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EDITED BY
Ruilian Zhang,
The University of Queensland, Australia

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S. Ale Raza Shah,
Xi'an Jiaotong University, China
Hasnain Abbas Naqvi,
University of Hafr Al Batin, Saudi Arabia

*CORRESPONDENCE
Jaffar Abbas
dr.j.abbas@outlook.com

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Land-use and food security in energy transition: Role of food supply

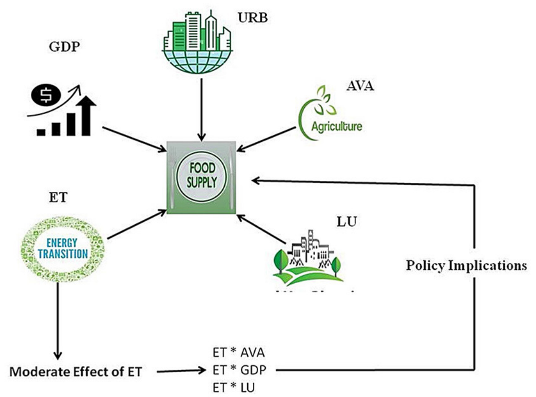
Daoyong Zhuang[1], Jaffar Abbas[2]*, Khalid Al-Sulaiti[3], Mochammad Fahlevi[4], Mohammed Aljuaid[5] and Sebastian Saniuk[6]

[1]School of Marxism, Hohai University, Nanjing, China, [2]School of Media and Communication & Antai College of Economics and Management, Shanghai Jiao Tong University, Shanghai, China, [3]Al Rayyan International University College, in Partnership With the University of Derby UK, Doha, Qatar, [4]Management Department, BINUS Online Learning, Bina Nusantara University, Jakarta, Indonesia, [5]Department of Health Administration, College of Business Administration, King Saud University, Riyadh, Saudi Arabia, [6]Department of Engineering Management and Logistic Systems, Faculty of Economics and Management, University of Zielona Góra, Zielona Góra, Poland

Food security in a just energy transition is a growing debate about designing sustainable food secure networks worldwide. Energy transition, land-use change, and food security are crucial factors for food security and provision. The increased demand for food products and customer preferences regarding food safety provide various issues for the current agriculture food supply chain (AFSC). Along with rising sustainability concerns, strict government regulation, food security, and traceability concerns compel managers, business houses, and practitioners working in AFSC to adopt new tools, techniques, and methodologies to model current food supply chain problems. Thus, in turn, design the food logistics network for food security. Hence, this study investigates the core determinants of food security and supply in Egypt, Morocco, Tunisia, and Lebanon over the period of 2010–2019. In order to estimate the objectives of the study, we employ the fully modified ordinary least square (FMOLS) and dynamic ordinary least squares estimators (DOLS) to draw the study findings. However, the estimated results show a negative association of land use with food security and supply. Likewise, energy transition, gross domestic product, and agricultural value added (AVA) contribute to the food security supply. In contrast, urbanization's negative but insignificant contribution to the food supply in selected economies exists. Besides, another core objective of the study is to investigate the moderate role of the energy transition on the gross domestic product, agriculture sector, and land use and find the significant contribution to the food supply. However, the current study also tries forecasting for the next 10 years and employs the impulse response function (IRF) and variance decomposition analysis (VDA). Congruently, this study uses the pairwise panel causality test and finds exciting outcomes. The COVID-19 crisis has posed challenges such as energy consumption and food security issues. On behalf of the results, the current study proposes imperative policies to investigate the desired level of food supply. The findings provide valuable insights for experts, policymakers, and officials to take practical measures for energy use and food security challenges.

KEYWORDS

land-use change, food security, resource development, energy transition, food supply, agricultural value added products, COVID-19 crisis management



GRAPHICAL ABSTRACT

Highlights

- This present study tries to summarize the heterogeneous factors of food security and supply.
- The research model focuses on examining the main and moderate role of energy transition.
- Land use and urbanization are responsible in declining the food supply in selected regions.
- Energy transition, agricultural value added and gross domestic product contribute to food supply.
- The Moderate role of energy transition significantly contributes to food supply.

Introduction

The flexible and diverse concept of food security has various definitions. Food security is a condition in which everyone, at all times, has physical, social, and financial access to enough, safely, and nutritious food to suit their dietary needs and food preferences for an active and healthy life (FAO, 2002). Food security's associated "pillars" were available, usable, accessible, and stable (Grainger, 2010; Aliaga and Chaves-Dos-Santos, 2014). In terms of (local) food production and distribution, with a focus on the supply side, food accessibility refers to how easily accessible nutritional sources are. The ability of a household or an individual to obtain easily available food is referred to as food access. We place a particular emphasis on food choice as part of the issue of food availability because the ability to get food does not always translate into actual acquisition (Pinstrup-Andersen, 2009). For this evaluation, using food involves preparing, processing, and cooking it. Stability, the last temporal element of food security, includes the capacity to bounce back from shocks and the potential for experiencing them. It is crucial to understand that, in this context, a person's food security is a necessary but not sufficient condition for good nutrition. The UNICEF malnutrition framework states that the relationship between food and nutrient consumption and health determines nutrition status (Black et al., 2008). However, because studies on how culture affects health have already been conducted (Briones Alonso et al., 2018; Gonzalez-Nahm et al., 2022), we limit the scope of our review to how culture influences the variables that affect food intake (Drisdelle et al., 2020). Our research concentrates on food security's direct drivers through deeper factors like socio-economic factors.

The experts of anthropogenetic climate change prioritize food security systems at large in time and space (Connolly-Boutin and Smit, 2015). Climate change, growing unpredictability in rainfall, prolonged droughts, and unexpected heavy floods have posed severe threats to the energy transition, sustainable livelihood, and food security for global population segments (Sa et al., 2017). These unavoidable fluctuations require a systemic transition in human socioeconomic systems to develop sustainable paths (Wheeler and von Braun, 2013). Thus, all countries must develop systems to become low-carbon emissions or decarbonized economies (Ziervogel and Ericksen, 2010; Ajayi et al., 2022). It will help mitigate the effects of climate change to protect the environment (Hassan et al., 2022). The practical ongoing strategies make a helpful and successful transition in reducing the usage and production of fossil fuels to zero (Ajjur and Al-Ghamdi, 2022; Yoon et al., 2022).

Green energy for food security is essential, and energy transition influences food systems because it affects traditional energy use patterns worldwide. It significantly affects global food production in a society that depends on fossil fuels (Rosillo-Calle, 2016; Strapasson et al., 2017). Nevertheless, this energy transition might pose indirect social consequences. The social impacts include effects that are more significant across the rational distribution of adverse outcomes on sustainable land use, human livelihood, positive opportunities, and food security. The systematic energy transition can help decrease food security inequalities' that might influence prevailing food security systems by avoiding the resource-intensive model (Kline et al., 2016). In addition, "just energy transition" safeguards workers' livelihoods and the future of the communities in the energy transitions and secures a low carbon emissions economy. It involves social discourse between working employees, unions, government, employers' consultation with civil society and the communities (Evans and Phelan, 2016; Galgóczi, 2020). Energy transition also emphasizes energy systems decentralization, place importance, and priority needs to marginalized societies and communities (Neill et al., 2018; Heffron et al., 2021). Besides, a just energy transition pursues to promote environmental integrity, economic sustainability, wellbeing, and social resilience underpinned with solid and smooth processes of democratic governance. Thus, it accelerates the mapping of energy transition that safeguards reasonable outcomes that are justifiably aligned with economic and social development among communities, towns, societies, and affected regions.

Socio-economic factors may affect how food security is measured, in addition to having an impact on the numerous pillars of food security. Besides the socio-economic factors, cultural differences also significantly impact the food supply (Renzaho and Mellor, 2010). Because intra-household food distribution practices are heavily influenced by culture and context, for example, the accuracy of food consumption or expenditure measures collected at the household level that are frequently translated to the individual level through assumptions on equitable distribution may be affected (Carletto et al., 2013). Dietary choices may also impact memory bias and other types of measurement error in such survey measures. When questioned about "consumption in a normal month," for example, reporting foods that are infrequently consumed may be more susceptible to telescoping bias or recall bias than reporting items that are consistently taken in similar proportions (Headey and Ecker, 2013). Also, cultural characteristics, as opposed to socio-economic position or factors impacting food supply, might cause dietary variety assessments to vary. Similar to those above, cultural factors may affect evaluations intended to document self-reported perceptions of or behavioral reactions to food insecurity. Depending on the circumstance, sharing meals with neighbors might be more of a social custom than a way to deal with food insecurity (Renzaho and Mellor, 2010). However, the development of experiential food insecurity measures like the Hunger Scale or Household Hunger index is the result of more recent studies that have identified types of responses that are typical across many ethnic groups. These scales are more suited for assessing cross-cultural food security, according to preliminary validation studies (Deitchler et al., 2010).

Due to increased concerns about food security, the energy sector performs well in expanding the food supply. Due to the massive use of traditional energy, the problem of food insecurity was solved at the cost of environmental damage. Therefore, the energy transition has become an essential topic in talks about the future of usage in human and economic activities. The energy transition, which is often related to the changes that must be done to shift toward renewable and sustainable energy sources, is currently being driven by the need for sustainable development (Luciani, 2020). Various political, social, environmental, and economic issues are covered. Prior attempts to supply energy services to many people have mainly failed, and current energy systems are frequently unsustainable. As a result, an energy transition is essential for sustainable food (Grubler, 2012).

Developed nations have gone through an energy transition due to rising income levels. The primary focus is on switching from traditional biomass to fossil fuels and, later, toward using natural gas and renewable energies like wind and solar (Kim, 2019). As a result of increases in industrial production, urbanization, and economic development, as well as the expansion of transportation systems, the energy transition in developing countries entails a significant increase in the accessibility and affordability of energy services, which in some cases may result in a decrease in the food supply. In order to accomplish the current aims of the energy transition agenda, some authors have advised avoiding centralized energy systems and adopting locally adaptable solutions to solve the socio-economic problems (Goldthau and Hughes, 2020). In this environment, decentralized, local energy systems have been created as a new frontier and alternative tactic that allows towns and regions to be energy-independent (Adil and Ko, 2016). Baker et al. (2014) has emphasized the significance of domestic policies to promote the energy transition, such as governance and capacity building.

The energy transition has garnered more attention recently in academia and politics, and numerous countries have incorporated it into their national energy strategy (Bridge et al., 2013). Although the literature highlights the importance of technological innovation and the market, price, and economics, policies and policymakers are vital to the transition to a sustainable energy system (Daszkiewicz, 2020). Policy action is required to direct the global energy system toward sustainable routes. Daszkiewicz (2020) highlights the fact that energy rules in a number of nations have helped achieve a successful energy transition in various industries, including transportation, home appliances, lighting, wind, and agriculture. Energy transitions are political processes that might encourage systemic adaptations in response to energy-related goals.

This study aims to identify the major challenges to food supply and examine the methods employed worldwide to get beyond them. The practices are now in use in nations that are successfully implementing the food supply globally. An overview of the available literature is given, and an outline is supplied based on the gaps that were either left unexplored or produced by information not being addressed in earlier studies. In the literature on implementing RE projects, impediments to the RET that have not yet been considered include prejudices against RE, societal, and economic situations. Even though there are numerous research studies on RET financing, these either concentrate on a single location or only cover a specific policy or plan. However, not even a single study has tried to investigate the role of energy transition in the selected economies, namely Egypt, Morocco, Tunisia, and Lebanon. Besides, numerous case studies have been demonstrated to elaborate on the heterogeneous association between food supply and its other determinants. Likewise, the energy transition has not been considered a significant determinant of food supply globally; hence, this study will be a novel contribution to future literature on whether energy transition could influence the food supply level. Besides the energy transition, this study also considers the other core variables of food supply: land use, agricultural value added, gross domestic product, and urbanization. Socio-economic factors are essential and can play a significant role in the food supply; alternatively, food supply significantly contributes to the Economic growth of economies. Similarly, agricultural value added also considerably contributes to the food supply. Another main contribution of this study is to investigate the moderate role of the energy transition on land use, agricultural value-added, and gross domestic product and their impact on food supply. It is a new door to future research on how they can check out the significant contribution of energy to different sectors. From this study, we can learn whether the energy transition in land use, agricultural sector, and economic growth significantly contribute to and cause food supply. It is understood that mentioned three food factors are directly linked with the energy sector, and it may cause to increase in the food supply. In contrast with previous case studies, the current research tries to investigate its objectives *via* a series of novel estimators. For this purpose, we employ the most reliable unit root (LLC and IMPs), co-integration tests (Pedroni and Kao), FMOLS, and DOLS estimators. However, the available data was short; therefore, the current study also focuses on future forecasting and employs the impulse response function (IRF) and variance decomposition analysis (VDA). Finally, the present study uses a pairwise panel causality test ton investigate the causal association among selected variables.

The remainder of the essay is structured as follows: The food supply justifications are discussed in Section Literature review, the factors influencing the food supply are outlined in Section Data and methodology, and the current outcomes are described in Section Results and discussion, the conclusion with policy recommendations are covered in Section Discussion, conclusion, and policy recommendations.

Literature review

Since the 1996 World Food Summit (WFS), enormous efforts have been undertaken to boost farm food production and security (Ericksen, 2008). Ending hunger is one of the 17 Sustainable Development Goals (SDGs) that the United Nations (UN) established in 2015. One in ten people worldwide presently endures severe food insecurity, despite the tremendous work done over the past few decades to build methods and policies to ensure global food security. Population growth, rapid urbanization, unsustainable use of non-renewable resources, climate change, and changes in food consumption patterns (such as an increase in total calorie intakes; a change in diet composition) are all important factors (Abd-Elmabod et al., 2020). According to Hall et al. (2017), extensive resource exploitation may cause land degradation and reduced soil productivity, whereas undernourishment is anticipated to increase with population growth. An increase in pests and illnesses brought on by climate change and a rise in extreme events like droughts and floods might lead to crop failure or loss (Richardson et al., 2020). Last but not least, the demand for more products and changing eating habits is increasing the use of land and water resources, depleting them, and raising issues with food security. Therefore, the global food security agenda calls for swift international action and comprehensive global food insurance (Ruben et al., 2018).

There are more than 200 definitions of food security and the elements that affect it in the literature (Kyeyune and Turner, 2016). The World Food Conference was convened in 1974 by the Food and Agriculture Organization of the United Nations, when it was decided that food availability was the main factor affecting food security. Food security was first defined by the World Bank in 1986 as "access by all people to enough food for an active and healthy life at all times", and this definition only took accessibility and availability into account. A situation in which "all members of the society have access to food in line with their needs, whether from their production, the market, or through government transfer mechanisms", as per the FAO definition from 1996, is considered to be one of food security (Pinstrup-Andersen, 2009). This concept includes the three requirements of accessibility, utilization, and food availability (Al-Sulaiti and Baker, 1998; Abaalzamat et al., 2021; Al-Sulaiti et al., 2021). According to an alternative definition given by FAO in 2002, a condition of food security is when "all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that fits their dietary needs and food preferences for an active and healthy life" (Al Khulaifi et al., 2005; Sulaiti et al., 2006; Gouvea et al., 2022). According to Kumar et al. (2017), due to incorrect estimation of food security, the amount of food available for consumption by the population in a specific location during a particular period of time reveals food security; this is accomplished through domestic agricultural production or imports from areas with a surplus of food. Hannum et al. (2014) and Headey et al. (2022) also, refer to the condition of having enough food on hand in a country to either meet domestic demand through domestic production or imports as food security. The Planning Commission (Government of India) defines a condition of food security as one in which "everyone has access, at all times, to food required for an active and healthy life" (Headey et al., 2022).

The garbage and transportation sectors are occasionally mentioned, similar to how the energy sector predominates the growing literature on renewable energy transitions. In assessments, socio-technical systems thinking is commonly employed in assessments to show the varied developmental routes that renewable energy technologies have taken (Raven and Geels, 2010). The social research that identifies farm-level motivations (Sutherland and Holstead, 2014); preferred types (Mbzibain et al., 2013); and characteristics of adopters (Tranter, 2011) is not connected to the (Mola-Yudego and Pelkonen, 2008). The papers that do so tend to focus on alternative farming practices and marketing strategies like organic farming and local food networks (Darrot et al., 2015). Socio-technical systems perspectives are also used to address transition processes in agriculture. The agro-food literature has recently seen a rise in the popularity of system transition, which draws on some conceptual stances that emphasize "sustainable transitions"

(Barbier and Elzen, 2012). This reflects the rising understanding over the past three decades that traditional farming practices are not environmentally or socially viable and that a change is therefore required.

The development of cities depends on the transformation of energy (Coelho et al., 2018). A renewable energy system will be necessary to power a metropolis with nearly no greenhouse gas emissions in the future smart society (Yuan et al., 2018). China's National Energy Administration published its 13th 5-Year Plan for the growth of renewable energy in 2016. It states that various demonstration projects for renewable energy should be carried out where required since they could teach us important lessons about creating power markets and redesigning the electrical system. In order to encourage the use of renewable energy sources and raise the proportion of renewable energy consumption, the demonstration project for energy transition needs to be constructed in various locations. A metropolis is the primary source of economic expansion and energy use. China needs to take important steps toward sustainable development, including reducing its reliance on fossil fuels and building sustainable energy infrastructure in metropolitan areas. The usage of renewable energy at the scale of a city must therefore be analyzed and evaluated as soon as possible. However, some recent case studies also tried demonstrating the importance of energy transition and found a significant role in different sectors. A case study of the Asia continent (Shah et al., 2020) tried to investigate the role of energy transition in environmental quality. The long-run outcomes show the positive contribution of energy transition toward environmental degradation. Another case study of income groups (Naqvi et al., 2021) also investigated the role of the energy transition to environmental sustainability. They employed the CCE-MG, AMG, and MG and found a significant contribution to environmental quality in high and upper middle incomes countries. Zhang et al. (2022a) also tried to explain the energy transition in environmental quality and employed the FMOLS to show the significant role of nuclear and wind energy in environmental quality. A study of WANA economies (Shah et al., 2021) also tried to investigate the impact of energy transition toward carbon emissions and ecological footprint. The estimated outcomes by D-CCE estimators showed the inverse association between energy transition and environmental degradation.

The development of renewable energy sources and urbanization are inextricably linked (Bao and Fang, 2013). Arenas-Aquino et al. (2017) discussed the potential benefits of using solar energy for urban development. The potential for developing solar resources in Turkey is evaluated (Ziya et al., 2017). In order to undertake comparative evaluations of various cities (Brito et al., 2017), added compressed natural gas to the urban bus fleet. Adam et al. (2016) created a technique to assess the potential for city-scale renewable energy generation for strategic energy infrastructure investment. Other examples of urban energy transition that have been investigated include the technical geothermal potential, district heating integration, and thermal geological model (Rivera et al., 2017). Some scholars questioned the integration of natural gas into the urban energy transition as well as the connections between the energy transition, water, and climate change (Osorio-Tejada et al., 2017). Past studies have looked at the experience throughout the world in creating urban low-carbon energy systems and provided some useful recommendations for China's creation of low-carbon cities (Liu et al., 2011). Later on, a case study in the USA (Pata et al., 2022) demonstrated the promotion of energy transition by the financial sector and found a significant impact on energy transition. Likewise, a case study of G-10 economies (Zhang et al., 2022b) also tried to investigate the leading role of energy transition in environmental quality and found a significant contribution toward environmental sustainability.

However, the literature solely focuses on developing and using one specific type of renewable energy in urban planning. There is little study on how economies switch to renewable energy is quantified (Woldeyohannes et al., 2016). The current renewable energy utilization system in economies aims to promote the expansion of the renewable energy industry. It only simplifies the definition and use of renewable energy in the economies by using the proportion of renewable energy consumption as a critical indicator. Shah et al. (2022a) investigating energy's role in environmental sustainability and found a significant contribution toward a green environment. In addition, a case study of top Asian tourist economies (Shah et al., 2022b) tried to investigate the leading role of renewable energy to environmental sustainability. Such a system certainly makes it challenging to serve as a foundation for and a source of guidance for the growth of renewable energy since it lays too much emphasis on consumption. The prior studies did not account for general city planning, social and natural environment benefits, returns on investment, etc. These researchers' policy suggestions don't center on selected economies' sustainable growth. In light of the aforementioned justifications, the main objective of this essay is to discover any potential linkages between energy transition and food security by analyzing the relationship between energy and food supply for selected economies between 2010 and 2019. Yao and Chang (2014) assert that one important factor in determining the degree of the energy transition is affordability, which will decline as energy prices rise and jeopardize the degree of security. As one of the essential elements in agricultural production, energy is expected to disrupt the agricultural supply and increase food prices.

In the existing literature, most studies have done their best to summarize the core determinants of food supply, in which traditional energies, transportation sector, and services sectors. Besides, the leading factor that may cause to boost in the level of sustainable growth has been neglected in the past literature, namely energy transition. Hence, this is the first contribution of the current study to future literature, which may bring a new research direction across the globe. It is expected that the energy transition will significantly change the food supply. Moreover, in past studies, the selected regions have been neglected over time; it will be a new contribution to existing literature. Finally, not even a single research tries to forecast and suggest whether the future food supply will decline or not. Hence this study will also contribute to future literature by adding such forecasting for food supply. Sustainable food supply requires local firms' interventions (Sattar et al., 2020; Xu and Sattar, 2020; Latief et al., 2021, 2022; Sattar, 2022).

Data and methodology

Theoretical background

Several initiatives have been put into place internationally to address the rising demand for energy supplies without using—depleting—fossil fuels that emit different damaging sectors (Qadir et al., 2021). The ozone layer significantly recovered due to the 1987 Montreal Protocol, which reduced the consumption of compounds that deplete the ozone layer (Zhang, 2009; Ruppel, 2022). The 1997 Kyoto Protocol, in a similar vein, required nations to finance green energy technologies. Later, the Paris Agreement/COP21 (Conference of the Parties) took its place in 2015, upon which the following energy policies and strategies were developed. Increased development of green energy technologies, such as solar, wind, and biomass, is essential (Imteyaz and Tahir, 2019). Other benefits of sustainable renewable energy (RE) include providing alternatives, which diversify energy sources and contribute to energy security. Additionally, RE may make energy more easily accessible, support social and economic advancement, and, most critically, lessen the effects of climate change on the environment and human health (Panwar et al., 2011).

Ingenious solutions are required to deal with the complex issues that emerge in this transition, such as the decoupling from inefficient and traditional methods while meeting energy needs (Pilz et al., 2018). The transition from fossil fuels to renewable energy (RE) is essential to achieving a cleaner future (Alasseri et al., 2020). The term "renewable energy transition" (RET) refers to the shift away from fossil fuel-based energy sources (Li et al., 2020). It will take a tremendous amount of capital to implement an effective RET. Despite recent technology breakthroughs greatly reducing the overall costs associated with RE production, there hasn't been a matching rise in investment (Irena and Desa, 2019). Financing the RET is perhaps one of the significant difficulties of the twenty-first century since investors are less ready to accept financial risk as a result of changes in legislation and the amount of cash required.

All aspects of food production, storage, processing, distribution, retail, and consumption are subject to a variety of environmental changes, such as slow changes in average conditions (such as climate, nutrient, and water cycling), smaller-magnitude variations around those means, and larger, anomalous disruptions. It is crucial to comprehend the possible unique dangers of how environmental variability is spread or suppressed within food systems as food supply chains become more globally interconnected. The emergence of multinational food firms and ongoing globalization has increased the complexity and efficiency of the relationship between producers and consumers. There is still much to learn about how these dynamics affect how environmental variability spreads through local and global food supply chains, how major occurrences (like blockades, recessions, and pandemics) may amplify these effects, and what these dynamics ultimately mean for the stability and accessibility of nutrient-dense diets. To lower the risks to food and nutrition security posed by recurring food shortages and to boost system resilience, it is essential to identify the fundamental processes and players in food supply chains and to comprehend how they interact with and are exposed to environmental variability and the economy.

The natural environment has significantly changed as a result of human activity. More land is required to increase food production as a result of rising food demand and a growing population, which accelerates land-use and land-cover changes. The LUCC project was cosponsored to understand better land-use and land-cover changes and the physical and human causes that drive these processes. To yet, no research has been done on how EG affects agricultural value added (AVA) in impoverished nations. AVA is also essential for improving the welfare and income of farmers in developing nations. Agriculture may generate value-added significantly impacting GDP growth rates and employment in developing countries. In order to increase export diversification in emerging nations, AVA is also essential. These nations' exports rely heavily on raw materials that have not been processed.

This is unprofitable since a country won't be able to foresee changes in market risk or the effect of trade degradation due to the low level of export diversification. AVA can reduce CO_2 emissions both immediately and over the long term since agriculture can absorb carbon and lessen its carbon footprint by using cutting-edge technologies and management. The internal and exterior urban-rural territorial system exchanges a lot of energy, materials, and information, which makes the primary land use areas more susceptible to societal and economic reactions. Economic development decisions frequently modify the supply of land services directly or indirectly, which leads to changes in land use structure and functions. Producing land has been substantially developed and transformed throughout the world as a result of population growth to suit people's diverse needs for land for living and production.

By having a lengthy debate on the variables and their economic explanation, it is necessary to introduce all the selected variables. Therefore, this study selects the panel data for four economies namely Egypt, Morocco, Tunisia, and Lebanon over the period of 2010–2019. The panel data consists of food supply, land use, gross domestic product, urbanization, energy transition and agricultural value added. However, the information concerning unit, definition and source is essential for the data reliability. Therefore, the food supply is measured by Kcal/capita/day and collected from food and agricultural organizations. Similarly, land use is a core variable measured by total agricultural land square kilometers; the data is taken from Eurostat. Moreover, gross domestic product and urbanization are collected from the World Development Indicators, and their units of measurement are annual percentages and percentages of the total population. Likewise, the agricultural value added is measured by GDP percentage, and data is collected from WDI. Finally, the core variable of this study is energy transition; across the globe, economies are trying to shift their traditional energy pattern to modern/green ones, which is considered energy transition. Therefore, the present study also used renewable energy consumption as a percentage of total energy consumption as a measure of energy transition and flowed to Najm and Matsumoto (2020) (see Table 1 below).

In the given Figure 1 it is showing the trend graphs of selected variables. The food supply, there observes Egypt has higher food supply for their nation which decline over time. Similarly, Tunisia followed an increasing trend in the food supply over time. Likewise, for land use, Tunisia has the maximum land use, while Lebanon has lower land use. Moreover, Egypt has higher economic growth, while Lebanon has a lower growth rate. Urbanization is the main economic progress factor; Lebanon has the highest urbanization rate. Likewise, Tunisia has the highest energy transition, while it declines over a period of time. In last, Morocco has the highest agricultural value added. Figure 1 below shows land use, food supply, urbanization, GDP, AVA, and energy transition in selected countries.

TABLE 1 Variables description.

Variables	Definition	Unit	Sources
FS	Food supply	Kcal/capita/day	Pinstrup-Andersen (2009)
LU	Land use	Total agricultural land square kilometers	Eurostat
ET	Energy transition	% of total energy consumption	WDI
AVA	Agriculture value added	% of GDP	WDI
GDP	Gross domestic product	Annual percentage	WDI
URB	Urbanization	% of total population	WDI

Model construction

As this study has the main target to investigate the food supply and its determinants, which may affect the supply of food. The current study has proposed the following models for analysis. However, the base model is considered land use, energy transition, agricultural value added, urbanization and economic growth as the determinants of food supply; therefore, the current study has the base model as follows,

$$FS_{i,t} = f(\beta_0, LU_{i,t}^{\beta 1}, ET_{i,t}^{\beta 2}, AVA_{i,t}^{\beta 3}, GDP_{i,t}^{\beta 4}, URB_{i.t}^{\beta 5}) \quad (1)$$

In the given Equation (1), FS, LU, AVA, GDP, and URB refer to food supply, land use, agricultural value added, gross domestic product and urbanization. In the given model, land use, agricultural value added, and energy transition are the explanatory variables; however, GDP and urbanization are the control variables. Similarly, the energy transition is the leading variable in the current study. We can transform the given model into log-log model, which can be written as follows. Moreover, i refers to the number of cross sections, and t refers to time period.

$$LFS_i, t = \beta_0 + \beta_1 lnLU_{i,t} + \beta_2 lnET_{i,t} + \beta_3 lnAVA_{i,t} + \beta_4 lnGDP_{i,t} + \beta_5 lnURB_{i.t} + \varepsilon_{i,t} \quad (2)$$

Equation (2) lnFS represents the natural log of food security, lnLU shows the natural log of land use, LET, LAVA, LGDP, and LURB represents the natural log of the energy transition, agriculture value added, economic growth, and urbanization. In this case study, it is expected that land use has a negative association with food supply; the logic is that when the land will use in building construction and infrastructure development it would decline the supply of food and therefore, this current study imagines that coefficient of land use will be less than zero ($\beta < 0$). Similarly, the energy transition can perform well to boost the level of food supply. This infers that traditional energies cause lower productivity due to massive cost, while in the case of green energies the total cost of production may decline and cause to boost the level of food supply further. Due to the positive role of energy transition in food production, this study considers the slope of ET is positive ($\beta > 0$). Also, agricultural value added is being another main determinant of food supply, and it is expected that agricultural value added increases the level of food supply. This study considers the slope would be positive ($\beta > 0$). However, the gross domestic product also considers the booster of food supply, and it slope is positive ($\beta > 0$). Finally, urbanization may decrease the food supply, and its slope will be less than zero ($\beta < 0$). Likewise, the main effect of the selected variables may not respond well; therefore, this study also tries to investigate the moderate role of the energy transition on the gross domestic product, land use, and agricultural value added and their impact on food supply in the selected panel.

$$\begin{aligned} \mathrm{lnFS}_{i,t} &= \beta_0 + \beta_1 lnLU_{i,t} + \beta_2 lnET_{i,t} + \beta_3 \mathrm{lnAVA}_{i,t} + \beta_4 \mathrm{lnGDP}_{i,t} \\ &+ \beta_5 \mathrm{lnURB}_{i.t} + \beta_6 \mathrm{lnET}^{*}\mathrm{LU} + \varepsilon_{i,t} \end{aligned} \quad (3)$$

$$\begin{aligned} \mathrm{lnFS}_{i,t} &= \beta_0 + \beta_1 lnLU_{i,t} + \beta_2 lnET_{i,t} + \beta_3 \mathrm{lnAVA}_{i,t} + \beta_4 \mathrm{lnGDP}_{i,t} \\ &+ \beta_5 \mathrm{lnURB}_{i.t} + \beta_6 \mathrm{lnET}^{*}\mathrm{GDP} + \varepsilon_{i,t} \end{aligned} \quad (4)$$

$$\begin{aligned} \mathrm{lnFS}_{i,t} &= \beta_0 + \beta_1 lnLU_{i,t} + \beta_2 lnET_{i,t} + \beta_3 lnAVA_{i,t} + \beta_4 lnGDP_{i,t} \\ &+ \beta_5 \mathrm{lnURB}_{i.t} + \beta_6 \mathrm{lnET}^{*}\mathrm{AVA} + \varepsilon_{i,t} \end{aligned} \quad (5)$$

In the given Equations (3–5) there exists moderate effect of energy transition and denotes with lnET*LU, lnET*GDP and lnET*AVA.

In Figure 2, this study explains the flow of estimation strategy for a quick review. From Figure 2 below, a reader can understand the flow of estimation techniques used in this research paper.

Estimation strategy

This study adopts a simple process to validate the panel data to assure reliable results.

Content of the methods

The contents of the method are given as follows,

- Descriptive statistics test
- Pairwise correlation test
- Unit root tests
- Co-integration tests
- Long-run estimators
- Impulse response function
- Variance decomposition analysis
- Pairwise panel causality test.

To assure the reliable outcomes, this study adopts a simple process to validate the panel data while the essential steps are as follows. To scrutinize the reliability of data, the initial step is to examine the Unit Root of given data. Through the co-integration such as Pedroni and Kao panel co-integration, it can be certain whether a group of stable or same order single integration data has a stable long-term relationship. If it does not exist, regression estimation is not necessary. On the other hand, the next investigation step can be carried out if a long-term relationship exists. This is a fundamental step to select an appropriate econometric technique. If this step is ignored, it may cause inaccurate results. The next step is the Hausman test, which determines whether the regression chose a random or fixed effect. Likewise, OLS and FMOLS estimations were selected in the next step to estimate the association between selected indicators. Finally, the Panel Granger causality test was employed to examine the causal association among concerned variables.

Panel unit root test

Firstly, the unit root tests (UR) are estimated before employing panel regression for empirical analysis. If the data does not pass the UR test, the data set is non-stationary in sequence; in this case, the regression may be pseudo. Current analysis has adopted two different types of UR tests.

The first is the LLC panel unit root test developed by Levin et al. (2002). The mathematical notation for LLC test is given as follows,

$\Delta f_{i,t} = \alpha_{i,t}\ y_{i,t} + \sum_{L=1}^{mn} \beta\rho i\ \Delta y_{i,t-L} + \delta\rho_i \gamma\rho t + \mu_{i,t}$ $\rho = 1, 2, 3$, the given notations represent the autoregression coefficient of proposed model and the corresponding vectors of coefficient are $\rho = 1, 2, 3$. The null hypothesis is $\alpha = 0$ there is a unit root; if $\alpha < 0$ there is no unit root.

Likewise, another UR test is the IPS panel unit root test introduced by Im et al. (2003). IPS overcome the limitation of the LLC test and allow ρi coefficient of a different individual in the panel to be different. The mathematical form of IPS as follows,

$$\begin{aligned} \Delta \mathrm{y}_{i,t} &= \rho_i y_{i,t-1} + \sum_{j=1}^{ki} \gamma ij\ \Delta y_{i,t-j} \\ &+ \mu_{i,t} \mathrm{i} = 1, 2, 3, \ldots., \mathrm{N}, \mathrm{t} = 1, 2, \ldots., \mathrm{N}, \end{aligned}$$

Null hypothesis $\rho_i = 0\ i = 1, 2, 3, \ldots..N$ unit root exists, and if less than zero there is no unit root test.

Panel co-integration tests

If the unit root test exists, which indicates that the data is stable or homogenous, then a panel co-integration test can take to check out whether there is a long-run connection found or not; the appropriate method can be selected for estimation; if it does not exist we cannot continue, we need to reselect the variables. This study uses the Pedroni panel co-integration test proposed by Pedroni (2001) to indicate the presence of panel co-integration. In the co-integration process proposed by Pedroni, there can be a non-uniform intercept and trend coefficient across the cross-sections. The Kao co-integration test is similar to that of Pedroni both developed by angle granger test, but at the first stage of regression analysis, it is assumed that there are specific intercept and homogeneity coefficients between the sections. The Kao test variable model is written as under.

$$\mathrm{Y}_{i,t} = \alpha_i + \mathrm{bx}_{i,t} + \mathrm{C}_{i,t} \quad (6)$$

Where, $Y_{i,t} = y_{i,t1} + \mu_{i,t}$, $x_{i,t} = x_{i,t-1} + V_{i,t}$, $t = 1, \ldots\ldots T$ and $i = 1, \ldots..N$. Generally, first-stage regression can be

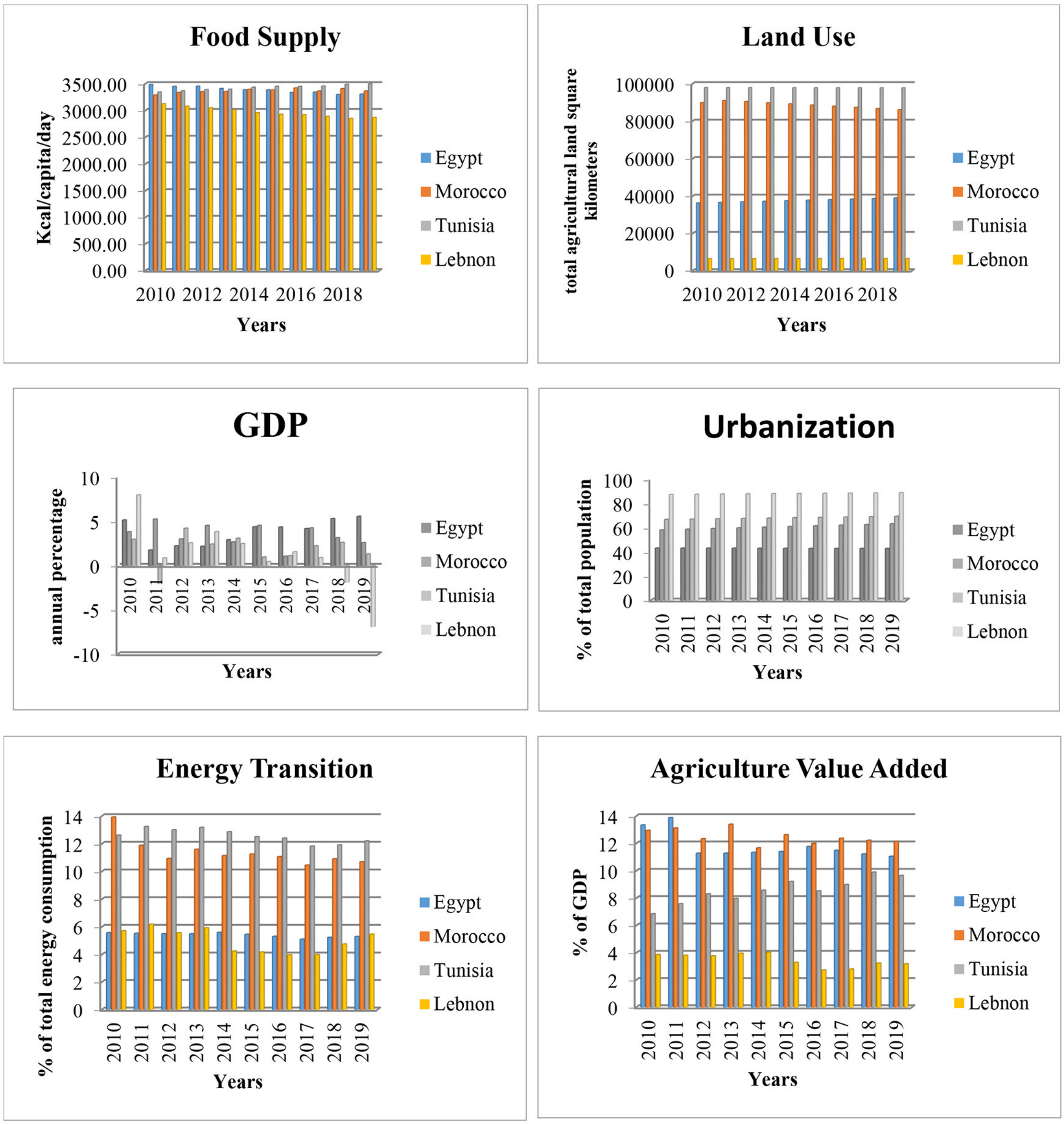


FIGURE 1
3D graphs showing land-use, food supply, and urbanization, GDP, AVA, and energy transition.

performed with the model. The alpha series is not the same, b is the same and all the trend coefficients are zero. Likewise, Kao co-integration executes an auxiliary regression on the residual term.

Model selection criteria

Past literature, as usual, selected the models through qualitative analysis to determine whether individual variable intercept, time variable intercept, fixed effect, or random effect rather than a statistical test. In addition, qualitative analysis is not rigorous, and, likely, the actual data does not conform to the usual methods of qualitative research. Thus, we set up the model through a statistical test. Finally, the Hausman test was used to conclude whether the effect was fixed or random. A likelihood function implements the test of the model dimension to detect whether the hypothesis is valid.

Panel regression estimation

After completing the specific setting of the model according to the likelihood ratio and Hausman test results, we select an effective method to conduct regression estimation

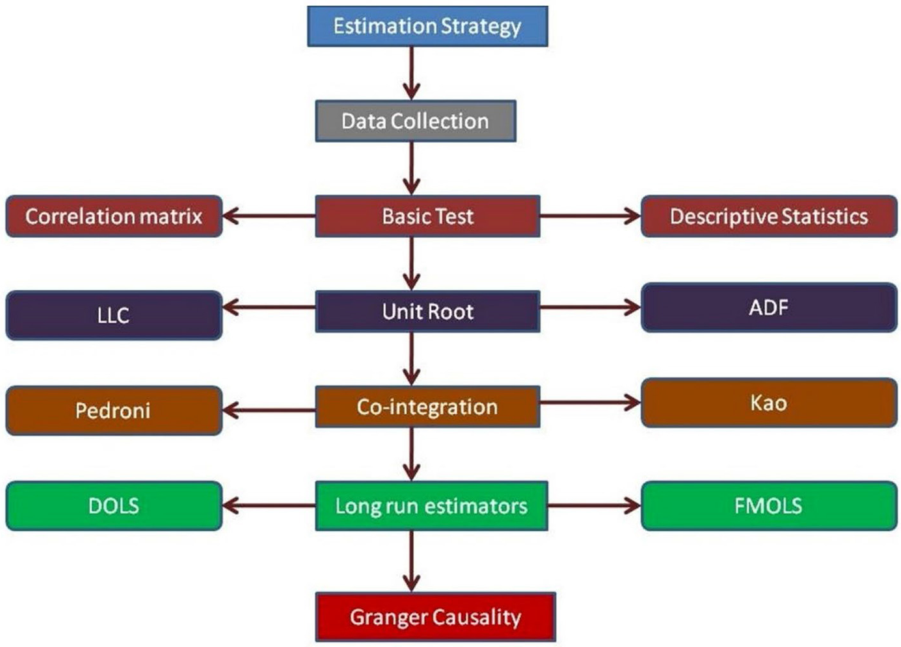


FIGURE 2
It shows the process of estimation strategy of this study.

on the panel data model. In this study, a single model is selected for the estimation. Equation A is the main quantitative regression model in this study. In this paper, the FE-model method is applied to regress the model. Likewise, for the robust empirical outcomes, this study also adopts the FMOLS method and this can correct sequence correlation Pedroni (2001) proposed a co-integration system as follows,

$$Y_{mn} = \beta_m + \alpha x_{mn} + \theta_{mn} \quad (7)$$

In the above equations, all parameters have a co-integration relationship Pedroni (2001), also propose an equation in which regressions and co-integration regression are added to manage the impact of endogeneity.

$$Y_{mn} = \beta_m + \alpha x_{mn} + \sum_{p=-pm}^{pm} \mu mp \Delta xmn - p + \theta_{mn} \quad (8)$$

$$\rho_{mn} = (\theta - hat, x_{mn}) = E[\frac{1}{D\sum_{d=1}^{D} \beta mn \sum_{d=1}^{D} \rho mn}],$$

definition δ_{mn} is the long term covariance of FMOLS regression process. The long term covariance can be decomposed into $\delta_m = \delta_m^0 = \omega_m = \omega_m^{'}$, where ω_m is automatic covariance and δ_m^0 is the weighted sum of covariance and ω_m. The mathematical form of FMOLS is given below,

$$\alpha_{FMOLS} = \frac{1}{\beta}\sum_{m}^{B}[\frac{1}{(\sum_{d=1}^{D} xmn - bar\ xmn)2} (\sum_{d=1}^{D}(xmn - bar\ xm)y_{mn}^{*} - \omega_{\mu m})] \quad (9)$$

The panel granger causality test

In the process of panel data estimation, the co-integration relationship tests the causality between variables in one direction. Thus, as to test the causality between the two variables in two directions, this study used the panel granger causality test by Engle and Granger to test the causal relationship between variables. This test is divided into two steps. The first step uses the regression to estimate the residual according to the long-run parameters given by the main model and the residual is used as the right variable. The further step uses the right variables to examine the short-run error correction model. The mathematical form of the Granger causality test is given as follows;

$$\Delta FS_{mn} = \delta_{1m} + \sum_t \delta_{11mt}\Delta FS_{mn-t} + \sum_t \delta_{12mt}\Delta LU_{mn-t} + \sum_t \delta_{13mt}\Delta ET_{mn-t} + \sum_t \delta_{14mt}\Delta AVA_{mn-t} + \sum_t \delta_{15mt}\Delta GDP_{mn-t} + \sum_t \delta_{16mt}\Delta URB_{mn-t} + \beta_{1m}ECT_{mn-1} + \alpha_{1mn} \quad (10)$$

$$\Delta FS_{mn} = \delta_{2m} + \sum_t \delta_{21mt}\Delta FS_{mn-t} + \sum_t \delta_{22mt}\Delta LU_{mn-t} + \sum_t \delta_{23mt}\Delta ET_{mn-t} + \sum_t \delta_{24mt}\Delta AVA_{mn-t} + \sum_t \delta_{25mt}\Delta GDP_{mn-t} + \sum_t \delta_{26mt}\Delta URB_{mn-t} + \beta_{2m}ECT_{mn-1} + \alpha_{2mn} \quad (11)$$

$$\Delta FS_{mn} = \delta_{3m} + \sum_t \delta_{31mt}\Delta FS_{mn-t} + \sum_t \delta_{32mt}\Delta LU_{mn-t} + \sum_t \delta_{33mt}\Delta ET_{mn-t} + \sum_t \delta_{34mt}\Delta AVA_{mn-t} + \sum_t \delta_{35mt}\Delta GDP_{mn-t} + \sum_t \delta_{36mt}\Delta URB_{mn-t} + \beta_{3m}ECT_{mn-1} + \alpha_{3mn} \quad (12)$$

$$\Delta FS_{mn} = \delta_{4m} + \sum_t \delta_{41mt}\Delta FS_{mn-t} + \sum_t \delta_{42mt}\Delta LU_{mn-t} + \sum_t \delta_{43mt}\Delta ET_{mn-t} + \sum_t \delta_{44mt}\Delta AVA_{mn-t} + \sum_t \delta_{45mt}\Delta GDP_{mn-t} + \sum_t \delta_{46mt}\Delta URB_{mn-t} + \beta_{4m}ECT_{mn-1} + \alpha_{4mn} \quad (13)$$

$$\Delta FS_{mn} = \delta_{5m} + \sum_t \delta_{51mt}\Delta FS_{mn-t} + \sum_t \delta_{52mt}\Delta LU_{mn-t} + \sum_t \delta_{53mt}\Delta ET_{mn-t} + \sum_t \delta_{54mt}\Delta AVA_{mn-t} + \sum_t \delta_{55mt}\Delta GDP_{mn-t} + \sum_t \delta_{56mt}\Delta URB_{mn-t} + \beta_{5m}ECT_{mn-1} + \alpha_{5mn} \quad (14)$$

Where ECT denotes error correction term, t denotes hypothesis testing, denotes hysteresis length and first-order difference of the variable, respectively. This study has followed the Akaike information standard to determine the optimal lag.

Results and discussion

Table 2 presents the summary of descriptive statistics. The mean value from the FS was 3.515%. The average LU was almost 4.570%. The mean annual ET was nearly 0.888%. Likewise, the average AVA and GDP was almost 0.908 and 0.426%, respectively. Finally, the average URB represented as a % of total population was ∼1.796% for selected economies. Moreover, there is no significant difference between the mean and median for selected panel data. On behalf of outcomes, there is no outlier in the given data (see Table 2 below).

There may be a risk of multicollinearity in particular panel data before moving on to the multivariate regression model. A pairwise correlation matrix was used to verify that this model did not contain multicollinearity. The pairwise correlation results, which are interesting, are shown in Table 4. The results show that land usage correlates positively with food security at a 1% level of significance. Similarly, at a 1% significant level, the energy transition and agriculture value positively correlate with the explained variable (FS). Furthermore, environmental deterioration is positively correlated with GDP at a 1% rate. Finally, there is a 1% negative correlation between urbanization and food security. Multicollinearity is not present in the model (see Table 3 below). The findings of the VIF test used in this study's verification are included in Table A1.

We employ panel unit root tests to determine the order of integration of each variable before performing any further

TABLE 2 Descriptive statistics.

Variables	Mean	Median	Maximum	Minimum	Std. Dev.	Probability
LFS	3.515	3.526	3.543	3.454	0.027	0.016
LLU	4.570	4.591	4.990	3.806	0.481	0.058
LET	0.888	0.790	1.143	0.597	0.189	0.091
LAVA	0.908	1.043	1.142	0.435	0.233	0.038
LGDP	0.426	0.464	0.901	−0.335	0.276	0.199
LURB	1.796	1.799	1.948	1.630	0.115	0.299

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analysis. We run two distinct unit root tests, and Table 4 displays the outcomes for each variable for both the ADF and LLC panel unit root tests. Each test is run for the initial difference and level of the variables. In the case of variables, the null hypothesis that variables assume common and individual unit root processes cannot be rejected. However, when the first difference is applied, every variable complies with the study's requirements. For the 95% confidence interval, we can therefore accept that they are stationary. According to a recent study, unit root testing are crucial since regression may be erroneous if variables are not incorporated (Roquez-Diaz and Escot, 2018). The summary of the unit root test is presented in Table 4. Results showed that all relevant, sustainable growth indicators are stationary at the first difference (see Table 4 here).

The next stage is to look at the explained and explanatory factors' long-term co-integration connection. Consequently, this research utilizes the Pedroni co-integration test created by Pedroni (2004). Both parametric and non-parametric frameworks are used, and seven test statistics are included. Consequently, results are shown in Table 5. Four tests were used in this investigation to prove that the chosen panel had long-term co-integration statistically. As a result, it is possible to conclude that a few FS indicators have long-term co-integration. Additionally, this study used the Kao panel co-integration approach (Kao, 1999) to confirm Pedroni's findings. The results demonstrate the presence of co-integration (see Table 5).

TABLE 3 Pairwise correlation test.

Variables	LFS	LLU	LET	LAVA	LGDP	LURB
LFS	1					
LLU	−0.8960**	1				
LET	0.6361*	0.7374*	1			
LAVA	0.6008*	0.6538**	0.5176*	1		
LGDP	0.1669*	0.1549*	0.0614**	0.3229**	1	
LURB	−0.6803*	−0.5001*	−0.0058*	−0.4773*	−0.3515**	1

*,**Shows the level of significance at 1 and 5%, respectively.

Long run results of FMOLS and DOLS estimators

Next, we estimated the long-run co-integration vector between food supply and its determinants using a panel using the FMOLS and DOLS approaches. We account for deterministic trends and constants using a panel data model and pooled weighted estimate. In order to examine how land use (LU), the energy transition (ET), agriculture value added (AVA), economic growth (GDP), and urbanization (URB) affect food security, Tables 6, 7 show the results of panel FMOLS and DOLS estimators for all the economies that were chosen (FS).

Land usage is recognized as the first factor of food security and exhibits an inverse relationship with food supply. According to the FMOLS specification, a 1% increase in this component would result in a drop in the food supply of −0.466, −0.513, −0.594, and −0.636%, respectively. Land use, however, is strongly tied to agricultural and food systems and is seen as a crucial component of the food supply (Stein, 2014). The land use analysis found a drop in output and its utilization in unproductive fields. Similar differences of opinion exist concerning food supply and land use. Food demand growth and other economic and political considerations are significant drivers of land use changes (Heilig, 1997). In many places, food availability falls mainly due to land transactions. Another argument is that, compared to the global average of 0.236 ha, the amount of cultivated land per person dropped far more slowly. Despite significant new agricultural land development in the nation, the per capita value has fallen as the population has grown. Agricultural structural changes, such as converting rice fields into orchards or fish ponds, were mostly responsible for the loss. However, industrial and urban growth was responsible for a significant loss percentage (Ellis and Rogers, 2000). Different effects may be expected on food production and other ecosystem values depending on the sources of the changes in cultivated land. When fertile land is converted to a non-agricultural use, as has happened in many places around the world where cropping intensities and population densities are

TABLE 4 Levin, Lin and Chu, and ADF unit root test.

Variables	Levin, Lin and Chu unit root test				ADF unit root test			
	Level		1st Difference		Level		1st Difference	
	Statistics	Probability	Statistics	Probability	Statistics	Probability	Statistics	Probability
LFS	2.002	0.062	1.599	0.054	9.009	0.341	18.286	0.019
LLU	0.389	0.651	37.464	0.000	1.420	0.095	36.841	0.000
LET	1.039	0.149	5.255	0.000	3.662	0.467	16.142	0.040
LAVA	8.734	0.000	8.049	0.000	2.058	0.234	38.801	0.000
LGDP	0.301	0.618	6.314	0.003	6.407	0.601	10.781	0.001
LURB	3.523	0.999	11.468	0.000	2.136	0.194	9.753	0.000

TABLE 5 Pedroni and Kao estimators.

Alternative hypothesis: Common AR coefficient (within-dimension)				
	Statistics	*p*-value	Statistics	*p*-value
Panel v-statistics	−2.398	0.991	−2.458	0.993
Panel rho statistics	1.623	0.947	1.686	0.954
Panel PP statistics	−6.348	0.000	−12.669	0.000
Panel ADF statistic	−1.795	0.036	−2.061	0.019
Alternative hypothesis: Individual AR coefficient (between-dimension)				
	Statistics	*p*-value		
Panel rho statistics	2.669	0.996		
Panel PP statistics	−18.554	0.000		
Panel ADF statistic	−2.182	0.014		
Kao co-integration				
ADF	−2.708	0.003		

TABLE 6 FMOLS estimators.

Variables	Model 1	Model 2	Model 3	Model 4
LLU	−0.466 (0.013)	−0.513 (0.007)	−0.594 (0.000)	−0.636 (0.000)
LET	0.043 (0.054)	0.966 (0.002)	0.126 (0.000)	0.073 (0.000)
LAVA	0.097 (0.000)	0.070 (0.003)	0.200 (0.000)	0.040 (0.000)
LGDP	0.007 (0.036)	0.007 (0.023)	0.007 (0.004)	0.011 (0.000)
LURB	−0.036 (0.838)	−0.692 (0.311)	−0.191 (0.145)	−0.342 (0.214)
LET * LU	-	0.234 (0.003)	-	-
LET * AVA	-	-	0.151 (0.011)	-
LET * GDP	-		-	0.0003 (0.001)
R^2	0.997	0.981	0.976	0.981
Adjusted R^2	0.970	0.974	0.968	0.971

notably high and the amount of arable land available per person is quite small, for example, reclaiming low-quality land typically cannot make up for the productivity lost (Lin and Ho, 2003). Since the last two decades, the world's cultivated area has significantly decreased, mostly due to the rapid rise of municipalities and industries in areas surrounding large cities (Long et al., 2007).

Given that agricultural value added has a positive correlation with the availability of food, an increase in this factor of 1% would result in increases in food availability of 0.097, 0.070, 0.200, and 0.040%, respectively. There are several logic at work behind the scenes, but it is possible to explain this upward trend. The first motivation is the expansion of the agriculture sector. A new technology for home usage in food preservation emerged at the start of the twentieth century. The company Kelvinator invented the compressor-driven refrigerator in 1918. Since cold storage made it possible to preserve fresh meals while reducing food losses and waste safely, refrigerators quickly became common in restaurants and grocery shops. The modern food industry and food transportation depend heavily on cold storage. There are many different kinds of cold stores, including refrigerated vans, warehouses, and buildings. Second, developing economies adopted the green revolution in the middle of the twentieth century to raise agricultural productivity. The term "green revolution" refers to a comprehensive initiative started in the 1960s to promote more environmentally friendly farming practices to increase food production in underdeveloped nations. Developing "friendlier" fertilizers and using higher-yielding plant types were two crucial ways to achieve this goal. The green revolution has many benefits and drawbacks. Some areas saw a more than 1,000% rise in food production, but it also contributed to biodiversity loss and other harmful environmental repercussions. The green revolution caused a population expansion in the target areas, which increased production costs and had detrimental ecological effects, but it also helped prevent famine and kept hunger at bay. Third, science-based agriculture is a phenomenon of the twentieth century. Its offspring, industrial agriculture, is a system that depends on advances in science for both survival and growth. Without these prerequisites in place, it is a whole framework that cannot function: pesticides and synthetic fertilizers to increase crop output, dependable and extensive irrigation systems, a global transportation network, and appropriate machine technology. The structure didn't exist all at once; instead, it progressively encircled the globe as government and business realized its advantages. There are several advantages to this new style of agriculture, including higher crop yields, far more efficient production, less expensive food, big company profitability, and broader export opportunities.

The food supply is impacted by economic growth in a statistically significant way. This reliable outcome demonstrates that greater GDP growth positively impacts food availability by 0.007, 0.007, 0.007, and 0.011% in this model, which calls for actions to increase food availability. By enabling farmers to adopt and use new technologies with greater costs but higher productivity, agricultural economic expansion can help raise the food production level. If the low food production level accounts for a higher portion of the lowness in Peal, the impact may be greater. Farmers' rising food demands are a result of their rising income levels, which in turn spurs an increase in domestic food production. Urban consumers' rising income levels and economic growth can boost food consumption, which will help Peal become better. Consumers' ability to buy more food from domestic or international markets thanks to income growth

TABLE 7 DOLS estimators.

Variables	Model 1	Model 2	Model 3	Model 4
LLU	−0.519 (0.000)	−0.512 (0.000)	−0.602 (0.000)	−0.981 (0.000)
LET	0.019 (0.022)	0.822 (0.000)	0.023 (0.465)	0.024 (0.000)
LAVA	0.061 (0.000)	0.046 (0.001)	0.062 (0.029)	0.031 (0.000)
LGDP	0.004 (0.014)	0.007 (0.001)	0.004 (0.003)	0.022 (0.000)
LURB	−0.170 (0.103)	−0.386 (0.111)	−0.026 (0.700)	−2.704 (0.365)
LET * LU	-	0.189 (0.000)	-	-
LET * AVA	-	-	0.023 (0.004)	-
LET * GDP	-	-	-	0.005 (0.000)
R^2	0.954	0.969	0.951	0.996
Adjusted R^2	0.942	0.059	0.936	0.994

improves their Peal. The impact is more significant if a sizable portion of the population is urban and non-farming. Also this outcome is in line with the case study by Fukase and Martin (2020).

The results demonstrate that, in this model, urbanization has a detrimental effect on food security. According to the findings, food security declines by −0.036, −0.692, −0.191, and −0.342% as urbanization increases. Agriculture employees are on the decline due to growing urbanization and population aging. The fact that urbanization has increased the number of employment available to migrant workers is one of the key factors. Migrant laborers in metropolitan areas earn more money than in the rural sector. This research ingeniously analyses the relationship between urbanization and food security, in contrast to other studies that concentrated more on the one-way impact of urbanization on food security and the difficulties that food security encountered during the urbanization process (Putra et al., 2020). In contrast to Yao's work, the CDUFS constantly swings in the low coordination interval. Urbanization and food security have experienced stable growth, but there hasn't been a corresponding increase in their relationship (Chengsheng et al., 2016). It primarily results from the fact that the development of urbanization continues to lag behind the growth of food security, and the unbalanced growth of the two hinders the advancement of coupling coordination level.

Besides the main effect, it is necessary to investigate the moderate role of the energy transition on land use, agriculture value added, and economic growth and their impact on food security. However, energy transition (ET)'s moderate role is positively impacting food security (FS). The result shows that the value of moderate role food security increases by 0.234, 0.151, and 0.0003% in this model. Finally, it can be concluded that the current study differs from the existing studies because it focuses on the critical role of energy transition and its implications in future literature. However, another main difference from the existing literature to introduce the moderate effect of energy transition and its impact on food supply. Also, from this analysis, policymakers can deal with food supply in the selected regions. The key findings of the whole study are given as,

- Land use shows the inverse association with food supply in the selected panel economies.
- Energy transition, agricultural value-added, and gross domestic product positively contribute to the food supply.
- Urbanization has a negative but insignificant impact on the food supply.
- The moderate role of energy transition shows a significant contribution to the food supply.

Here Table 6 shows FMOLS estimators of the selected model of this study.

Robust check by dynamic ordinary least square

This model demonstrates how, in this case, land usage has a detrimental effect on food security. According to the outcome, as land usage increases, food security falls by −0.519, −0.512, −0.602, and −0.981% in this scenario. Similar to how energy transition improves food security by the indicated values of 0.019, 0.822, 0.023, and 0.024%. In this scenario, agriculture value added also has a favorable effect on food security. As AVA increases, food security increases by 0.061, 0.046, 0.062, and 0.031%, according to the results. GDP also has a favorable effect on food security, as evidenced by the results below at 0.004, 0.007, 0.004, and 0.022%. Another indication demonstrates that, in this model, as urbanization increases, food security reduces by −0.170, −0.386, −0.026, and −2.704%. The study's results of 0.189, 0.023, and 0.005% indicate that the moderate effect positively impacts food security (see below Table 7).

Forecasting for the food supply

In addition to long-term estimates, predicting how each variable will interact with the food supply over the following 10 years is required. The current study uses the impulse response function and variance decomposition analysis to examine this phenomenon. However, there are two fascinating aspects to this study's predictions. First, it attempts to use other carefully chosen factors to account for variations in the food supply. Similarly, the Impulse Response Function (IRF) determines whether each variable's volatility extends to other variables. With these function styles, one can follow the effects of a shock on a variable's present and future values as well as IRF graphs 1. The graphic shows that the other variables respond to this innovation if a positive standard deviation shock is applied to a positive supply of food. In reaction, land usage can be seen to increase initially before declining, and over time, it is observed that there is a zigzag variation in the supply of food as a result of the shock to land use. Contrarily, the long-term effects of the energy shift cause the food supply to the rise first and then become static. When the agricultural value is added to the food supply, it initially has a favorable impact on the food supply, but over time, this effect becomes static. Additionally, the results demonstrate that innovation in the gross domestic product initially grows, decreases, and further improves food availability for the chosen panel. Finally, even though urbanization has changed significantly, there has been little alteration in the food supply. However, the response of each variable to others can be observed *via* the given diagram.

Figure 3 presents the outcomes of the Impulse Response Function (IRF) and shows the variation in dependent variables due to independent variables (see Figure 3 below).

We also used a different technique known as the variance decomposition approach to compare the extent of the impact the relevant variables provided to EFP. Table 8 contains the findings of this analysis. This analysis takes a 10-year horizon into account. The results for the selected economies showed that 90.47% of the variation in the food supply could be explained by shocks to innovation within the variable, while the respective contribution of land use is 0.7616%. Similarly, the energy transition, agricultural value-added, and economic growth contributions to the food supply are 2.5683 and 0.8375%, respectively. The findings also demonstrate that by considering these variables, 1.770% of the variation in urbanization can be explained by innovation shocks (see Table 8).

Pairwise granger causality test

Confirming a long-term correlation among the relevant variables points to a causal relationship in at least one direction. However, the estimates shown in Table 7 do not provide any details regarding the direction of the causal relationship between food availability and other relevant variables. The bi-direction causality between food supply and land use is discovered in the light of the presented finding. This suggests that significant land use changes would increase food availability and that a feedback hypothesis linking food availability to land use already exists. In other words, to achieve the targeted output level, the land use and food supply policies are coordinated. A unidirectional causal relationship between land usage and agricultural value added was discovered in addition to the feedback hypothesis. Whereas, there is no such thing as the feedback hypothesis. This suggests that land usage affects agricultural value significantly, although AVA does not account for this. Therefore, policymakers must concentrate on budget allocation to profitable land use. The hiring authority should reconsider their investment strategy and shift their funds to the urban, industrial, and other sectors that could impact the food supply level. Similar to this, there is a one-way causal relationship between the transfers from energy to food. For instance, despite the absence of the feedback theory, the energy shift in some economies has a considerable impact on food availability. Other recommendations include encouraging decision-makers to use renewable energy sources like solar energy in their operations. Thanks to this initiative, they can allocate their scarce resources to the agriculture sector and reduce production costs. Additionally, land use is impacted by the energy transition. Due to the cost reduction in the agricultural sector caused by clean, green energy, which would increase the food supply, this relationship may be justified using economic logic. Therefore, policymakers should reshape their land use and energy transition policies. The food supply and land usage are the final effects of urbanization in Granger. Table 9 shows the Pairwise panel granger causality test. Table 9 displays the results.

Figure 4 presents the graphical presentation of the pairwise panel granger causality test concerning Uni-directional and Bi-directional causality association among selected variables of this research study.

Discussion, conclusion, and policy recommendations

The main objective of this study is to analyze factors affecting food availability in particular economies for the years 2010–2019. The study runs a first-generation panel unit root tests to examine long-term relationships between selected variables for the chosen nations. The study uses FMOLS and DOLS estimators to create long-run co-integration parameters for estimations based on the validation of the co-integration relationship. Overall, the findings show a strong correlation between land use and food production. Food supply is also increased by the energy transition, GDP, and added agricultural values. Finally, urbanization has a minor but insignificant impact on the food supply. Besides, the main effect the current study also tries to investigate the moderate impact of energy transition on gross domestic product, land use and agricultural value added and finds the significant contribution to food supply. A pairwise panel causality test, the final step in the empirical application, identifies the type of link between the study variables. Therefore, there is a two-way causal relationship between the use of land and the availability of food. However, there is a one-way causal effect between the transition in energy to the availability of food and land use. Similarly, the selected economies have observed the one-way causality from urbanization to land use and food supply.

This study provides further research directions to examine the challenges of the COVID-19 crisis. The ongoing coronavirus disaster has developed health-related needs, harassment issues at workplace, economic crisis, energy consumption and food security challenges in the world (Asad et al., 2017; NeJhaddadgar et al., 2020; Aqeel et al., 2021; Azadi et al., 2021; Al Halbusi et al.,

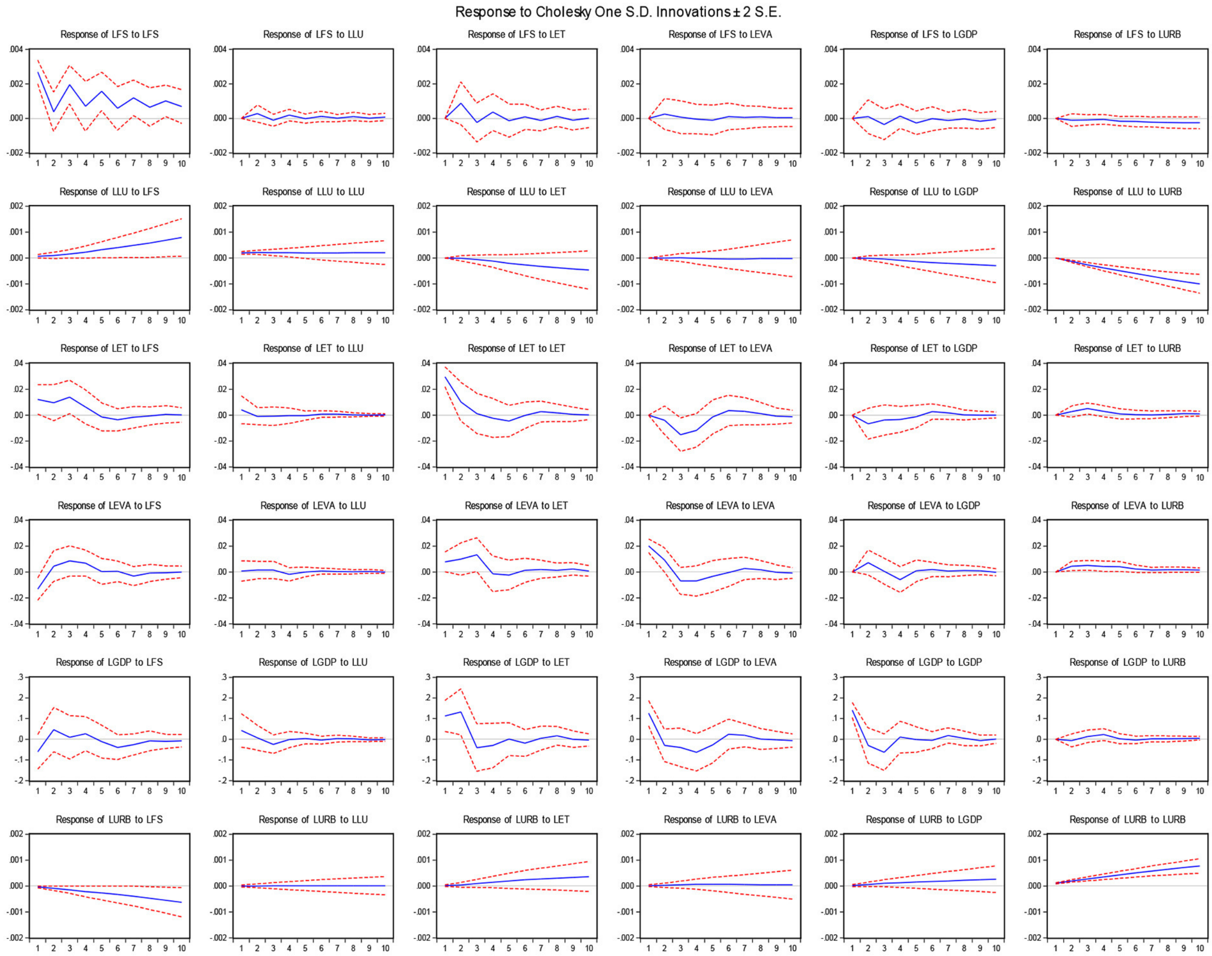

FIGURE 3
Forecasting *via* impulse response function.

TABLE 8 comes of variance decomposition analysis (VDA).

Variables	Periods	VDA					
		LFS	LLU	LET	LAVA	LGDP	LURB
LFS	10	90.47124	0.761606	2.568310	0.837516	3.591315	1.770015
LLU	10	26.88532	5.294953	3.480277	0.921127	10.18976	53.22856
LET	10	23.67384	0.952029	43.16075	5.889591	23.97065	2.353146
LAVA	10	21.81956	0.599988	14.01960	18.48056	38.43163	6.648648
LGDP	10	9.647273	2.656738	20.34030	4.031946	62.42581	0.897933
LURB	10	28.90125	0.007852	2.729349	0.843218	13.49708	54.02125

2022; Li et al., 2022b; Schmidt et al., 2022; Yao et al., 2022). The crisis has not only posed energy and food security issues, it has also posed questions to health systems performance, emotional sentiments, health priority, tourism activities challenges, and job stress among employees (Aqeel et al., 2021; Farzadfar et al., 2022; Geng et al., 2022; Li et al., 2022a; Zeidabadi et al., 2022). Survival in COVID-19 time remains the utmost priority of everyone that has raised concerns for corporate business strategy, women's entrepreneurial activities, and role of social media is important to cope with the crisis (Li et al., 2021; Aqeel et al., 2022; Ge et al., 2022; Mubeen et al., 2022; Yu et al., 2022; Zhang et al., 2022c). The COVID-19 crisis affected tourism industry,

TABLE 9 Pairwise panel causality test.

DV	Types of granger causality					
	Short run (lag)			Long run		
	ΔLFS	ΔLLU	ΔLET	ΔLAVA	ΔLGDP	ΔLURB
ΔLFS	-	8.74231 (0.001)	0.11107 (0.895)	2.92967 (0.070)	0.13801 (0.871)	0.19190 (0.826)
ΔLLU	22.1542 (0.000)	-	2.06691 (0.146)	3.06968 (0.062)	0.22146 (0.802)	0.13173 (0.877)
ΔLET	9.41055 (0.000)	7.08873 (0.003)	-	2.84810 (0.075)	4.34855 (0.024)	0.03253 (0.968)
ΔLAVA	2.30051 (0.119)	0.22808 (0.797)	0.18088 (0.835)	-	0.39495 (0.677)	0.14312 (0.867)
ΔLGDP	0.89960 (0.419)	0.18617 (0.831)	1.23453 (0.308)	1.14302 (0.335)	-	1.3688 (0.272)
ΔLURB	4.12965 (0.027)	987.511 (0.000)	0.23141 (0.795)	0.40691 (0.669)	1.55201 (0.231)	-

educational institutions, health systems, and increased suicidal behavior (Shoib et al., 2021; Su et al., 2021; Wang et al., 2021; Zhou et al., 2021; Fu, 2022; Rahmat et al., 2022).

The experts of anthropogenetic climate change prioritize food security systems at large in time and space (Connolly-Boutin and Smit, 2015). Climate change, growing unpredictability in rainfall, prolonged droughts, and unexpected heavy floods have posed severe threats to the energy transition, sustainable livelihood, and food security for global population segments (Sa et al., 2017). These unavoidable fluctuations require a systemic transition in human socioeconomic systems to develop sustainable paths (Wheeler and von Braun, 2013). Thus, all countries must develop systems to become low-carbon emissions or decarbonized economies (Ziervogel and Ericksen, 2010; Ajayi et al., 2022). It will help mitigate the effects of climate change to protect the environment (Hassan et al., 2022). The practical ongoing strategies make a helpful and successful transition in reducing the usage and production of fossil fuels to zero (Ajjur and Al-Ghamdi, 2022; Yoon et al., 2022).

Green energy for food security is essential, and energy transition influences food systems because it affects traditional energy use patterns worldwide. It significantly affects global food production in a society that depends on fossil fuels (Rosillo-Calle, 2016; Strapasson et al., 2017). Nevertheless, this energy transition might pose indirect social consequences. The social impacts include effects that are more significant across the rational distribution of adverse outcomes on sustainable land use, human livelihood, positive opportunities, and food security. The systematic energy transition can help decrease food security inequalities' that might influence prevailing food security systems by avoiding the resource-intensive model (Kline et al., 2016). In addition, "just energy transition" safeguards workers' livelihoods and the future of the communities in the energy transitions and secures a low carbon emissions economy. It involves social discourse between working employees, unions, government, employers' consultation with civil society and the communities (Evans and Phelan, 2016; Galgóczi, 2020). Energy transition also emphasizes energy systems decentralization, place importance, and priority needs to marginalized societies and communities (Neill et al., 2018; Heffron et al., 2021). Besides, a just energy transition pursues to promote environmental integrity, economic sustainability, wellbeing, and social resilience underpinned with solid and smooth processes of democratic governance. Thus, it accelerates the mapping of energy transition that safeguards reasonable outcomes that are justifiably aligned with economic and social development among communities, towns, societies, and affected regions.

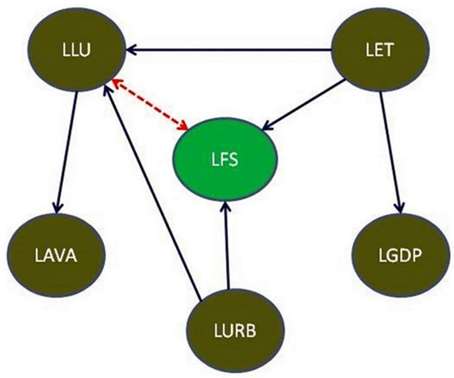

FIGURE 4
Pairwise panel granger causality test.

The study's empirical results lead to several insightful deductions that could have significant policy ramifications. In conclusion, while a shift in consumption from energy to food commodities may have detrimental effects on the energy sector, it may also advance the SDGs by improving food and energy security and fostering a cleaner, more sustainable production processes with minimum negative externalities. The international economy's production procedures have become more sophisticated over the last few decades. In production processes that have come to be known as "global value chains", each finished good now often embodies value added from many countries of origin, with this value-added frequently traversing multiple borders en route to its place of consumption. Traditional export statistics consequently provide less information on the pattern of production and income worldwide. Therefore, the cost of food goods should be minimized to boost the level of human wellbeing.

The bumper crops for the economy as a whole and food supply are still pending due to continuous shocks. Although we have provided changes to numerous variables that may impact both GDP and food security, we do not yet know what these changes will entail for the remainder of the year. We should remark that, in contrast to the prior research, which may not have expected that the effects of shocks would continue as long, our model's estimate of the land use and urbanization losses are considerable. Given our emphasis on food supply, we place a greater focus on supplying agriculture with the best available inputs, whereas the majority of the literature has been more concerned with manufacturing and services. It might be possible to combine these two strategies in future work. Given the rising global population or urbanization, adequate increases in food supplies are necessary. Food supply chain management and circular economy strategies for decreasing food waste are crucial to ensuring food security because agricultural land and natural resources are scarce. As a result, issues with non-usable excess food and food waste can also be linked to sustainability issues related to society, the environment, and the economy.

Limitation of the study

However, there are certain restrictions on the inferences from this study. First, the study uses data from institutions, which could contain measurement errors. Second, the empirical strategy uses FMOLS and DOLS estimators under some specific conditions, while other panel data techniques based on non-linear structures could be different results. Thirdly, although the food supply is used in this study to quantify food security, other food indicators may respond to the study variables differently. Consequently, new studies should be conducted by following various data with a wide period, estimation techniques that are newly developed or non-linear, new control variables, and more thorough measurements of food supply to confirm the validity of the findings obtained in this study and to reveal how food reacts to alternative determinants. The more interesting future gap this study does not consider in the empirical estimation is COVID-19 and its impact on food supply. As the pandemic spread across the globe, the strict lockdown and minimum economic activities were seen. Due to such initiatives, the demand for food items was increased in pandemic situation and as a result there seen the hyper-inflation across the economies. Therefore, economies have faced a food shortage and cannot cover this gap. Due to limited data, this study has not focused on this essential factor; hence, future studies must include this factor to investigate the variation in the food supply.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Appendix

Table A1 VIF test for multicollinearity.

Variable	VIF	1/VIF
LLU	7.27	0.1375
LET	2.67	0.3745
LURB	5.01	0.1996
LAVA	7.23	0.1383
LGDP	1.35	0.7432