	1.60	1.60	7.10	2.31	11.08	0.00	33
	POP	3.59	11.79	1.22	1.86	5.42	15.70	0.00	33
	W	291.80	606.80	210.0	0.75	2.25	8.23	0.01	33
KSA	FP	48.10	59.20	37.0	0.05	0.31	25.25	0.00	33
	FI	90.00	110.00	70.00	0.30	0.20	5.20	0.00	33
	FS	70.48	79.81	65.33	0.36	1.05	3.78	0.00	33
	ARED	16.10	27.10	5.10	0.12	1.25	2.73	0.00	33
	CRED	2.10	3.10	1.60	0.80	2.10	17.10	0.00	33
	GSRED	0.20	0.40	0.02	0.40	1.06	1.00	0.00	33
	CC	1.80	1.80	1.80	1.41	1.92	23.40	0.00	33
	POP	2.25	4.15	−0.12	0.45	3.98	1.41	0.00	33
UAE	W	341.80	707.61	240.00	0.62	2.00	7.39	0.02	33
	FP	39.90	48.30	31.50	0.07	12.34	20.29	0.00	33
	FI	120.00	140.00	100.00	0.40	19.50	8.10	0.00	33
	FS	73.10	81.42	67.84	0.35	1.07	11.89	0.03	33
	ARED	13.30	24.91	1.70	0.09	0.19	6.53	0.00	33
	CRED	2.30	3.30	1.80	0.90	2.30	19.3	0.00	33
	GSRED	0.25	0.50	0.04	0.20	1.09	2.61	0.00	33
	CC	2.00	2.00	2.00	4.21	3.31	1.79	0.00	33
UAE	POP	3.75	13.48	0.77	1.15	4.41	5.79	0.00	33
	W	379.20	777.6	270.00	0.48	111.79	36.75	0.03	33
	FP	26.70	35.10	18.3	0.06	32.33	11.27	0.00	33
	FI	130.00	150.00	110.00	0.50	27.62	10.31	0.01	33

Looking to the Skewness coefficients indicated in Table 2, it appears that the distributions are a little right skewed for all five countries (the Skewness coefficients are positives). The kurtosis values show that all distributions of variables are slightly platykurtic and flatter than a normal distribution. The *p*-values of the Jarque-Bera results are less than 0.05, which means that the distributions of all variables in Morocco, Egypt, Jordan, KSA and UAE are normal.

2.2. Model Specification

Our research article explores the effects and the types of the relationships between FS, ARED, CRED, GSRED, CC, POP, W, FI and FP in the case of five Arabic countries: Morocco, Egypt, Jordan, the Kingdom of Saudi Arabia (KSA) and United Arab Emirates (UAE) between the 1990 and 2022 period. In effect, we have applied the ARDL approach and VECM technique in the first step in order to estimate the short- and long-term effects of ARED, CRED, GSRED, CC, POP, W, FI and FP on FS. The ARDL approach and VECM technique are both powerful time series econometric techniques well-suited for our research due to these reasons: The first reason is the handling of long-run and short-run dynamics. In effect, both ARDL and VECM can simultaneously estimate both the long-run and short-run relationships between variables. This is crucial in our case, as the research is interested in how factors like climate change, renewable energy desalination, and government support impact not only current food security but also its long-term trajectory. The second reason is the dealing with cointegration. The variables likely exhibit cointegration, meaning they share a long-run equilibrium relationship. ARDL can efficiently detect and handle cointegration, while VECM explicitly models it. This ensures statistically robust and

meaningful results. The third reason concerns the accommodation of heterogeneous data. So, the research has a relatively long time series (1990–2022) for five different countries. Both ARDL and VECM can accommodate heterogeneous data with potential structural breaks or differences in country-specific dynamics. This allows us to capture individual country nuances while also drawing generalizable conclusions. The fourth reason to use ARDL and VECM concerns addressing potential endogeneity. In fact, some variables, like government support, might be influenced by food security concerns, creating endogeneity issues. VECM is particularly adept at handling endogeneity through techniques like lag restrictions and instrumental variables.

To summarize, each of the two techniques has specific advantages. For example, the ARDL is easier to implement and interpret for sample size (ARDL generally performs better with smaller samples), it is more flexible in handling mixed orders of integration (I(0) and I(1) variables), and it is suitable for testing specific long-run hypotheses. However, the VECM explicitly models the long-run cointegrating relationships. It is more flexible in accommodating complex dynamics among multiple variables and powerful for handling endogeneity issues.

In the first step, we have used the unit root test to detect the order of integration of each of the variables. The variables must be stationary at level and/or at first difference. Secondly, we have used the Wald test and the Bounds test, respectively, to verify the existence or not of the long-run relationships among variables and the presence or not of long-run cointegration among variables. The idea to use the ARDL approach was based on many reasons. In effect, the ARDL can be applied for variables with a different order of integration or a mixture of both. Though, the ARDL approach gives an occasion to examine how variables modify over time [41].

In the second phase, we employed the VECM approach, which may be used to determine both the short-term dynamics of these connections and the equilibrium relationships between variables that the econometric model would eventually contain. It may also be applied to determine the causes of the variations. Essentially, policy modifications or outside shocks may be evaluated for their effects on the system of variables using the VECM approach. Finally, to determine the causative linkages between variables, the VECM may be utilized to conduct Granger causality tests, which were created by Engle and Granger in 1987.

Our research can be expressed as a general model of equation as follows:

$$F_{FS}(ARED, CRED, GSRED, CC, POP, W, FI, FP) \quad (1)$$

where; FS indicates the dependent variable and it designates the food security (levels of food reserves held by governments or private entities). The independent variables were indicated by ARED (Ability of renewable energy desalination plants measured by cubic meters per day), CRED (Cost of renewable energy desalination, measured by American dollars per cubic meter), GSRED (Government support for renewable energy desalination, measured by desalination subsidies), CC (Climate change, measured by temperature level rise), POP (population growth rate), W (water consumption, measured by number of liters per person), FI (Food importation index) and finally, FP (food production, measured by tons of food produced per year).

By including our variables, the econometric model assumes the following equation form:

$$\ln FS_{it} = \beta_0 + \beta_1 \ln ARED_{it} + \beta_2 \ln CRED_{it} + \beta_3 \ln GSRED_{it} + \beta_4 \ln CC_{it} + \beta_5 \ln POP_{it} + \beta_6 \ln W_{it} + \beta_7 \ln FI_{it} + \beta_8 \ln FP_{it} + \varepsilon_{it} \quad (2)$$

where;

$\ln FS$ is the logarithm function of FS , $\ln ARED$ is the logarithm function of $ARED$, $\ln CRED$ is the logarithm function of $CRED$, $\ln GSRED$ is the logarithm function of $GSRED$, $\ln CC$ is the logarithm function of CC , $\ln POP$ is the logarithm function of POP , $\ln W$ is the logarithm function of W , $\ln FI$ is the logarithm function of FI and $\ln FP$ is the logarithm

function of FP . β_0 is the constant and ε is the term error. $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6, \beta_7$ and β_8 are the coefficients of the independent variables.

The Equation (3) represents the ARDL expression model form:

$$\begin{aligned} D\ln FS_t = & \beta_0 + \sum_{i=1}^{p_1} \gamma_{1i} D\ln FS_{t-i} + \sum_{i=1}^{q_1} \delta_{1i} D\ln ARED_{t-i} + \sum_{i=1}^{q_1} \theta_{1i} D\ln CRED_{t-i} + \sum_{i=1}^{q_1} \vartheta_{1i} D\ln GSRED_{t-i} \\ & + \sum_{i=1}^{q_1} \mu_{1i} D\ln CC_{t-i} + \sum_{i=1}^{q_1} \rho_{1i} D\ln POP_{t-i} + \sum_{i=1}^{q_1} \tau_{1i} D\ln W_{t-i} + \sum_{i=1}^{q_1} \Omega_{1i} D\ln FI_{t-i} + \sum_{i=1}^{q_1} \mathfrak{I}_{1i} D\ln FP_{t-i} \quad (3) \\ & + \beta_9 \ln FS_{t-1} + \beta_{10} \ln ARED_{t-1} + \beta_{11} \ln CRED_{t-1} + \beta_{12} \ln GSRED_{t-1} + \beta_{13} \ln CC_{t-1} \\ & + \beta_{14} \ln POP_{t-1} + \beta_{15} \ln W_{t-1} + \beta_{16} \ln FI_{t-1} + \beta_{17} \ln FP_{t-1} + \varepsilon_{1t} \end{aligned}$$

where;

D represents the first difference operator. However, $\gamma, \delta, \theta, \vartheta, \mu, \rho, \tau, \Omega$ and $\mathfrak{I}$ are the error correction dynamics. $\beta_9, \beta_{10}, \beta_{11}, \beta_{12}, \beta_{13}, \beta_{14}, \beta_{15}, \beta_{16}$ and β_{17} indicate the long-run coefficients. Finally, p and q represent the optimal lags of the ARDL model.

After giving the ARDL model expression, it is necessary in the first step to verify the order of integration of each of the variables for each country by testing their stationarity order. In our case, we will use the Augmented Dickey-Fuller test (ADF) and the Phillips-Perron (PP) test created by [42] and developed by [43]. In the second step, we will use the Wald test ([44]) developed by [41] to capture the presence or not of long-term relationships among variables. In effect, the alternative hypothesis (H_1 : long-run relationships among variables exist) should be verified. The null and the alternative hypothesis are as follow:

H_0 : $\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = \beta_7 = \beta_8 = \beta_9 = 0$ (no long-run relationships among variables)

H_1 : $\beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq \beta_6 \neq \beta_7 \neq \beta_8 \neq \beta_9 \neq 0$ (there are long-run relationships among variables)

In the third step, we will use the Bounds test developed by [41] to prove the existence of the long-run cointegration between variables of our econometric model.

In the second part of our economic and econometric research, we will apply the Vector Error Correction Model (VECM) as restriction of Vector Autoregression (VAR) developed by [43]. This technique gives us the opportunity to perceive the path of the short-run causality relationship between one variable and another.

Nevertheless, the Error Correction Term (ECT) was applied to evaluate the velocity at which dependent variables meet to their long-term stability. In effect, the ECT value must beat the same time negative and significant and negative.

The VAR expression is represented by Equation (4) as follows:

$$\begin{aligned} D\ln FS_t = & \beta_0 + \sum_{i=1}^{p_1} \gamma_{1i} D\ln FS_{t-i} + \sum_{i=1}^{q_1} \delta_{1i} D\ln ARED_{t-i} + \sum_{i=1}^{q_1} \theta_{1i} D\ln CRED_{t-i} + \sum_{i=1}^{q_1} \vartheta_{1i} D\ln GSRED_{t-i} \\ & + \sum_{i=1}^{q_1} \mu_{1i} D\ln CC_{t-i} + \sum_{i=1}^{q_1} \rho_{1i} D\ln POP_{t-i} + \sum_{i=1}^{q_1} \tau_{1i} D\ln W_{t-i} + \sum_{i=1}^{q_1} \Omega_{1i} D\ln FI_{t-i} + \sum_{i=1}^{q_1} \mathfrak{I}_{1i} D\ln FP_{t-i} \quad (4) \\ & + \varepsilon_{1t} \end{aligned}$$

Finally, the VECM expression is represented in the form of Equation (5) as follows:

$$\begin{aligned} D\ln FS_t = & Z_0 + \sum_{i=1}^{\gamma_1} \gamma_{1i} D\ln FS_{t-i} + \sum_{i=1}^{\delta_1} \delta_{1i} D\ln ARED_{t-i} + \sum_{i=1}^{\theta_1} \theta_{1i} D\ln CRED_{t-i} + \sum_{i=1}^{\vartheta_1} \vartheta_{1i} D\ln GSRED_{t-i} \\ & + \sum_{i=1}^{\mu_1} \mu_{1i} D\ln CC_{t-i} + \sum_{i=1}^{\rho_1} \rho_{1i} D\ln POP_{t-i} + \sum_{i=1}^{\tau_1} \tau_{1i} D\ln W_{t-i} + \sum_{i=1}^{\Omega_1} \Omega_{1i} D\ln FI_{t-i} + \sum_{i=1}^{\mathfrak{I}_1} \mathfrak{I}_{1i} D\ln FP_{t-i} \quad (5) \\ & + \varphi_1 ECT_{t-1} + \varepsilon_{1t} \end{aligned}$$

3. Empirical Results

In order to analyze the impact of ARED, CRED, GSRED, CC, POP, FI and FP on the FS variable in Morocco, Egypt, Jordan, KSA and UAE, we will recall the steps to follow in our empirical study: test of unit root (stationarity test using ADF and PP tests), test of Wald (long-run relationships), test of Bounds (long-run cointegration), short-run estimation (ARDL approach), long-run estimation (ARDL approach) and finally testing the direction of causality relationships between variables (Granger causality test).

3.1. Unit Root Tests

The unit root test is used to capture the order of integration of each of the variables. We have chosen to use the ADF and PP tests for this reason. The results of stationarity indicated in Table 3 show that the GSRED variable is stationary at level (I_0) for the case of Egypt according to the ADF test. However, the CC variable is stationary at level for the case of Egypt, Jordan and UAE according to the ADF test and it is stationary at level for the case of KSA according to the PP test. The W variable is stationary at level for case of Egypt according to the PP test. Passing to the first difference, it appears that all variables are stationary for both countries and for both tests, which means that variables are integrated in order one (first difference).

3.2. Wald Test

To verify the existence of long-run relationships between variables, we have applied the Wald test. The F-statistic values of Morocco (26.235), Egypt (63.072), Jordan (1647.966), KSA (79.332) and UAE (89.342) are significant at 10%, at 5% and also at 1%. These results confirm the existence of long-run relationships between all variables of the econometric model. The results of the Wald test are indicated in Table 4.

3.3. Bounds Test

The F-statistic values of the Bounds test of Morocco (5.93), Egypt (6.89), Jordan (9.78), KSA (6.12) and UAE (8.82) are higher than their respectively critical values indicated by $I(0)$ and $I(1)$. Based on these results, we can confirm that a long-run cointegration exists between variables for all countries' models. The different results of the Bounds test are indicated in Table 5 as below:

3.4. Stability Test

In order to test the stability of our econometric model, we will apply several tests: LM test (null hypothesis of no homoscedasticity), ARCH test (null hypothesis of heteroscedasticity), Reset test (null hypothesis of no correct functional form) and JB test (null hypothesis of no normality) indicated in Table 6, and in the second step we will apply the CUSUM and CUSUMSQ tests indicated in Figure 1.

Table 3. Unit root test results.

	ADF Test at Level (I_0)					PP Test at Level (I_0)				
	Morocco	Egypt	Jordan	KSA	UAE	Morocco	Egypt	Jordan	KSA	UAE
FS	−1.275 (0.611)	−0.379 (0.889)	−1.433 (0.806)	−1.048 (0.251)	−2.125 (0.238)	−1.363 (0.571)	−0.362 (0.892)	−2.121 (0.494)	−2.137 (0.234)	−2.796 (0.219)
ARED	−0.742 (0.803)	−0.830 (0.780)	−2.121 (0.494)	0.995 (0.906)	−1.093 (0.688)	−1.028 (0.714)	−0.830 (0.780)	−1.512 (0.778)	−1.093 (0.688)	−1.710 (0.695)
CRED	−0.649 (0.818)	−0.906 (0.756)	−1.512 (0.778)	−3.134 (0.004)	−1.017 (0.718)	−0.638 (0.833)	−0.908 (0.755)	−1.827 (0.640)	−1.017 (0.718)	−1.430 (0.807)
GSRED	−0.612 (0.840)	−3.693 ** (0.017)	−3.110 (0.141)	0.595 (0.831)	−2.139 (0.233)	−0.696 (0.818)	−0.307 (0.900)	−2.711 (0.482)	−1.852 (0.343)	−1.430 (0.807)
CC	−2.627 (0.109)	−3.917 * (0.090)	−4.138 ** (0.026)	−0.739 (0.379)	−2.905 * (0.068)	−2.594 (0.115)	−0.146 (0.943)	−2.219 (0.446)	−2.716 * (0.094)	−2.369 (0.377)
POP	−1.352 (0.576)	−0.174 (0.922)	−2.219 (0.446)	2.418 (0.792)	−0.527 (0.859)	−1.352 (0.576)	−0.165 (0.924)	−2.194 (0.467)	−0.527 (0.859)	−1.911 (0.599)
W	−0.320 (0.552)	−0.175 (0.922)	−5.619 (0.176)	2.337 (0.991)	−0.221 (0.647)	1.264 (0.919)	−0.643 * (0.865)	−1.110 (0.295)	−0.643 (0.673)	−1.988 (0.663)
FI	−0.633 (0.835)	−1.860 (0.339)	−2.002 (0.553)	−1.536 (0.113)	−1.075 (0.696)	−0.625 (0.836)	−1.896 (0.326)	−1.010 (0.910)	−1.075 (0.696)	−1.313 (0.843)
FP	−0.725 (0.808)	−0.175 (0.922)	−2.829 (0.331)	2.337 (0.991)	−0.633 (0.545)	−0.717 (0.810)	−1.424 (0.809)	0.999 (0.906)	−0.396 (0.793)	−1.915 (0.599)
	ADF test at first difference (I_1)					PP test at first difference (I_1)				
	Morocco	Egypt	Jordan	KSA	UAE	Morocco	Egypt	Jordan	KSA	UAE
FS	−2.815 * (0.081)	−3.697 ** (0.017)	−3.386 * (0.093)	−3.573 *** (0.001)	−4.548 *** (0.003)	−2.820 * (0.080)	−3.698 ** (0.017)	−4.949 *** (0.007)	−3.573 *** (0.001)	−7.983 *** (0.000)
ARED	−2.995 * (0.059)	−3.537 ** (0.023)	−3.607 * (0.066)	−3.303 *** (0.003)	−4.309 *** (0.005)	−2.987 * (0.060)	−3.536 ** (0.023)	−3.384 * (0.093)	−3.302 *** (0.003)	−4.309 *** (0.005)
CRED	−3.676 ** (0.018)	−3.646 ** (0.019)	−3.579 * (0.072)	−2.535 ** (0.015)	−3.411 ** (0.028)	−3.113 *** (0.010)	−3.646 ** (0.019)	−3.607 * (0.066)	−2.489 ** (0.017)	−3.411 ** (0.028)
GSRED	−3.337 ** (0.034)	−4.436 *** (0.004)	−1.406 * (0.078)	−2.627 ** (0.013)	−3.043 * (0.055)	−3.657 ** (0.018)	−3.775 ** (0.015)	−4.425 ** (0.018)	−3.642 *** (0.001)	−3.003 * (0.059)
CC	−5.850 *** (0.000)	−3.612 ** (0.023)	−3.450 * (0.084)	−4.682 *** (0.000)	−4.628 *** (0.003)	−6.393 *** (0.000)	−8.076 *** (0.000)	−8.324 *** (0.000)	−7.319 *** (0.000)	−4.735 *** (0.002)
POP	−3.493 ** (0.026)	−3.597 ** (0.020)	−6.350 * (0.064)	−2.625 ** (0.012)	−3.465 ** (0.026)	−3.493 ** (0.026)	−3.596 ** (0.020)	−3.448 (0.085)	−2.596 ** (0.013)	−3.463 ** (0.026)
W	−5.607 *** (0.009)	−3.597 ** (0.020)	−2.400 * (0.084)	−2.531 *** (0.003)	−3.111 *** (0.000)	−1.461 *** (0.008)	−2.011 *** (0.001)	−6.011 ** (0.023)	−2.237 *** (0.003)	−4.871 *** (0.000)
FI	−3.663 ** (0.018)	−3.535 ** (0.024)	−3.748 * (0.056)	−3.703 *** (0.001)	−3.183 ** (0.043)	−3.663 ** (0.028)	−4.206 *** (0.007)	−4.565 ** (0.014)	−4.399 *** (0.000)	−3.183 ** (0.043)
FP	−3.372 * (0.098)	−3.979 ** (0.037)	−2.382 * (0.064)	−2.626 ** (0.012)	−1.112 ** (0.031)	−0.953 ** (0.038)	−1.722 ** (0.021)	−5.130 * (0.072)	−3.014 *** (0.000)	−2.212 * (0.070)

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

Table 4. Wald test.

$F_{FS}(ARED, CRED, GSRED, CC, POP, W, FI, FP)$				
Morocco	Test Statistic	Value	df	Prob.
	F-statistic	26.235	(9, 24)	0.000 ***
	Chi-square	52.468	9	0.000 ***
Egypt	Test Statistic	Value	df	Prob.
	F-statistic	63.072	(9, 12)	0.000 ***
	Chi-square	126.145	9	0.000 ***
Jordan	Test Statistic	Value	df	Prob.
	F-statistic	1647.966	(9, 81)	0.000 ***
	Chi-square	3295.932	9	0.000 ***
KSA	Test Statistic	Value	df	Prob.
	F-statistic	79.332	(9, 13)	0.000 ***
	Chi-square	158.665	9	0.000 ***
UAE	Test Statistic	Value	df	Prob.
	F-statistic	89.342	(9, 14)	0.000 ***
	Chi-square	178.685	9	0.000 ***

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

Table 5. Bounds test results.

Countries	Morocco		Egypt		Jordan		KSA		UAE	
Optimal lags	(2,0,0,1,0,0,2,1,1)		(1,1,0,1,0,2,2,2,1)		(1,3,0,2,2,0,3,1,0)		(1,0,0,2,0,0,0,1,0)		(0,1,0,1,0,2,1,0,0)	
F-statistic	5.93		6.89		9.78		6.12		8.82	
	Critical value bounds									
Significance level	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
10%	3.12	4.39	3.40	3.48	4.11	4.20	3.22	4.51	3.22	4.64
5%	4.32	5.33	3.46	4.92	4.33	5.13	4.93	5.76	4.81	5.64
1%	5.43	5.83	4.23	5.97	5.97	6.79	6.34	7.85	5.72	6.96

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

Table 6. Diagnostic test.

Country	Dependent Variable	LM Test (p-Value)	ARCH Test (p-Value)	Reset Test (p-Value)	JB Test (p-Value)
Morocco	$F_{FS}(ARED, CRED, GSRED, CC, POP, W, FI, FP)$	0.137	0.244	0.137	0.814
Egypt	$F_{FS}(ARED, CRED, GSRED, CC, POP, W, FI, FP)$	0.253	0.637	0.770	0.326
Jordan	$F_{FS}(ARED, CRED, GSRED, CC, POP, W, FI, FP)$	0.254	0.643	0.643	0.673
KSA	$F_{FS}(ARED, CRED, GSRED, CC, POP, W, FI, FP)$	0.324	0.323	0.213	0.121
UAE	$F_{FS}(ARED, CRED, GSRED, CC, POP, W, FI, FP)$	0.913	0.945	0.139	0.954

Note: H_0 is accepted if the p-value is less than the significance level (0.05).

Based on the Table 6 results, it appears that H_0 should be rejected, and H_1 will be accepted in both countries; meaning that there is evidence of homoscedasticity in the data (LM and ARCH tests results), there is evidence of functional form misspecification in the data (Reset test results) and the data is normally distributed (JB test results).

The CUSUM and CUSUMSQ are chronological monitoring measures applied to discover bounds volatility in geometric models, chiefly regression models. They are founded on the cumulative sum of residuals and the cumulative sum of squared residuals, correspondingly. If the cumulative sum of the residuals (indicated by the blue line in our analysis) exceeds the threshold (indicated by the two red lines in our analysis), then this is evidence of instability of the econometric model. The different CUSUM and CUSUMSQ results of the five countries are recapitulated in Figure 1 in the form of graphics.

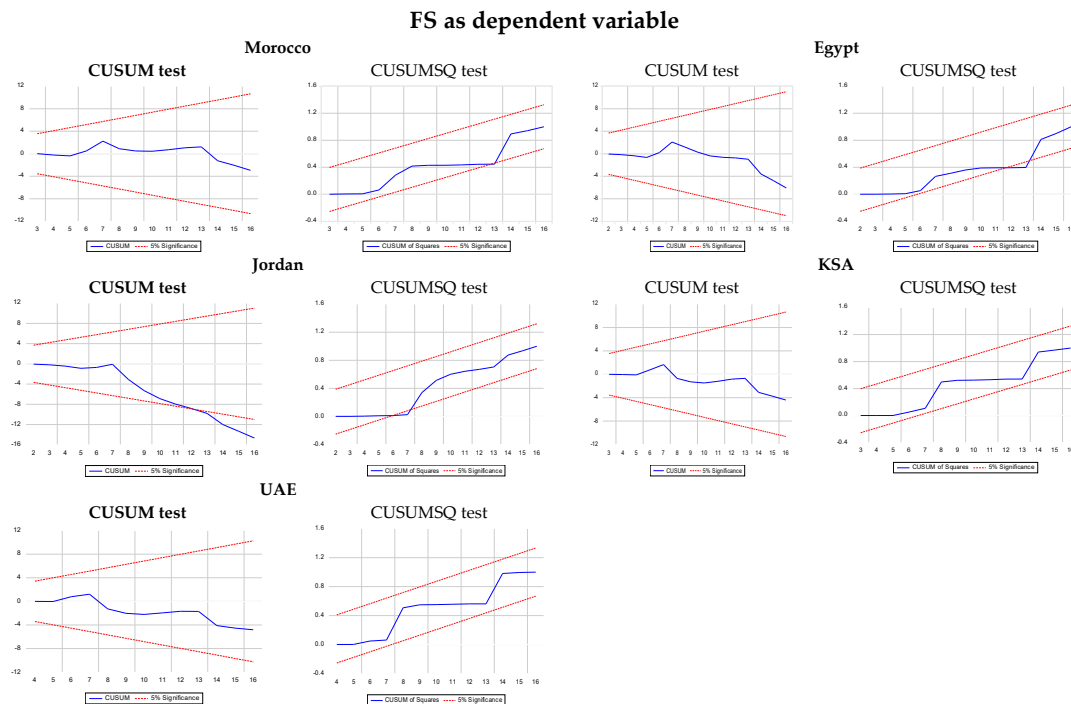


Figure 1. CUSUM and CUSUMSQ tests.

3.5. Short-Run ARDL Estimations

The short-run estimations of the ARDL approach give mixed results indicated in Table 7 for the five countries.

Table 7. Short-run ARDL estimation coefficients.

Independent Variable (FS)	MoroccoOp.lag (2,0,0,1,0,0,2,1,1)	EgyptOp.lag (1,1,0,1,0,2,2,2,1)	JordanOp.lag (1,3,0,2,2,0,3,1,0)	KSAOp.lag (1,0,0,2,0,0,0,1,0)	UAEOp.lag (0,1,0,1,0,2,1,0,0)
LnFS(t)	0.023(0.015) **	−0.410(0.005) ***	−0.036(0.174)	0.944(0.089) *	1.713(0.784)
LnFS(t−1)	−0.011(0.267)	−0.125(0.000) ***	0.191(0.658)	2.317(0.113)	-----
LnFS(t−2)	−0.387(0.156)	-----	-----	-----	-----
LnARED(t)	0.008(0.818)	−0.021(0.053) *	−0.027(0.090) *	0.019(0.083) *	0.421(0.087) *
LnARED(t−1)	-----	0.251(0.846)	0.223(0.731)	-----	0.692(0.004) ***
LnARED(t−2)	-----	-----	0.067(0.070) *	-----	-----
LnARED(t−3)	-----	-----	0.802(0.438)	-----	-----
LnCRED(t)	−2.092(0.837)	−1.927(0.153)	−6.094(0.092) *	−0.007(0.635)	−0.002(0.643)
LnGSRED(t)	−0.729(0.003) ***	−0.014(0.0781) *	−0.836(0.032) **	−0.911(0.032) **	1.836(0.007) ***
LnGSRED(t−1)	−0.527(0.036) **	−0.736(0.032) **	−1.005(0.538)	−0.069(0.001) ***	0.568(0.061) *
LnGSRED(t−2)	-----	-----	−0.128(0.325)	0.017(0.098) *	-----
LnCC(t)	−6.038(0.083) *	−0.022(0.946)	−2.065(0.085) *	−0.033(0.963)	0.452(0.815)
LnCC(t−1)	-----	-----	−2.093(0.091) *	-----	-----
LnCC(t−2)	-----	-----	−1.635(0.742)	-----	-----
LnPOP(t)	0.725(0.034) **	−0.231(0.110)	0.279(0.066) *	0.510(0.537)	0.634(0.097) *
LnPOP(t−1)	-----	−0.542(0.836)	-----	-----	0.120(0.030) *
LnPOP(t−2)	-----	−0.772(0.015) **	-----	-----	0.423(0.431)
LnW(t)	−0.579(0.003) ***	−1.007(0.049) **	−0.927(0.916)	0.442(0.000) ***	0.110(0.551)
LnW(t−1)	−0.522(0.000) ***	3.102(0.122)	−0.247(0.040) **	-----	0.004(0.108)
LnW(t−2)	−0.881(0.937)	2.076(0.004) ***	−0.558(0.835)	-----	-----
LnW(t−3)	-----	-----	−1.023(0.276)	-----	-----
LnFI(t)	0.037(0.254)	4.028(0.461)	0.034(0.003) ***	1.006(0.006) ***	0.442(0.033) **
LnFI(t−1)	0.160(0.836)	3.037(0.972)	0.165(0.261)	0.562(0.035) **	-----
LnFI(t−2)	-----	1.739(0.246)	-----	-----	-----
LnFP(t)	1.638(0.037) **	6.980(0.892)	−0.026(0.421)	−0.340(0.936)	−1.048(0.261)
LnFP(t−1)	0.732(0.253)	2.039(0.032) **	-----	-----	-----
C	0.435(0.000) ***	189.735(0.036) **	4014.065(0.002) ***	22.257(0.000) ***	10.836(0.038) **

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

Starting with the FS variable, it appears that in the short-run, the FS variable at period (t), at period (t−1), at periods (t and t−1) and at period (t) affect positively the actual values of FS respectively in Morocco, Jordan, KSA and UAE. These positive effects can be explained by the good food security index which gives a feeling of security among individuals and governments that there is a surplus in food stocks which will stabilize or even reduce prices and subsequently keep amounts that will be spent on future purchases of food products. However, the actual FS of Morocco, Egypt and Jordan were negatively affected by respectively the FS at periods (t−1 and t−2), the FS at periods (t and t−1) and the FS at period (t). Due to the creation of vulnerabilities that last into the present, poor food security in the previous year might have a detrimental effect on real food security. In other words, households that have experienced food insecurity in the previous year could have to sell valuable possessions or spend all of their money in order to cover their basic food needs. Households may have had to take on debt in order to satisfy their food demands in the previous year, which makes it more difficult for them to purchase food now and in the future. Also, the malnutrition and health issues might result from food insecurity in the previous year, which can lower people's productivity and make it more difficult for them to get food in the present.

The results show that an increase of one unit of the ARED variable results in an increase in the FS variable of 0.008 units in Morocco, 0.230 units in Egypt, 1.065 units in Jordan, 0.019 units in KSA and 1.113 units in UAE.

The CRED variable leads to a strong decrease of the FS in Morocco, Egypt and Jordan respectively by −2.092, −1.927 and −6.094 units, nevertheless it slightly decreases the FS in KSA and UAE respectively by −0.007 and −0.002 units.

The GSRED and CC variables decrease the FS of all countries except UAE. However, the POP variable increases the FS of all countries except Egypt.

It appears that the W variable represents a real problem in the short-run for FS in Morocco and Jordan. In effect, the per capita share of water negatively affects Moroccan and Jordanian food security in equal proportion respectively at 1.962 units and 2.755 units in the short-run.

In the short-term, the results show that all of our five countries, especially Egypt, depend on the outside world to secure its food security, and this is shown by the positive impact of the food importation on FS.

Finally, we have found that local food production or agricultural production is insufficient to achieve food security in Jordan, Saudi Arabia and in UAE. However, FP has an important role to attain food security in Morocco and in Egypt.

3.6. Long-Run ARDL Estimations

The long-run ARDL estimations indicated in Table 8 give mixed results for the five countries studied. We will try to study the effect of each variable on food security, country by country. Starting with the ARED variable, it appears that an increase of this variable by one unit in the long-term positively and significantly influences FS in both countries ([45,46]). Effectively, the amplifying of ARED can advance food security in numerous means such as the increase of freshwater availability derived from renewable energy desalination which can offer a new basis of freshwater for irrigation to enlarge afterwards agricultural production and raise food availability ([47]). Also, it is a solution to minimize reliance on fossil fuels (major source of greenhouse gas emissions) and alleviate climate change, which can have a negative impact on agriculture.

The CRED has two different impacts on FS in our sample countries. First, it is considered as a factor reducing food security in Morocco, Egypt and Jordan ([48]). Economically, the high cost related to desalination via new technology can be transformed into higher water prices for cultivators, increasing as a consequence their production costs and decreasing their agricultural productivity. However, CRED has positive impacts on FS in the case of KSA and UAE ([49]). This phenomenon can be justified by the considerable financial and budgetary wealth of these two countries (rich countries) which can allow it to

finance renewable energy desalination projects and to bear its enormous costs throughout the entire planting cycle. In other words, the more these countries invest supplementary in desalination technology, the better the availability of fresh water and subsequently the possibility of developing the agricultural sector and increasingly achieving food security. We must not forget that the Arab Emirates is among the leading and emerging countries in terms of investment in modern technologies in renewable energies.

Table 8. Long-run ARDL coefficients.

Countries	Dep. Variable (FS)	Morocco	Egypt	Jordan	KSA	UAE
Independent variables	LnARED	0.542(0.001) ***	0.104(0.661)	2.863(0.088) *	1.837(0.013) **	5.001(0.021)**
	LnCRED	−2.441(0.738)	−0.632(0.000) ***	−1.442(0.198)	5.802(0.005) ***	1.026(0.075) *
	LnGSRED	0.106(0.051)*	−1.027(0.014)	3.802(0.397)	2.933(0.026) **	2.371(0.498)
	LnCC	−11.743(0.000) ***	−0.840(0.741)	−0.914(0.093) *	0.020(0.685)	0.088(0.029) **
	LnPOP	−1.056(0.587)	−2.884(0.009) ***	−0.078(0.656)	−0.013(0.423)	−0.007(0.064) *
	LnW	−0.408(0.061) *	7.165(0.098) *	−9.714(0.000) ***	−0.006(0.838)	−0.743(0.813)
	LnFI	0.810(0.421)	10.431(0.000) ***	0.886(0.920) *	10.094(0.008) ***	11.825(0.507)
	LnFP	0.785(0.034) **	0.602(0.755)	0.305(0.782)	0.067(0.063) *	−0.012(0.930)
	Constant	135.932(0.000) ***	79.721(0.019) **	−2021.428(0.025) *	31.067(0.000) ***	−176.063(0.012) **
CUSUM		Stable	Stable	Unstable	Stable	Stable
CUSUMSQ		Unstable	Unstable	Unstable	Stable	Stable

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

In the long-run, the GSRED positively affects FS in both countries (Report of British International Investment, 2022; IRENA, 2015 and [50]), with the exception of Egypt (the International Water Management Institute (IWMI), 2014; the World Food Programme (WFP), 2015 and FAO, 2018). The positive effect can be explained by the increases of fresh water access in the long-term which gives an opportunity to ameliorate agricultural production. However, the negative effect of GSRED on FS can be explained by the massive economic costs which can negatively affect the food supply chain in terms of quantity and quality, thus negatively affecting food security. In effect, Egypt is considered the most prominent example as it is among the most important suppliers of wheat in the world.

The climate change has negative impacts on Moroccan, Egyptian and Jordanian food security and especially in Morocco (a decrease of FS by 11.743 units) in the long-run ([51,52]). The rise of temperature as an indicator of climate change leads to the drying up of water sources such as rivers and springs, a decrease in water levels in dams, and prolonged periods of drought. All of these factors negatively affect agricultural production and thus food security. On the contrary, climate change may represent an opportunity for some countries, ([53–55]) such as KSA and UAE, to achieve their food security, albeit relatively (an unexpected result), as the Arabian Gulf region has witnessed a significant increase in the rate of rainfall in recent years, such as the western center of Saudi Arabia, as well as an opportunity to invest in water desalination projects.

The results find that population enlargement is a reason that is contributing to the raise in food insecurity [56]. Report of FAO (2022): “The State of Food Security and Nutrition in the World”). The negative impact of POP on FS is virtually explained by the increase in demand for food products, in contrast to the limited supply, which contributes to rising prices, which poses a risk to low-income individuals to meet their basic food needs. Rapid demographic growth also contributes to the shrinking of agricultural land in favor of urban areas.

It appears that most of the countries (Morocco, Jordan, KSA and UAE) suffer from a lack of sufficient water, which negatively touches their food security (United Nations Environment Program (UNEP), 2017; [57]) and it has come into sight clearly in the case of Jordan (−9.714 units in long-run). Actually, agriculture is the principal consumer of water, so every lack of water means less food production which means insecurity of food. On the contrary, water is an essential factor to realize food security in the case of Egypt which benefits from the water of the “Nile” which is among the longest rivers in the world (International Water Management Institute (IWMI), 2012; FAO, 2023, and [58]).

For the FI variable, the results show that all of the five countries depend on importation in order to cover their food needs. In effect, the coefficient of FI is positive which means that an increase of FI leads to an increase in the FS variable ([59]). This result was expected since the majority of these countries are characterized by a dry climate, where the desert covers a very significant part of their territory. So, they need to rely on the rest of world to achieve their food security.

Finally, the results indicate that FP has positive effect on FS ([60]) in most of these countries with the exception of UAE. In fact, investing in local food production improves the accessibility of a diversity of nutrient-rich foods. This enhanced admission to varied food foundations supports healthier nutrition. However, the negative impact of FP on FS ([61]) in the case of UAE can be explained by the requirement of a lot of resources, including essentially ground and water. So, these inputs are becoming more and more limited, which is creating difficulty on food production structures in the future. However, agricultural production is a main cause of environmental degradation in the form of water pollution and soil erosion. These elements can all decrease the efficiency of soil and water properties, making it additionally hard to produce food.

3.7. Granger Causality Relationships and ECT Test

The results of the Granger causality test indicated in Table 9 indicate the existence of unidirectional and bidirectional causality relationships between variables (mixed causal relationships).

Nevertheless, the results of the ECT test confirm the presence of long-run relationships between variables. Every variable has at the same time a negative and significative coefficient of ECT, meaning that this variable has a bidirectional relationship in the long-run and it is considered as an adjustment component previously, causing the econometric model to deviate from the equilibrium.

The results of ECT show that in the long-run, there are three long-run bidirectional causality relationships between the ARED, CC and W variables in Morocco and Jordan, and these variables cause the rest of the variables. In Egypt, there are long-run bidirectional causality relationships between POP, W and FI, and there are unidirectional causality relationships running from these three variables to the rest of the variables. Also, there are three bidirectional causality relationships in the long-run in KSA among ARED, GSRED and FI, and these variables cause the rest of the variables. However, in UAE there are two bidirectional causality relationships among ARED and FI. In effect, ARED and FI cause the rest of the variables in the long-term.

We have tried to explain and to simplify the results in the long- and short-run of the Granger causality test and ECT test (indicated in Table 9) in the form of graphics recapitulated in Figure 2 as below:

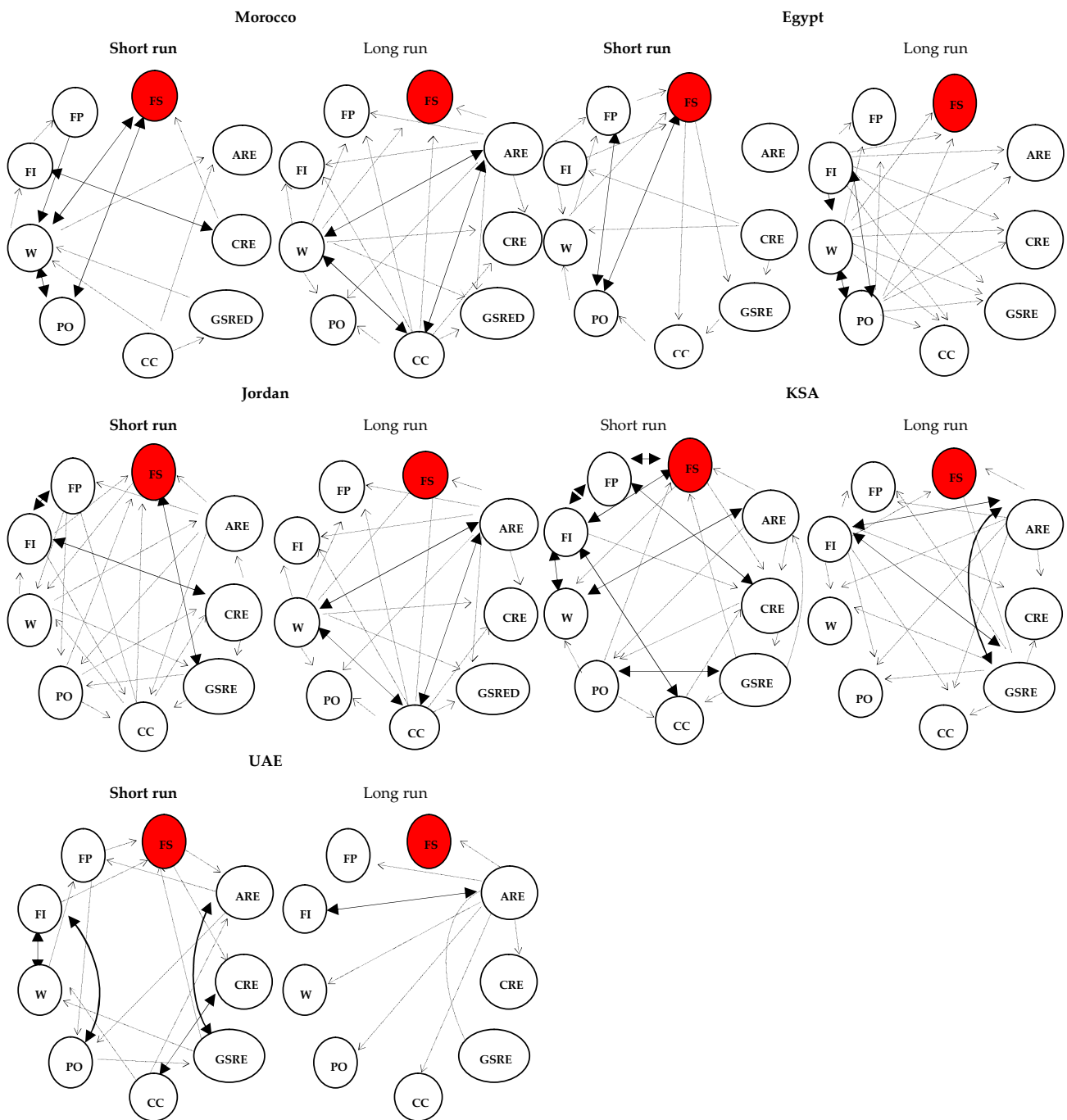


Figure 2. Synthetic circuits of unidirectional and bidirectional causality relationships for the different dependent variables. Note: ↔ indicates a bidirectional causality relationship. → indicates a unidirectional causality relationship.

Table 9. Granger causality test results.

Causality Directions											
	Dep.Var	Short Term									Long Term
		DLnFS	DLnARED	DLnCREd	DLnGSRED	DLnCC	DLnPOP	DLnW	DLnFI	DLnFD	ECT
Morocco	LnFS	-----	1.342 (0.534)	0.844 (0.553)	0.725 (0.533)	0.782 (0.401)	2.700 * (0.022)	0.602 ** (0.027)	0.783 (0.903)	0.722 (0.991)	1.252 (0.610)
	LnARED	0.663 (0.013)	-----	0.105 (0.432)	1.384 (0.754)	0.993 (0.546)	0.966 (0.432)	0.545 (0.938)	0.965 (0.836)	2.831 (0.793)	−3.036 * (0.093)
	LnCREd	0.098 * (0.085)	0.344 (0.434)	-----	0.053 (0.983)	0.843 (0.935)	0.571 (0.876)	0.372 (0.635)	0.637 *** (0.002)	4.729 (0.848)	0.804 (0.846)
	LnGSRED	1.202 (0.487)	0.613 (0.697)	0.953 (0.490)	-----	1.002 (0.987)	0.600 (0.409)	1.255 ** (0.011)	0.943 (0.638)	0.532 (0.526)	0.271 (0.063)
	LnCC	0.842 (0.039)	0.966 * (0.098)	0.782 (0.765)	0.562 * (0.053)	-----	0.980 (0.321)	1.930 * (0.093)	0.992 (0.445)	0.860 (0.332)	−0.801 * (0.070)
	LnPOP	0.454 *** (0.002)	3.783 (0.112)	0.223 (0.698)	1.632 (0.719)	0.546 (0.581)	-----	0.985 *** (0.002)	1.530 (0.831)	0.443 (0.721)	3.391 (0.706)
	LnW	0.679 * (0.053)	1.902 *** (0.002)	0.933 (0.125)	2.021 (0.984)	0.878 (0.442)	1.223 *** (0.003)	-----	4.032 *** (0.000)	0.930 ** (0.050)	−0.163 *** (0.002)
	LnFI	0.221 (0.436)	0.819 (0.656)	0.820 ** (0.044)	0.882 (0.612)	0.325 (0.802)	1.790 (0.432)	0.764 (0.637)	-----	0.704 *** (0.001)	1.035 (0.904)
	LnFP	3.873 (0.618)	0.771 (0.909)	0.745 (0.650)	0.781 (0.661)	0.937 (0.361)	0.802 (0.221)	0.893 * (0.088)	1.002 (0.762)	-----	0.738 (0.034)
Egypt	LnFS	-----	0.833 (0.837)	0.449 (0.112)	0.089 *** (0.001)	0.692 * (0.098)	0.569 * (0.081)	0.224 (0.602)	0.717 (0.537)	0.911 (0.814)	2.974 (0.048)
	LnARED	0.836 (0.882)	-----	0.837 (0.601)	2.736 (0.672)	0.554 (0.445)	1.993 (0.338)	1.992 (0.880)	1.530 (0.220)	1.989 (0.440)	0.738 (0.622)
	LnCREd	0.738 (0.526)	0.842 (0.902)	-----	0.992 ** (0.023)	0.429 (0.728)	1.537 (0.914)	0.903 * (0.064)	0.657 ** (0.034)	3.042 (0.562)	0.936 (0.944)
	LnGSRED	0.002 (0.761)	2.212 (0.563)	0.562 (0.827)	-----	0.981 ** (0.050)	0.592 (0.482)	1.783 (0.919)	0.099 (0.985)	0.945 (0.930)	4.738 (0.693)
	LnCC	0.425 (0.180)	3.936 (0.662)	0.042 (0.943)	0.637 (0.833)	-----	2.773 * (0.098)	0.891 (0.832)	0.023 (0.643)	1.562 (0.621)	0.940 (0.738)
	LnPOP	0.623 *** (0.002)	0.021 (0.827)	0.932 (0.113)	0.527 (0.892)	0.026 (0.874)	-----	0.093 *** (0.007)	2.902 * (0.092)	0.401 ** (0.022)	−0.994 *** (0.000)
	LnW	2.823 *** (0.000)	0.890 (0.891)	0.031 (0.637)	0.002 (0.761)	0.738 (0.949)	0.678 (0.391)	-----	0.664 (0.538)	0.502 *** (0.006)	−2.936 ** (0.036)
	LnFI	0.032 *** (0.000)	1.883 (0.776)	2.880 (0.872)	0.092 (0.931)	0.911 (0.784)	2.213 (0.320)	0.937 * (0.065)	-----	0.753 *** (0.000)	−4.627 ** (0.048)
	LnFP	2.701 * (0.087)	0.661 (0.637)	0.216 (0.342)	0.637 (0.836)	4.703 (0.663)	0.873 * (0.056)	0.676 (0.837)	0.031 (0.597)	-----	0.706 (0.842)
Jordan	LnFS	-----	1.562 (0.720)	0.581 (0.314)	1.672 *** (0.002)	0.672 (0.865)	0.627 (0.022)	0.211 ** (0.042)	0.231 (0.846)	0.776 (0.543)	2.037 (0.001)
	LnARED	0.367 * (0.063)	-----	0.937 (0.539)	0.725 (0.882)	0.015 *** (0.001)	1.927 *** (0.000)	0.748 (0.313)	0.674 (0.533)	2.490 *** (0.002)	−0.738 ** (0.036)
	LnCREd	0.773 (0.839)	0.820 ** (0.022)	-----	0.921 ** (0.035)	0.537 (0.973)	0.213 (0.637)	0.037 (0.432)	0.846 ** (0.028)	1.660 (0.537)	1.973 (0.937)
	LnGSRED	0.036 ** (0.039)	2.560 (0.829)	2.315 (0.739)	-----	0.416 ** (0.012)	0.883 ** (0.026)	3.057 (0.993)	0.873 (0.425)	0.425 (0.836)	0.836 (0.117)
	LnCC	0.833 *** (0.001)	0.772 (0.640)	1.731 * (0.062)	0.936 (0.421)	-----	2.783 (0.863)	4.927 ** (0.044)	0.947 (0.214)	1.953 * (0.098)	−3.028 * (0.053)
	LnPOP	0.651 ** (0.026)	0.121 (0.513)	0.772 ** (0.037)	2.093 (0.314)	0.231 ** (0.036)	-----	0.782 (0.862)	4.947 (0.936)	0.561 (0.140)	0.937 (0.738)
	LnW	2.736 (0.909)	3.893 *** (0.006)	0.561 (0.836)	0.376 *** (0.010)	0.425 (0.686)	0.662 (0.853)	-----	0.047 *** (0.004)	0.536 (0.667)	−0.926 *** (0.006)
	LnFI	1.801 ** (0.044)	1.892 (0.637)	4.638 *** (0.000)	0.678 (0.211)	0.028 ** (0.044)	2.627 (0.517)	0.177 (0.164)	-----	0.114 *** (0.003)	−1.038 (0.836)
	LnFP	3.632 (0.802)	0.920 (0.221)	0.730 (0.933)	0.725 (0.839)	0.726 (0.927)	0.752 *** (0.004)	0.047 *** (0.000)	0.536 ** (0.017)	-----	0.937 (0.028)

Table 9. Cont.

		Causality Directions									
		Short Term					Long Term				
KSA	LnFS	-----	1.710 (0.930)	1.983 ** (0.037)	0.652 (0.426)	0.022 (0.536)	0.763 (0.253)	0.638 *** (0.001)	0.778 *** (0.003)	0.884 ** (0.013)	5.530 (0.937)
	LnARED	0.838 * (0.084)	-----	0.562 ** (0.026)	0.859 (0.435)	0.425 (0.087)	1.902 * (0.095)	2.537 ** (0.039)	0.536 (0.937)	2.462 (0.537)	−1.820 * (0.083)
	LnCRED	0.672 (0.740)	0.783 (0.139)	-----	0.946 ** (0.018)	0.974 (0.241)	0.652 *** (0.000)	0.547 (0.722)	0.903 (0.891)	2.671 *** (0.004)	1.384 (0.837)
	LnGSRED	0.526 *** (0.002)	2.730 ** (0.022)	2.002 (0.425)	-----	0.453 ** (0.038)	0.942 ** (0.028)	5.839 (0.563)	0.548 (0.927)	0.538 (0.937)	−0.802 ** (0.042)
	LnCC	3.937 (0.647)	0.082 * (0.073)	0.037 *** (0.000)	0.869 (0.537)	-----	2.003 (0.735)	0.029 (0.113)	0.047 * (0.055)	1.910 (0.428)	−1.993 (0.922)
	LnPOP	0.048 *** (0.004)	0.427 (0.923)	0.426 (0.193)	2.561 *** (0.007)	1.093 *** (0.008)	-----	0.940 ** (0.037)	4.920 (0.318)	0.937 (0.113)	0.936 (0.746)
	LnW	0.622 (0.452)	0.435 ** (0.045)	0.027 (0.425)	4.023 (0.552)	0.563 (0.315)	0.068 (0.836)	-----	0.930 ** (0.019)	0.037 (0.698)	0.825 (0.643)
	LnFI	0.903 *** (0.003)	2.048 (0.882)	2.901 *** (0.004)	0.947 (0.894)	1.903 * (0.073)	2.314 (0.836)	0.849 ** (0.038)	-----	0.932 *** (0.005)	−3.028 * (0.061)
	LnFP	0.663 ** (0.030)	0.937 (0.783)	0.122 * (0.072)	0.773 (0.683)	0.863 (0.973)	0.038 (0.773)	0.783 (0.993)	0.893 *** (0.005)	-----	0.202 (0.936)
UAE	LnFS	-----	1.401 ** (0.036)	2.938 *** (0.002)	0.927 (0.875)	0.937 (0.562)	0.929 (0.704)	0.974 (0.252)	0.921 (0.123)	0.942 (0.574)	3.682 (0.937)
	LnARED	0.771 (0.937)	-----	0.592 (0.411)	0.049 *** (0.000)	0.673 (0.638)	1.317 * (0.089)	1.660 (0.137)	0.312 (0.957)	4.039 ** (0.037)	−6.003 ** (0.050)
	LnCRED	0.960 (0.748)	0.892 (0.993)	-----	0.425 (0.774)	0.781 *** (0.006)	0.537 (0.367)	0.931 (0.847)	0.025 (0.993)	1.903 (0.912)	0.321 (0.536)
	LnGSRED	0.960 *** (0.009)	2.833 ** (0.037)	2.883 (0.972)	-----	0.536 (0.334)	0.978 (0.112)	1.833 * (0.048)	0.425 (0.915)	0.562 (0.730)	0.719 (0.602)
	LnCC	0.047 (0.637)	0.993 *** (0.000)	0.981 ** (0.036)	0.638 (0.438)	-----	-----	0.435 (0.856)	0.947 ** (0.049)	3.937 ** (0.038)	1.522 (0.793)
	LnPOP	0.619 (0.975)	0.673 (0.163)	0.870 (0.142)	0.913 * (0.094)	0.683 (0.166)	-----	0.121 (0.229)	2.121 *** (0.000)	0.772 (0.910)	0.424 (0.082)
	LnW	0.0276 (0.588)	0.947 (0.137)	0.946 (0.267)	0.900 (0.987)	0.093 (0.166)	0.417 (0.967)	-----	0.819 *** (0.002)	0.647 * (0.065)	2.964 (0.772)
	LnFI	0.112 * (0.058)	1.666 (0.936)	2.425 (0.885)	0.038 (0.217)	2.003 (0.565)	2.773 ** (0.035)	0.091 ** (0.026)	-----	0.937 (0.982)	−1.026 * (0.081)
	LnFP	0.7238 ** (0.028)	0.094 (0.101)	0.127 (0.607)	0.973 (0.139)	0.931 (0.451)	0.946 ** (0.030)	0.702 (0.921)	0.937 (0.111)	-----	0.635 (0.591)

*, ** and *** indicate the significant respectively at 10%, 5% and 1%.

4. Conclusions

The complex network of variables influencing food security in five Arab countries, Morocco, Egypt, Jordan, Saudi Arabia, and the United Arab Emirates, has been examined in this research. Equipped with advanced econometric instruments, we discovered insights into the intricate relationship between desalination of renewable energy, climate change, water shortage, population increase, and domestic food production through the use of the ARDL method and VECM technique. Desalination with renewable energy offers some optimism even if the picture shows several obstacles. The initial phase denotes the various variables and provides sources and definitions for each. Secondly, the order of integration of each variable has been verified by the use of the ADF and PP tests. Next, we performed the Wald and Bounds tests, respectively, to confirm the correlations between the variables and the presence or absence of long-run cointegration. The CUSUM and CUSUMSQ tests were used in step four to verify the stability of the economic models. In the fifth phase, we used the ARDL model to estimate the short- and long-term associations between the variables. The econometric model's equilibrium is demonstrated in the last stage by capturing the causation direction between variables using the Granger causality and VECM approach.

Our research shows how much promise this technology has to improve food security, but its success depends on a number of significant obstacles being removed. Cost reduction through government assistance and technology breakthroughs becomes a top priority, especially in Morocco, Egypt, and Jordan. Strategies for adapting to climate change must be prioritized, taking into account both its unknown benefits and hazards to places like the United Arab Emirates and Saudi Arabia. It is imperative that water scarcity be addressed via creative and sustainable resource management, particularly for Jordan, the country with the worst water shortage. The causal links that have been found highlight the necessity of integrated policy approaches that take into account how various elements are interrelated. It is crucial to customize solutions to the unique vulnerabilities and dynamics of every country. Morocco may give priority to affordable renewable desalination in addition to other options in order to alleviate its water issues. Egypt's expanding population needs a multifaceted strategy that strikes a balance between domestic food production, imports, and reasonably priced desalination. Jordan has to make immediate investments in renewable desalination technology in addition to water conservation measures because of its limited water supplies. Despite its affluence, Saudi Arabia must acknowledge the problem of water shortage and should use its influence to support environmentally friendly desalination technology. Ultimately, by sharing its knowledge and encouraging regional cooperation, the UAE, a shining example of innovation, can firmly establish its leadership position.

The paper makes some really good observations that, by going deeper into two important areas, might boost the research. The first is desalination innovation. The research essentially touches on the promise of desalination using renewable energy, but a closer look at certain advancements would confirm the technology's potential for cost savings. Investigating developments such as next-generation membranes, which can generate water of greater quality while using less energy, can result in more effective and selective membranes. the cost-effectiveness and regional suitability of emerging desalination technologies, such as forward osmosis, electrodialysis, and solar desalination. Finally, the discussion of developments in using solar, wind, and other renewable energy sources to power desalination plants thereby guaranteeing sustainability and grid independence can be facilitated by integration with renewable energy sources. Regional collaboration is the subject of the second point. The potential for cooperative efforts among the five Arab countries is really highlighted by the interconnection of the elements that have been identified. It could investigate options like pooling information and best practices to create knowledge-sharing platforms and collaborative research projects to boost creativity and improve resource management. In order to address water scarcity, it is crucial to develop regional water management strategies through cooperative efforts on infrastructure projects such as shared desalination plants or water pipelines. Additionally, it is important to lobby

for changes in policy and standardized regulations to encourage investment in sustainable desalination technologies on a global scale.

There is no one magic solution, as this exploration of the nuances of food security in the Arab world makes clear. Rather, a diverse strategy is needed to ensure a sustainable and secure future. Crucial pillars include embracing renewable energy desalination while scrupulously resolving financial obstacles, adjusting to climate change, appropriately managing water resources, and promoting sustainable farming techniques. Policymakers can turn the barren landscapes of the Arab world into a thriving oasis of food security for future generations by recognizing the complex linkages between these elements and adjusting responses to the unique difficulties and possibilities of each country.

5. Policy Implementations

A comprehensive policy response is necessary in light of the complex riddle that is food security in five Arab nations, as revealed by this research. Desalination with renewable energy has potential, but its viability depends on lowering costs. Thus, it is imperative to fund research and development for economically viable desalination technology, especially in Morocco, Egypt, and Jordan. In addition, for this technology to be widely available and reasonably priced, government assistance for desalination infrastructure and renewable energy sources is crucial. Threats and possibilities are both brought about by climate change. Proactive adaptation measures are therefore essential, especially in susceptible areas like Morocco, Egypt, and Jordan. For improved water security, nations with more rainfall, such as the United Arab Emirates and Saudi Arabia, should investigate the potential benefits of combining desalination with climate change adaptation. Since the region's food security is being strained by rapid population expansion, family planning programs, investments in economic possibilities and education, and economic growth may all help control population growth and empower individuals. In addition, it is critical to support sustainable farming methods that maximize water use and boost yields, especially in Jordan where water is scarce. The necessity for coordinated policy approaches is highlighted by the found causal linkages. Coordination of desalination, water resource management, and climate change adaptation is essential in Morocco and Jordan. It is crucial to concentrate on population control, water conservation, and food source diversification in Egypt. Policies that strike a balance between local agricultural output, food imports, and desalination within a sustainable framework are necessary for the UAE and KSA. Policymakers can unleash the promise of renewable energy desalination, handle water scarcity, control population expansion, and promote sustainable agriculture practices by customizing solutions to the unique dynamics of each nation and creating regional collaboration. This will set the Arab world up for a resilient and safe food future.

6. Avenues for Future Research

Although the intricate interactions between food security, climate, population, water, and renewable energy desalination in five Arab nations have been clarified by this research, a number of important problems still need to be addressed. Subsequent investigations may explore these complexities in greater detail, opening the door for more sophisticated and successful policy measures. First, evaluating the long-term effects of desalination on society and the environment. Although the emphasis of our analysis was the economic impact, further research is required to understand the wider social and environmental ramifications of large-scale desalination plants. This should include details assessing possible effects on brine disposal, coastal ecosystems, and the fair allocation of water resources. Examining the possibilities of alternate water sources is the second step. Other creative approaches to water management, in addition to desalination, should be investigated further. This might entail looking at wastewater treatment systems that are suited to the unique requirements of each area, as well as rainfall collection and gray water reuse. Third, creating reliable models to forecast the effects of various climate change scenarios on food security and the efficacy of desalination techniques should be the main goal of future research. Our study

only offered a picture of the current situation. Proactive adaptation strategies and long-term resource allocation can benefit from this. Finally, examining the function of government and social factors: Food security is closely related to social justice, political stability, and cultural norms; it is not only a technological issue. Subsequent investigations ought to explore the ways in which social elements such as land ownership, gendered resource accessibility, and governance frameworks impact the effectiveness of food security measures, such as desalination initiatives. We can better grasp the potential and complicated difficulties related to food security in the Arab world by exploring these study topics. With a changing climate and an aging population, this understanding will be crucial for developing policies that will protect the region's sustainability.

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