Environment, Development and Sustainability (2024) 26:5689–5708
https://doi.org/10.1007/s10668-023-03032-3

REVIEW

Developing an analytical framework for estimating food security indicators in the United Arab Emirates: A review

Khalil A. Ammar[1] · Ahmed M. S. Kheir[1] · Beshir M. Ali[2] · Balan Sundarakani[2] · Ioannis Manikas[2]

Received: 12 June 2022 / Accepted: 10 February 2023 / Published online: 22 February 2023
This is a U.S. Government work and not under copyright protection in the US; foreign copyright protection may apply 2023

Abstract

Rapid population growth, climate change, limited natural resources, and the COVID-19 pandemic contribute to increased global hunger, necessitating intensive efforts to ensure food security and nutrition (FSN). Previous FSN approaches covered some dimensions, but not all, resulting in significant gaps in food security indicators. The Gulf Cooperation Council (GCC) and the Middle East and North Africa (MENA) regions have received less attention in food security studies, thus far necessitating considerable effort to develop an appropriate analytical framework. This study reviewed articles and international reports of FSN indicators, drivers and policies, methods, and models and extracted the challenges and gaps from the global and UAE contexts. The UAE and the world have gaps in FSN drivers, indicators, and methods, necessitating potential solutions to meet future challenges such as rapid population growth, pandemics, and limited natural resources. As a result, we created a newly developed analytical framework that addresses the shortcomings of previous approaches such as sustainable food systems developed by FAO and the Global Food Security Index (GFSI) and covers all aspects of food security. Gaps in knowledge in FSN drivers and policies, indicators, big data, methods, and models were considered in the developed framework, which has specific advantages. The novel developed framework addresses all food security dimensions (access, availability, stability, and utilization), ensuring poverty reduction, food security, and nutrition security while outperforming previous approaches (i.e., FAO and GFSI). The developed framework could be used successfully not only in the UAE and MENA, but also, globally, helping to solve food insecurity and malnutrition for future generations. The scientific community and policymakers should disseminate such solutions to address global food insecurity and ensure nutrition for future generations in the face of rapid population growth, limited natural resources, climate change, and spreading pandemics.

Keywords Food security dimensions · Indicators · Models and methods · Drivers and policies · Gaps · Novel analytical framework

✉ Ahmed M. S. Kheir
a.kheir@biosaline.org.ae

[1] International Center for Biosaline Agriculture, ICBA, Dubai, UAE

[2] Faculty of Business, University of Wollongong in Dubai, Knowledge Park, Dubai 20183, UAE

Abbreviations

FSN	Food security and nutrition
GCC	Gulf Cooperation Council
MENA	Middle East and North Africa
GFSI	Global Food Security Index
FS	Food security
CAGR	Compound annual growth rate
WOS	Web of Science
IoT	Internet of Things
IEEE	Institute of Electrical and Electronics Engineers
SC	Supercomputing
CC	Cloud computing
AgBD	Big data of agriculture
FI	Food insecurity
POU	Prevalence of undernourishment
BMI	Body mass index
PCI	Proteus Composite Index
FIES	Food Insecurity Experience Scale
VFS	Vertical farming systems

1 Introduction

Food security (FS) is regarded as one of the most important issues globally, as it represents a country's level of self-sufficiency and the well-being of its population (Clapp, 2017). Even before the Covid-19 pandemic, the world has failed to meet its goal of ending hunger by 2030. The current pandemic situation and related measures have increased the number of challenges to ending hunger (Hodson, 2017). However, they have also emphasized the need for further in-depth consideration of properly addressing the key drivers of the current global food insecurity and malnutrition situation (Jerzak & Śmiglak-Krajewska, 2020; Pawlak & Kołodziejczak, 2020). The sustained drop in world hunger that began in 2005 ended in 2014. Economic expansion, population increase, and urbanization boost global food demand (Halloran et al., 2014). Compared to current food demand, future demand is expected to increase by 60% by 2050 (Alexandratos and Bruinsma 2012, Asseng et al., 2018). The current population growth rate is accelerating, and it is expected to exceed 9.0 billion people by 2050, requiring attention to increase food production by at least 70% to combat the demand (Godfray et al., 2010; Röös et al., 2017, Fróna, Szenderák et al. 2019). Despite dramatic increases in total production over the last half-century, one out of every seven people today suffers from protein, energy, and micronutrient malnutrition (FAO., 2009). Due to increased competition for soil, water, and energy, negative environmental impacts of food production have increased, posing new challenges to food producers (Tilman et al., 2001, Assessment. 2005). The major challenges facing global food security are matching the larger food demand resulting from affluent population growth, sustainability of social and environmental issues, and ensuring that the world's poorest people never face starvation (von Braun, 2007). This problem necessitates changes in how food is produced, stored, processed, delivered, and accessed, comparable to those seen during the eighteenth- and nineteenth-century industrial and agricultural revolutions and the twentieth-century Green Revolution. Increasing production could be a significant key to addressing such challenges, but it faces unprecedented constraints due to finite atmospheric, land, and marine resources (Conway 1997).

Current challenges include rapid population growth, limited freshwater resources, expanded urbanization, and the conversion of agricultural activities to other industrial and commercial activities (Godfray et al., 2010; Kumar & Kalita, 2017; Rosegrant Mark & Cline Sarah, 2003). In addition, the significant increase in crop productivity to meet the huge food requirements has caused environmental impacts such as changing climate and desertification (Schmidhuber & Tubiello, 2007; Stone & Rahimifard, 2018; Wheeler & von Braun, 2013).

The Middle Eastern and North African (MENA) regions are home to a diverse range of countries. They range from low-income and least-developed countries (such as Sudan, Mauritania, and Yemen) to high-income, well-developed oil exporters (e.g., the UAE, Qatar, and Saudi Arabia) (Araujo-Enciso & Fellmann, 2020). The MENA region consists of 18 countries, including the UAE, and only 15 of these are participated in the Global Food Security Index. Despite their differences in general economic advancement levels, they all share several traits. One of the most prominent characteristics is the country's substantial and growing reliance on fundamental food imports, such as wheat. Due to a lack of natural resources, agricultural infrastructure, a dry environment, and a population rising faster than the global average, the MENA area is considered the world's greatest wheat importer (Araujo-Enciso & Fellmann, 2020). In addition, the MENA region's limited water resources have a significant impact on food stability, food security, and nutrition. The dry climate affects water quality and supply, surface and subsurface water availability, and water resource management (Zscheischler et al., 2020). The climate of the United Arab Emirates is hot and arid, posing significant challenges to food security. The UAE's strong economic position and political stability, on the other hand, are important factors in the country's current food security situation.

Due to the scarcity of arable land, water, and a high reliance on imported food, FS has become a top policy priority for the UAE (Wam., 2017). Despite importing 80–90% of its food, the UAE is considered food secure because of its ability to buy food on the international market, albeit at higher prices (Malek. & Caline., 2015). Nonetheless, FS remains a big challenge, particularly in the long term, due to production and import constraints (House. 2013). The significance of focusing on FS policy increased in 2007 when the UAE struggled to procure essential foodstuffs due to rising global food costs (Security 2016). Food costs in the UAE are rising and will only increase further if Value-Added Tax (VAT) is implemented (Deulgaonkar, 2017). Good diplomatic and trade connections, easy access to trade markets, and well-functioning trade ports have made food import methods possible.

However, the UAE confronts various difficulties that will likely continue to endanger food security in the future. The UAE's most obvious difficulty is the harsh climate. This sets it apart from many other food-secure countries. Water availability is highly limited, and agricultural output is challenging due to desalination dependency. The strengths, difficulties, possibilities, dangers, and potential solutions to the UAE's food security are discussed in the sections below. However, the UAE is vulnerable to changes in food and oil prices because of its lack of economic diversification and reliance on fossil fuels to pay for its food imports (House. 2013). Food subsidies are necessary to make food affordable because food imports are also expensive. Higher food prices due to supply disruptions do not pose a direct threat to the UAE because they can currently finance the risks. Still, any economic shocks would immediately impact food availability and affordability. If people are unwilling or unable to pay the costs, rising domestic food prices may represent a political risk. If subsidies are eliminated, some people might find it difficult to afford food due to rising living expenses. Rising food demand, as well as increasingly diverse and globalized eating tastes, exacerbates these issues. Food consumption in the Gulf Cooperation Council (GCC) is expected to grow at a compound annual growth rate (CAGR) of 4.2%, from a projected 48.1 million MT in 2016 to 59.2 million MT in 2021 (Capital. 2017). A rise in "lifestyle diseases," such as diabetes and obesity, has been attributed to changing and increasingly globalized diets and sedentary lifestyles. Nonetheless, addressing the main drivers and policies, indicators, and gaps for food security has received less attention thus far, not only in the UAE but also globally, necessitating further research.

During the examination of the literature, it was found that there is an absence of research that systemically evaluates and provides policy recommendations that could improve food security in the UAE. Therefore, there is a need to identify the major drivers, indicators, big datasets, models and methods (Ali et al., 2020, Kheir, Alkharabsheh et al. 2021, Kheir et al., 2022), and requirements to transform food security systems in a realistic, logic, systematic, and rigorous manner through analyzing current literature on the subject. Therefore, this review aims to investigate the status, key challenges, and potential solutions to food security in the UAE and globally by critically examining the four dimensions of FS. Furthermore, previous approaches to FS did not cover all dimensions, which prompted us to develop a new analytical framework to fill the gaps left by such approaches.

2 Methods

This study aimed to identify the major drivers, indicators, methods, and challenges of FS worldwide and explore their benefits to enhance it in the UAE context by developing an appropriate analytical framework for food security. We used the approach described by (Tranfield et al., 2003) to ensure the least bias when screening published peer-review papers. Furthermore, it was necessary to identify, analyze, and synthesize the selected secondary data sources related to food security in various contexts. While conducting the literature review, this paper considers both the (Tranfield et al., 2003) approach, which includes the three steps of planning, conducting, and reporting/disseminating, and the (Brocke, Simons et al. 2009) approach. However, to enhance the research process, (Denyer & Tranfield, 2009) used a five-step guideline to conduct a literature review. These steps include formulation of a review question, locating relevant literature, selection and evaluation of relevant literature, analysis and synthesis, and application of the findings. According to (Tranfield et al., 2003), detailed documentation was provided to ensure the transparency and replicability of this systematic literature review. The research began by formulating different and specific questions to ensure the purposes and to define the scope of the review. The purpose of this study is to conduct a literature review to identify the key factors that influence FS globally and within the context of the United Arab Emirates. This study provides a critical review of the existing literature published in Scopus and Web of Science (WOS) databases to answer the main research questions. Therefore, we reviewed, analyzed, and summarized the scientific evidence from 1350 food security-related articles (Supplementary Tables 1, 2, and 3). The review used four stages to select the most relevant articles: identification, screening, eligibility, and inclusion (Fig. 1). The first stage involved identifying sources for 1500 documents by searching databases and other sources. During the screening process, we excluded the duplicates (100 documents). Then, through the eligibility process, we assessed and chose the best full texts (1350) while excluding non-significant articles (50). Consequently, about 1350 studies were included in the review's

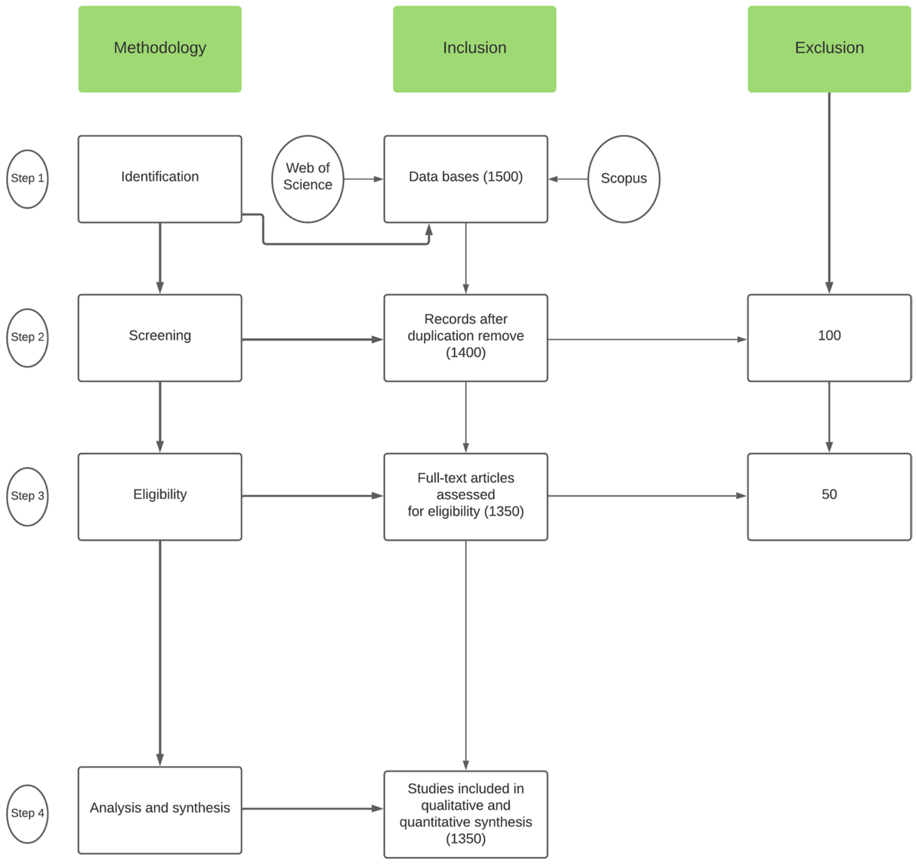

Fig. 1 Preferred reporting items for systematic reviews and meta-analysis flow diagram

qualitative and quantitative synthesis, out of a total of 750 documents (Fig. 1). The following keywords were used to cover the research objectives: food security, food insecurity, food availability, food access, food utilization, food stability, agri-food supply chain, UAE food, MENA food, sustainable supply chain, resilient supply chain, food safety, food diversity, food quality, food standards, micronutrient availability, agricultural infrastructure, agricultural production volatility, vulnerability assessment, food loss, food waste, policy recommendation, nutrition security, nutrition insecurity, big data, FS models and methods, gaps, limitations, multi-model ensemble, analysis, and visualization. Only English-language peer-reviewed journal articles were considered. Another round of retrieval was performed with a set of secondary keywords to narrow the search in specific areas of food security.

3 Results and Discussion

3.1 Big data, methods, and models required for FNS studies

Global hunger has increased as a result of dietary changes, low income, and population growth (Janssens et al., 2020). Clean air, water, and productive land are necessary to sustain growing food production, but they are all in jeopardy (Wunderlich & Martinez, 2018). Therefore, big data (BD) of food security and nutrition needs to be explored and analyzed (Jin et al., 2020, Ammar, Kheir et al., 2022). Because BD is frequently produced at a high rate from various sources, new tools and techniques must be developed to handle it, such as potent processors, algorithms, and software (Marvin et al., 2017). There are some examples of data sources which include but not limited to online database, omics, the internet, sensors (Bouzembrak et al., 2019), mobile applications, social media, video monitoring (Subudhi et al., 2019),Internet of Things (IoT) (Pal & Kant, 2019), GIS and RS (Strawn, Brown et al.), survey (Delphi rounds), and blockchain technology (George et al., 2019, Shaikh, Butala et al.2019). Based on availability, the type of data needed, the proximity of the experts, and the scientific background, these sources vary by region.

Moreover, the overpopulation trend and rising food demand require using fast, digital data sources to ensure FS dimensions and measurements (Fritz et al., 2019). However, these sources still require considerable attention worldwide for use in various environments and cultures. Consequently, stakeholders identified five key challenges impeding the effectiveness of agri-food systems collaboration (OECD., 2021): (1) a lack of political visibility and prioritization; (2) a lack of long-term investment in statistics and data; (3) a lack of configuration and issues of political economy; (4) a lack of new technologies and capacity building skills; and (5) limited access to recent data sources. The supplementary file contains more information about the global data sources and their relationships with FS dimensions.

Unfortunately, it was discovered that there has been a significant gap in the gathering and analysis of large data sources in the case of the UAE. Additionally, there is a lack of long-term investment in data statistics, digital proficiency, and adequate data in science, technology, engineering, and mathematics (STEM). The UAE was found to lack access to big data, stability, and utilization of FS-based methods and models. In order to quantify the related gap and offer policy recommendations to close it, a systematic review of the literature is needed to identify the detailed background of big data, methods, and models on a global and regional scale. As a result, this section showcases the screening of big data, techniques, and models for FS and. Thus, this section discusses the screening of BD, methods, and models for FS on a global and local level and focuses on related issues and potential solutions in the UAE.

3.2 Big data for Food Security

3.2.1 Literature search

The literature for this review was collected on the period (2010–2020) from four main databases: Google Scholar, Science Direct, Institute of Electrical and Electronics Engineers (IEEE), and Scopus. Different groups of search terms were used to improve the accuracy of the search results, yielding a total of 500 papers, of which 130 were relevant (i.e., dealing with big data, methods, and models in FS) and used for this review.

3.2.2 Tools of extracting data (Global and UAE contexts)

The literature shows that different sources of data extraction include online databases, smartphones, the internet, sensors, omics, social media, IoT, GIS, satellite images, web mining, FAOSTAT, governmental dataset, statistical yearbooks, and blockchain technology (Strawn, Brown et al., Bouzembrak et al., 2019; George et al., 2019; Marvin et al., 2017; Pal & Kant, 2019; Subudhi et al., 2019). Online databases are widely used in food safety (Jin et al., 2021; Marvin et al., 2017), covering only one dimension of FS (utilization) and neglecting other dimensions. More information about these tools can be found in the supplementary file.

3.2.3 Infrastructure and format of data

Food security data can be stored in various formats, such as txt, JSON, and CSV, even they are unstructured or structured. For example, (Singh et al., 2018) extracted social media data from Twitter in JSON and txt formats and then implemented the parsing method to convert JASON data to CSV data. On the other hand, (Song et al., 2020) stored data in related database with various attributes as rows. Alfian et al. (2017) used NoSQL and SQL databases to store IoT-generated sensor data from the gateway, with unstructured data and continuous generation characteristics. They also created real-time food quality data using smartphone sensor data and stored it in the MongoDB database.

Supercomputing (SC) and cloud computing (CC) are major data infrastructure components. SC has become an urgent tool to address BD limitations. Improving supercomputing infrastructure is also a priority for the EU. The EU has built eight supercomputing centers as of June 2019 to support bioengineering, drug design, forecasting, and climate change applications (https://ec.europa.eu/digital-single-market/en/news/).

Several CC infrastructures have been developed to enable big data research. To integrate European Research Infrastructure in 2019, the EU Food Nutrition Security Cloud project brought together FNS data to address diet, health, consumer behavior, sustainable agriculture, and the bioeconomy (https://cordis.europa.eu/project/id/863059). The MENA and GCC regions are still not interested in using supercomputing and cloud computing infrastructures as separate big data environments, despite the significance of big data. This requires serious attention to help them address food insecurity. To integrate European Research Infrastructure in 2019, the EU Food Nutrition Security Cloud project brought together FNS data to address diet, health, consumer behavior, sustainable agriculture, and the bioeconomy.

3.2.4 Potential, current, and limitations of agricultural big data

In order to meet demand, agricultural production and food supply chains must be optimized through the production and delivery of effective food, feed, fiber, and fuel (Abe 2017). Urbanization, climate change, and water scarcity make this goal more difficult (Ahmed et al., 2022; Ejaz et al., 2022). Big data of agriculture (AgBD) will be considered the key factor of the Second Green Revolution, required to meet these demands. Many countries and commodity markets have already used AgBD sets to detect supply chain disruptions in commodity crops such as wheat, rice, corn, and soybeans (George Hanuschak, 1993; Rosenzweig et al., 2013, Bock and Kirkendall 2017). Precision agriculture has progressed due to advancements in RS data collection, such as enhanced temporal, spatial and spectral resolution, and different sensor platforms (e.g., satellite, aerial, ground-based), among other things (Mulla, 2013). Precision agriculture has recently demonstrated a significant increase in crop yield production (Loures, Chamizo et al.2020, Singh, Pandey et al. 2020). In addition, the AgBD can be used with spatial data mining techniques to identify crops grown in small geographic areas or groups of regions that are vulnerable to climate change and natural disasters (Vatsavai, Ganguly et al. 2012, Shekhar et al., 2015; Jiang & Shekhar, 2017, Xie, Eftelioglu et al. 2017).

The AgBD could help agricultural decision-makers through descriptive, prescriptive, predictive, and proactive ways (Shekhar, Colletti et al. 2017). The goal of the descriptive axis is to use AgBD data to differentiate temporal and spatial variability in land cover, soil characteristics, plant growth, and weather forecasting and identify stressors, traits, and infectious disease risk factors that need to be better managed. The prescriptive method is to look for the required innovations for farm management. The predictive axis is a predictive analysis that forecasts outcomes such as crop yields and food insecurity using historical datasets and integrated soil, crop, weather, and market models. Predictive analytics can also help forecast the spread of infectious agents and limit their impact on crops and livestock. Finally, crop development and stress observations from multiple farms across large regions and time scales were included in the proactive analysis.

The current state of agricultural big data can be divided into public and private. Some examples of public agricultural big data are summarized in Supplementary Table 2. Big data differs from region to region based on various factors, including but not limited to the data availability, capacity building, and target of the study. Exploring sustainable food security requires detailed data covering all aspects of FS, putting pressure on decision-makers and scientists to initiate and prepare the necessary big data. The big data paradigm should employ techniques, paradigms, and decision-making technologies to fill this void, as illustrated in S. Figure 1.

4 Food systems' transformation to FSN

Many food systems have been used to combat food insecurity over the past decades. Still, population growth and the recent COVID-19 pandemic have rendered food systems incapable of providing safe and nutritious food to the entire world's population. Furthermore, the current global population consumes high energy, sugar, fats, and salts' diets (Baker, Machado et al. 2020). As food systems are unable to provide sufficient nutritious feed to households, particularly with the emergence of the COVID-19 pandemic, the transformation of food systems to FSN has become an urgent need to ensure safe health diets and affordable foods for all (). Consequently, there has been a recent debate among regional and global communities about addressing challenges to sustainable development, particularly those related to food insecurity, hunger, and malnutrition, by 2030. This transformation necessitates innovative systemic changes, which must be accompanied by collaboration between institutions, policies, laws, regulations, and investments that have a common and complementary goal (I.G.S., 2019, Baker, Machado et al. 2020). Based on previous case studies worldwide, we developed policy recommendations for food system transformation to make them more resilient to the major drivers of food security and nutrition.

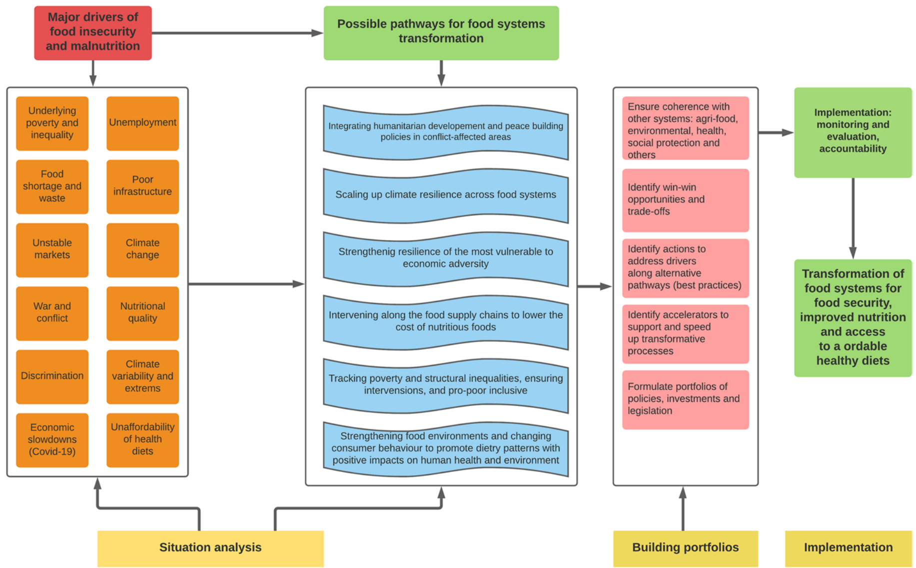

Fig. 2 Framework of food systems transformation in food security to enhance nutrition, and access to a fordable healthy diet

We summarized the analytical framework of food system transformation based on previous case studies, new FAO reports, and policy recommendations from the scientific community (Fig. 2). This figure depicts the guide steps in the overall process of transforming food systems to address the major drivers of food insecurity, malnutrition, and the affordability of healthy diets for all. This transformational approach requires three major steps: in-depth situation analysis, coherent portfolios, and portfolio implementation. Based on available data and information, the situation analysis includes the major drivers that negatively impact food systems and potential pathways for food system transformation (UNICEF., 2019, Initiatives. 2020, IPC., 2021). Stakeholders can determine the necessary changes to the food system for the transformation based on evidence about the drivers' impacts on food insecurity and malnutrition. A multi-stakeholder consultation is also used to identify the country's relevant policy, investment, and governance environments, considering the most important institutions and political economy issues. This helps determine which food system transformation pathways are most appropriate in each situation. Coherence and other relevant systems are necessary for transformational processes facilitation.

5 Challenges and gaps

The knowledge gaps related to FS indicators, big data, models and methods, and drivers and policies from the UAE and the literature perspective are summarized in S. Figure 3. Based on the findings of a systematic literature review on FS indicators, big datasets, methods, and models, we identified knowledge gaps in the literature (global context) and the UAE context. The global and regional gaps of such components were determined using the FS dimensions and components. The sections that follow present the identified knowledge

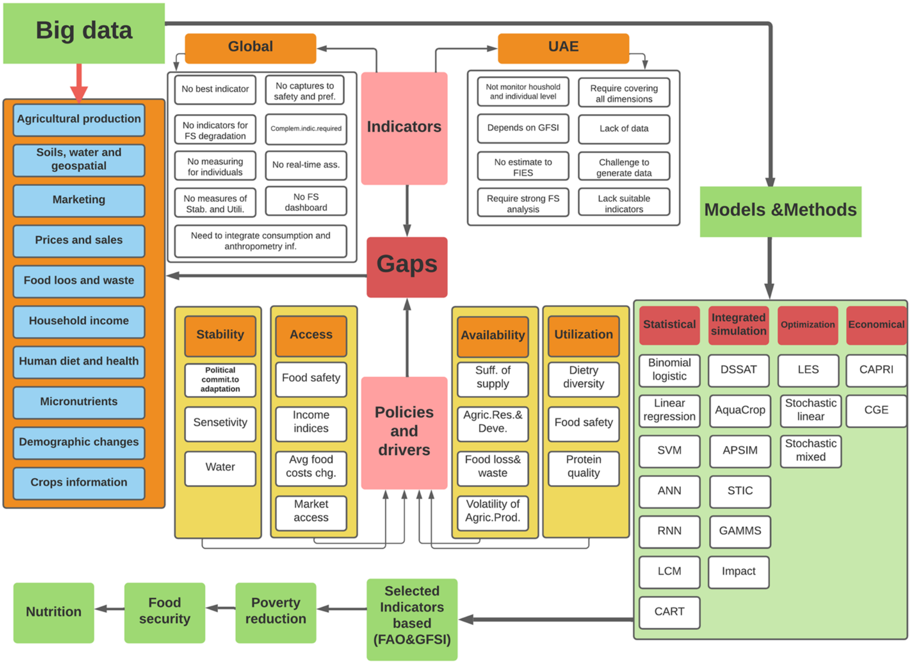

Fig. 3 A developed analytical framework for food security and nutrition (own elaborations by authors)

gaps in FS measurement (indicators), big data sets, models, and methods for both the global and UAE contexts.

5.1 Gaps related food security indicators (global and UAE contexts)

Food Consumption Score, Household Food Insecurity Access Scale, Prevalence of Undernourishment and Food Insecurity Experience Scale, and Global Food Security Index are some of the FS indicators used by different international organizations. Despite calls for harmonization, the scientific community, governments, and practitioners cannot agree on a single "best" FS indicator for measuring, analyzing, and monitoring FS (Caccavale & Giuffrida, 2020; Carletto et al., 2013). The Scientific Group for the United Nations Food Systems Summit recently stated that current food insecurity (FI) early warning systems lack suitable indicators for monitoring food system degradation. The group noted that the existing FS measurement practices were once again exposed by the COVID-19 pandemic, highlighting the weaknesses of current FS measurement systems (Bisoffi, Ahrné et al. 2021). As a result, the Johns Hopkins University and the Global Alliance for Improved Nutrition, in collaboration with other organizations, including the FAO, have recently launched a Food Systems Dashboard (https://foodsystemsdashboard.org/) to track food systems around the world (Fanzo et al., 2020). Although the dashboard is also accessible in the UAE, some of the indicators used to measure the various components of the food system (including FS) are not “valid” indicators, and the data available are also outdated (https://foodsystemsdashboard.org/countrydashboard). For example, the dashboard uses the FAO’s prevalence of undernourishment (POU) indicator to measure FS in the UAE, which is a poor national level measure of FS as described in D1. Data on child anthropometry measures (stunning, wasting, and underweight) are not available in the dashboard for the UAE, unlike most other countries. An ideal FS indicator should capture all four FS dimensions (availability, access, utilization, and stability) and components (quantity, quality, safety, preference/cultural acceptability) at the individual level, according to the 1996 World Food Summit definition. However, most existing FS indicators in the literature are food access measures at the household level. When measuring FS, the food utilization and stability dimensions are rarely captured. At the national and individual levels, only a few composite indicators and anthropometry measures can be used to capture food consumption. Furthermore, anthropometry measures that are widely accepted and used are indicators of nutritional outcomes in children under the age of five. There are no universally accepted anthropometry measures for adults and children over the age of 5 years (although some studies use body mass index (BMI) as a nutritional outcome indicator for adults). The stability dimension, on the other hand, can be captured at the national level by estimating FS indicators over time or using composite indicators like the Global Food Security Index (GFSI), Suite of FS Index, and the Proteus Composite Index (PCI) (Caccavale & Giuffrida, 2020), which directly measure food stability. It is difficult to figure out which dimensions, components, or levels of FS, the various indicators are supposed to reflect because there are so many in the literature. Furthermore, because the different types of FS indicators used in the literature (experience-based, dietary diversity, calorie adequacy, coping strategy, and anthropometry measures) reflect different aspects of FS, there are inherent trade-offs when choosing one type of FS indicator over another (Upton et al., 2016). As a result, most used indicators can be thought of as complements rather than replacements for one another. Following that, estimating a set of complementary FS indicators over time is required for a comprehensive FS analysis at the individual, household, and national levels (analyses of FI prevalence, drivers/determinants, monitoring, early warning) (ideally using near real-time data). One of the knowledge gaps related to FS measurement is the selection of complementary FS indicators, taking data availability, the goal of FS measurement, and other factors into account.

Several countries track their citizens' food security by calculating the prevalence of household-level food insecurity (FI) (on top of prevalence estimates published by different international agencies such as FAO and EIU). For example, the experiential Household Food Security Survey Module indicator (Bickel, Nord et al. 2000) is used in the USA and Canada to estimate the prevalence of FI and to monitor household-level FS on an annual basis. Similarly, Latin American and Caribbean countries use the Latin American and Caribbean Household Food Security Scale to monitor household-level FS annually. The UAE, on the other hand, does not track FS at the household or individual level, instead estimating the prevalence of FI annually using data from a nationally representative sample. The Ministry of Food Security uses the EIU's Global Food Security Index (GFSI) to track the UAE's food security at a national level. The GFSI is a relative measure of FS that focuses on the causes/drivers of FI rather than citizens' FS status or nutritional outcomes (Izraelov & Silber, 2019).

The POU estimates for the UAE are also published by the FAO as a three-year average. The Food Insecurity Experience Scale (FIES) (an experience-based measure of the prevalence and severity of FI at the individual level) has been used in over 140 countries since 2014, but not in the UAE. Because FAO publishes FIES estimates for over 100 countries worldwide, the UAE would be able to compare its FI situation to that of other countries. As a result, the UAE must identify a set of complementary FS indicators that can be reliably estimated over time to conduct a comprehensive FS analysis (prevalence, drivers, monitoring, and early warning), ideally at the individual level. The most difficult aspect of FS measurements and analyses is consistently obtain the relative dataset at the household and individual levels (de Haen et al., 2011). Measuring a high frequency and consistency of FS at the individual level over time (e.g., quarterly rather than annually) allows for better food security analysis and monitoring. A national approach to measurement is less informative for decision-making when compared to a household annual FS measure. Because of the interdependence of food, nutrition, health, consumption, and income, anthropometry and food consumption integration is proposed as a key to addressing the FS measurement data-related challenge (de Haen et al., 2011). Although several data sources (e.g., FAOSTAT, World Bank) can be used to analyze and monitor the UAE's FS progress at a national level, there is a scarcity of data for measuring FS at the household or individual level. Integrating food consumption (intake, expenditure, diet diversity) and anthropometry data into the UAE's regular household living standard surveys allows for the collection of complete and consistent data that allows for a comprehensive FS measurement and analysis, which is currently a knowledge gap in the UAE.

6 Development of analytical framework

Many studies on food security and nutrition have been conducted worldwide, but none have addressed all aspects of food security (i.e., availability, access, stabilization, and utilization). Furthermore, population growth and the COVID-19 pandemic necessitate a greater focus on food system transformation to ensure food security and nutrition. The United Arab Emirates (UAE), a hyper-arid region, is under-researched in terms of food security and nutrition drivers, data, methods, and indicators. These factors require non-traditional solutions to address global and regional food insecurity. Potential solutions arise based on previous research and identification of global and regional gaps in FNS. These could include developing an appropriate analytical framework, disseminating vertical farming (Asseng et al., 2020, van Delden, SharathKumar et al. 2021), and assessing the implications of new technologies for future food systems (Asseng et al., 2021). The previous analytical framework of food security and nutrition, such as the sustainable food system approach (SFS) (FAO., 2018) and the Global Food Security Index approach (GFSI., 2019), did not cover all gaps and dimensions in food security, requiring substantial updates.

Using the advantages of both approaches and considering the knowledge gaps, we developed an analytical framework to ensure that all dimensions and components of food security and nutrition were covered (Fig. 3). The SFS is a food system that ensures food security and nutrition for future generations by providing food security and nutrition while also ensuring the economic, social, and environmental foundations for future generations' food security and nutrition. Thus, the FW framework incorporates poverty alleviation, food security, and nutrition. These are embedded in the overall system performance, referring to the three dimensions of sustainability (i.e., economic, social, and environmental). On the other hand, the 2019 GFSI includes new metrics and indicators not included in previous editions. The GFSI is a comprehensive assessment of a country's food system that considers the ability to supply enough calories to the population and how the food system is affected by factors such as political stability and climate threats. The current index includes new information and data on critical metrics, such as agricultural infrastructure and nutritional standards. It also includes a deeper understanding of the relationship between food security and climate innovation and index trends and results. Big data; policies and drivers; FS indicators; gaps from policies, drivers, and indicators; and models and methods are all part of the developed analytical framework. The identified gaps in FS policies, drivers, and indicators aided in the enhancement of big data, which was then used as inputs for the corresponding methods and models. We can derive the selected indicators that will lead to poverty reduction, food security, and nutrition from methods and model analysis. Using the existing data in UAE and with help of methods and models, we can identify the yield gap of the strategic crops currently or even under future climate change, contributing to estimating new and more meaningful indicators for food security and nutrition in UAE. Furthermore, the developed analytical framework could be used to predict future scenarios of yield gap and water use under variable conditions such as climate change, wars, political instability, embargo, and groundwater depletion. In addition to the developed analytical framework, vertical farming can produce food in a climate-resilient way, using fewer pesticides and fertilizers and less land and water than traditional agriculture. Vertical farming systems (VFSs) are resilient food systems that can meet daily consumer demands for nutritious fresh products, especially in and around densely populated areas. While there are limited water and arable land resources in the UAE, the spread of VFS as multi-layer indoor crop cultivation systems and automation, robotics, system control, and environmental sustainability could help address food insecurity quickly. To ensure successful upscaling of VFS to future food systems, research and development, socioeconomic, and policy-related institutions must collaborate. The scientific community and policymakers should disseminate integration of such solutions to address global food insecurity and ensure nutrition for future generations in the face of rapid population growth, limited natural resources, climate change, and spreading pandemics.

7 Conclusion

Given the importance of the current study, less attention has been paid to developing an appropriate analytical framework for food security in hyper-arid environments such as the UAE. To create the food security analytical framework, it is necessary to identify the major drivers and policies, indicators and big data, methods, and models. In the developed analytical framework, we identified knowledge gaps in drivers, indicators, and big data, as well as methods and models for food security. Furthermore, we integrated two previously used approaches for food security, FAO and GFSI, so that the developed framework avoided the limitations achieved by each approach individually. The newly developed framework addresses all food security dimensions (access, availability, stability, and utilization), ensuring poverty reduction, food security, and nutrition security while outperforming previous approaches. Despite the fact that the work has produced an excellent framework for identifying data sources, the challenge is to apply the analytical framework to real-time data, databases, methods, and models.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10668-023-03032-3.

Acknowledgements The research was funded by Ministry of Education, the UAE through the Resilient Agri-food Dynamism through Evidence-Based policies—READY project (No. UOWD.01_UOWD READY). We would like to thank Editage (www.editage.com) for English language editing.

Declarations

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

References

Abe, N. (2017a). Data science for food, energy and water. A Workshop Report ACM SIGKDD Explorations Newsletter.

Ahmed, M., Hayat, R., Ahmad, M., ul-Hassan, M., Kheir, A. M. S., ul-Hassan, F., ur-Rehman, M. H., Shaheen, F. A., Raza, M. A., & Ahmad, S. (2022). Impact of climate change on dryland agricultural systems: a review of current status, potentials, and further work need. *International Journal of Plant Production, 16*(3), 341–363.

Alexandratos, N., Bruinsma, J. (2012). World Agriculture Towards 2030/2050: the 2012 Revision. ESA Working Paper, Nr.12–03. : FAO, Rome

Alfian, G., Syafrudin, M., Rhee, J. (2017). Real-time monitoring system using smartphone-based sensors and NoSQL database for perishable supply chain. Sustainability **9**(11).

Ali, M. G. M., Ibrahim, M. M., El Baroudy, A., Fullen, M., Omar, E.-S.H., Ding, Z., & Kheir, A. M. S. (2020). Climate change impact and adaptation on wheat yield, water use and water use efficiency at North Nile Delta. *Frontiers of Earth Science, 14*(3), 522–536.

Allen, T., Prosperi, P., Cogill, B., Padilla, M., & Peri, I. (2019). A delphi approach to develop sustainable food system metrics. *Social Indicators Research, 141*(3), 1307–1339.

Amede, T., & Delve, R. J. (2008). Modelling crop–livestock systems for achieving food security and increasing production efficiencies in the ethiopian highlands. *Experimental Agriculture, 44*(4), 441–452.

Ammar, K. A., Kheir, A. M. S., & Manikas, I. (2022). Agricultural big data and methods and models for food security analysis—A mini-review. *PeerJ, 10*, e13674. https://doi.org/10.7717/peerj.13674

Araujo-Enciso, S., & Fellmann, T. (2020). Yield variability and harvest failuresin russia, ukraine and kazakhstan andtheir possible impact on food securityin the Middle East and North Africa. *Journal of Agricultural Economics, 71*(2), 493–516. https://doi.org/10.1111/1477-9552.12367

Asseng, S., & Asche, F. (2019). Future farms without farmers. *Science Robotics, 4*(27), eaaw1875.

Asseng, S., Guarin, J. R., Raman, M., Monje, O., Kiss, G., Despommier, D. D., Meggers, F. M., & Gauthier, P. P. G. (2020). Wheat yield potential in controlled-environment vertical farms. *Proceedings of the National Academy of Sciences, 117*(32), 19131.

Asseng, S., Kheir, A. M. S., Kassie, B. T., Hoogenboom, G., Abdelaal, A. I. N., Haman, D. Z., & Ruane, A. C. (2018). Can Egypt become self-sufficient in wheat? *Environmental Research Letters, 13*(9), 094012.

Asseng, S., Palm, C. A., Anderson, J. L., Fresco, L., Sanchez, P. A., Asche, F., Garlock, T. M., Fanzo, J., Smith, M. D., Knapp, G., Jarvis, A., Adesogan, A., Capua, I., Hoogenboom, G., Despommier, D. D., Conti, L., & Garrett, K. A. (2021). Implications of new technologies for future food supply systems. *The Journal of Agricultural Science, 159*(5–6), 315–319.

Assessment., M. E. (2005). Ecosystems and Human Well-Being (World Resources Institute. Washington **DC**.

Baker, P., P. Machado, T. Santos, K. Sievert, K. Backholer, M. Hadjikakou, C. Russell, O. Huse, C. Bell, G. Scrinis, A. Worsley, S. Friel and M. Lawrence (2020b). Ultra-processed foods and the nutrition transition: global, regional and national trends, food systems transformations and political economy drivers. Obesity Reviews **21**(12).

Baker, P., P. Machado, T. Santos, K. Sievert, K. Backholer, M. Hadjikakou, C. Russell, O. Huse, C. Bell, G. Scrinis, A. Worsley, S. Friel and M. Lawrence (2020a). Ultra-processed foods and the nutrition transition: global, regional and national trends, food systems transformations and political economy drivers. Obesity Reviews, **21**(12).

Bermeo-Almeida, O., M. Cardenas-Rodriguez, T. Samaniego-Cobo, E. Ferruzola-Gómez, R. Cabezas Cabezas and W. Bazán-Vera (2018). Blockchain in agriculture: a systematic literature review. In: *International conference on technologies and innovation*. Springer, Cham,: 44–56.

Bertrand, A. M., Hawkins, M., Cotter, E. W., Banzon, D., & Snelling, A. (2021). Interest in receiving nutrition information through social media among food-security program participants in Washington, DC. Prev Chronic Dis **18**: 200596. https://doi.org/10.5888/pcd18.200596

Beyene, L. M., & Engida, E. (2016). Public investment in irrigation and training, growth and poverty reduction in Ethiopia. *International Journal of Microsimulation, 9*(1), 86–108. https://doi.org/10.34196/IJM.00129

Bharwani, S., Bithell, M., Downing, T. E., New, M., Washington, R., & Ziervogel, G. (2005). Multi-agent modelling of climate outlooks and food security on a community garden scheme in Limpopo, South Africa. *Philosophical Transactions of the Royal Society B: Biological Sciences, 360*(1463), 2183–2194.

Bickel, G., M. Nord, C. Price, W. L. Hamilton and J. T. Cook (2000). Guide to Measuring Household Food Security, Revised 2000. USDA, Food and Nutrition Service. https://www.fns.usda.gov/sites/default/files/FSGuide_0.pdf.

Bisoffi, S., L. Ahrné, J. Aschemann-Witzel, A. Báldi, K. Cuhls, F. DeClerck, J. Duncan, H. O. Hansen, R. L. Hudson, J. Kohl, B. Ruiz, G. Siebielec, S. Treyer and G. Brunori (2021). COVID-19 and Sustainable Food Systems: What Should We Learn Before the Next Emergency. Frontiers in Sustainable Food Systems **5**.

Bouzembrak, Y., Klüche, M., Gavai, A., & Marvin, H. J. P. (2019). Internet of Things in food safety: Literature review and a bibliometric analysis. *Trends in Food Science & Technology, 94*, 54–64.

Bock, M. E. and N. J. Kirkendall (2017b). Panel on Methods for Integrating Multiple Data Sources to Improve Crop Estimates. National Statistics; Division of Behavioral and Social Sciences and Education; **Committee on National Academies of Sciences, Engineering, and Medicine**.

Brocke, J., A. Simons, B. Niehaves, B. Niehaves, K. Reimer, R. Plattfaut and A. Cleven (2009). Reconstructing the giant: On the importance of rigour in documenting the literature search process. ECIS 2009 Proceedings **161**: https://aisel.aisnet.org/ecis2009/2161.

Caccavale, O. M. and V. Giuffrida (2020). The Proteus composite index: Towards a better metric for global food security. World Development **126**(C).

Caine, A., P. Dorward, G. Clarkson, N. Evans, C. Canales, D. Stern and R. Stern (2015). Mobile applications for weather and climate information: their use and potential for smallholder farmers.

Capital, A. (2017). GCC Food Industry. https://www.alpencapital.com/downloads/reports/2017/GCC-Food-Industry-Report.February-2017.pdf.

Carletto, C., Zezza, A., & Banerjee, R. (2013). Towards better measurement of household food security: Harmonizing indicators and the role of household surveys. *Global Food Security, 2*, 30–40.

Chamara, R. M. S. R., Senevirathne, S. M. P., Samarasinghe, S. A. I. L. N., Premasiri, M. W. R. C., Sandaruwani, K. H. C., Dissanayake, D. M. N. N., De, S. H. N. P., & Silva Ariyaratne and B. Marambe, W. M. T. P. (2020). Role of artificial intelligence in achieving global food security: A promising technology for future. *Sri Lanka Journal of Food and Agriculture*. https://doi.org/10.4038/sljfa.v6i2.88

Christensen, A. J., Srinivasan, V., Hart, J. C., & Marshall-Colon, A. (2018). Use of computational modeling combined with advanced visualization to develop strategies for the design of crop ideotypes to address food security. *Nutrition Reviews, 76*(5), 332–347.

Clapp, J. (2017). Food self-sufficiency: Making sense of it, and when it makes sense. *Food Policy, 66*, 88–96.

de Haen, H., Klasen, S., & Qaim, M. (2011). What do we really know? Metrics for food insecurity and undernutrition. *Food Policy, 36*(6), 760–769.

Denyer, D., & Tranfield, D. (2009). Producing a systematic review. In D. A. Buchanan & A. Bryman (Eds.), *The SAGE handbook of organizational research methods* (pp. 671–689). Sage Publications Ltd.

Deulgaonkar, P. (2017). GCC food import bill to hit $53.1bn @@in 2020. Alpen Capital. Arabian Business https://www.arabianbusiness.com/gcc-food **import-bill-hit-53–1bn-in-2020-alpen-capital-664599.html.**

Donovan, K. (2017). Anytime, anywhere: Mobile devices and services and their impact on agriculture and rural development.

Ejaz, M., Abbas, G., Fatima, Z., Iqbal, P., Raza, M. A., Kheir, A. M. S., Ahmed, M., Kakar, K. M., & Ahmad, S. (2022). Modelling climate uncertainty and adaptations for soybean-based cropping system. *International Journal of Plant Production, 16*(2), 235–250.

eMarketer (2014). 2 billion consumers worldwide to get smart (Phones) by 2016–over half of mobile phone users globally will have smartphones in 2018.

Conway, G. (1997). The Doubly Green Revolution. Penguin Books **London**.

Fan, W., C. Chong, G. Xiaoling, Y. Hua and W. Juyun (2015). Prediction of crop yield using big data. 2015 8th International Symposium on Computational Intelligence and Design (ISCID) **1**(IEEE): 255–260.

Fanzo, J., Covic, N., Dobermann, A., Henson, S., Herrero, M., Pingali, P., & Staal, S. (2020). A research vision for food systems in the 2020s: Defying the status quo. *Global Food Security, 26*, 100397–100397.

FAO. (2009). State of Food Insecurity in the World. FAO, Rome, **Italy**.

FAO. (2018). Systainable Food Systems. Concept and framework http://www.fao.org/about/what-we-do/so4.
FAO. (2020b). The State of Food Security and Nutrition in the World 2020b. Transforming food systems for affordable healthy diets. Rome, FAO. (also availableat https://doi.org/10.4060/ca9692en).
FAO. (2020a). "Forthcoming. Country examples of best practices in addressing drivers of food insecurity and malnutrition towards the transformation of food systems." Rme.
FAO. (2021b). The State of Food Security and Nutrition in the World 2021b. Transforming food systems for food security, improved nutrition and affordable healthy diets for all. Rome, FAO. https://doi.org/10.4060/cb4474en.
FAO. (2021a). High Level Panel of Experts open e-consultations. Data collection and analysis tools for food security and nutrition - HLPE e-consultation on the Report's scope https://www.fao.org/fsnforum/cfs-hlpe/discussions/data-collection-analysis.
Friedl, M. A. (2018). 6.06 - Remote Sensing of Croplands. Comprehensive Remote Sensing. S. Liang. Oxford, Elsevier**:** 78–95.
Fritz, S., See, L., Carlson, T., Haklay, M., Oliver, J. L., Fraisl, D., Mondardini, R., Brocklehurst, M., Shanley, L. A., Schade, S., Wehn, U., Abrate, T., Anstee, J., Arnold, S., Billot, M., Campbell, J., Espey, J., Gold, M., Hager, G., … West, S. (2019). Citizen science and the United Nations Sustainable Development Goals. *Nature Sustainability, 2*(10), 922–930.
Fróna, D., J. Szenderák and M. Harangi-Rákos (2019). The Challenge of Feeding the World. Sustainability **11**(20).
George Hanuschak, J. D. (1993). Utilization of Remotely Sensed Data and Geographic Information Systems (GIS) for Agricultural Statistics in the United States and the European Union. Advances in planning, design and management of irrigation systems as related to sustainable land use,: 14–17,.
George, R. V., Harsh, H. O., Ray, P., & Babu, A. K. (2019). Food quality traceability prototype for restaurants using blockchain and food quality data index. *Journal of Cleaner Production, 240*, 118021.
GFSI. (2019). Global Food Security Index 2019. Strengthening food systems and the environment through innovation and investment file:///C:/Users/a.kheir/Downloads/Global%20Food%20Security%20Index%202019%20report%20(1).pdf
Godfray, H. C. J., Beddington John, R., Crute Ian, R., Haddad, L., Lawrence, D., Muir James, F., Pretty, J., Robinson, S., Thomas Sandy, M., & Toulmin, C. (2010). Food Security: The Challenge of Feeding 9 Billion People. *Science, 327*(5967), 812–818.
Godfray, H. C. J., & Robinson, S. (2015). Contrasting approaches to projecting long-run global food security. *Oxf. Rev. Econ. Pol., 31*(1), 26–44. https://doi.org/10.1093/oxrep/
Hajduk, M. (2016). Identification of palletizing/depalletizing operations in food industry suitable for robotics. Applied Mechanics and Materials **844**: TransTech Publications, Zurich, pp. 19–24.
Halloran, A., Clement, J., Kornum, N., Bucatariu, C., & Magid, J. (2014). Addressing food waste reduction in Denmark. *Food Policy, 49*, 294–301.
Hether, H. J., Murphy, S. T., & Valente, T. W. (2014). It's better to give than to receive: the role of social support, trust, and participation on health-related social networking sites. *Journal of Health Communication, 19*(12), 1424–1439.
Hilt, M., D. Shao and B. Yang (2018). RFID security, verification, and blockchain: vulnerabilities within the supply chain for food security. In: *Proceedings of the 19th Annual SIG Conference on Information Technology Education, International World Wide Web Conferences Steering Committee*: 145.
Hodson, R. (2017). Food security. *Nature, 544*(7651), S5–S5.
House, C. (2013). Edible Oil: Food Security in the Gulf. Chatham House. 1 Nov, 2013 https://www.chathamhouse.org/publications/papers/view/195281.
I.G.S. (2019). Independent Group of Scientists appointed by the Secretary-General. 2019. Global Sustainable Development Report 2019: the future is now – science for achieving sustainable development." New York, USA, UN. **(also available at** https://sustainabledevelopment.un.org/content/documents/24797GSDR_report_2019.pdf**).**
IFAD. (2020). The State of Food Security and Nutrition in the World 2020. Transforming food systems for affordable healthy diets. Rome, FAO. (also availableat https://doi.org/10.4060/ca9692en).
Initiatives, D. (2020). Global Nutrition Report: action on equity to end malnutrition. Bristol, UK. **(also available at** https://globalnutritionreport.org/reports/2020-global-nutrition-report**).**
IPC. (2021). Integrated Food Security Phase Classification. Home. In: IPC [online]. Rome. [Cited 21 June 2021]. https://www.ipcinfo.org/ipc-country-analysis.
Iqbal, J., Khan, Z. H., & Khalid, A. (2017). Prospects of robotics in food industry. *Food Science and Technology, 37*(2), 159–165.
Irani, Z., & Sharif, A. M. (2016). Sustainable food security futures: Perspectives on food waste and information across the food supply chain. *Journal of Enterprise Information Management, 29*(2), 171–178.

Izraelov, M., & Silber, J. (2019). An assessment of the global food security index, Food Security: The Science, Sociology and Economics of Food Production and Access to Food. *Springer;the International Society for Plant Pathology, 115*(5), 1135–1152.

Janssens, C., Havlík, P., Krisztin, T., Baker, J., Frank, S., Hasegawa, T., Leclère, D., Ohrel, S., Ragnauth, S., Schmid, E., Valin, H., Van Lipzig, N., & Maertens, M. (2020). Global hunger and climate change adaptation through international trade. *Nature Climate Change, 10*(9), 829–835.

Jerzak, M. A. and M. Śmiglak-Krajewska (2020). Globalization of the Market for Vegetable Protein Feed and Its Impact on Sustainable Agricultural Development and Food Security in EU Countries Illustrated by the Example of Poland. Sustainability **12**(3).

Jiang, Z. and S. Shekhar (2017). Spatial and Spatiotemporal Big Data Science. In Spatial Big Data Science **Springer**: 15–44.

Jin, C., Bouzembrak, Y., Zhou, J., Liang, Q., van den Bulk, L. M., Gavai, A., Liu, N., van den Heuvel, L. J., Hoenderdaal, W., & Marvin, H. J. P. (2020). Big Data in food safety: A review. *Current Opinion in Food Science, 36*, 24–32.

Jin, C., Levi, R., Liang, Q., Renegar, N., Springs, S., Zhou, J., & Zhou, W. (2021). Testing at the source: Analytics-enabled risk-based sampling of food supply chains in China. *Management Science, 67*(5), 2985–2996.

Jones, A. D., Ngure, F. M., Pelto, G., & Young, S. L. (2013). What are we assessing when we measure food security? A compendium and review of current metrics. *Advances in Nutrition, 4*(5), 481–505.

Juan Ding, M., Jie, F., Parton, K. A., & Matanda, M. J. (2014). Relationships between quality of information sharing and supply chain food quality in the Australian beef processing industry. *The International Journal of Logistics Management, 25*(1), 85–108.

Kaur, H. (2021). Modelling internet of things driven sustainable food security system. *Benchmarking an International Journal, 28*(5), 1740–1760. https://doi.org/10.1108/BIJ-1712-2018-0431

Kheir, A. M. S., H. M. Alkharabsheh, M. F. Seleiman, A. M. Al-Saif, K. A. Ammar, A. Attia, M. G. Zoghdan, M. M. A. Shabana, H. Aboelsoud and C. Schillaci (2021) Calibration and Validation of AQUACROP and APSIM Models to Optimize Wheat Yield and Water Saving in Arid Regions. Land 10. https://doi.org/10.3390/land10121375.

Kheir, A. M. S., Hoogenboom, G., Ammar, K. A., Ahmed, M., Feike, T., Elnashar, A., Liu, B., Ding, Z., & Asseng, S. (2022). Minimizing trade-offs between wheat yield and resource-use efficiency in the Nile Delta: A multi-model analysis. *Field Crops Research, 287*, 108638.

Kumar, D. and P. Kalita (2017). Reducing Postharvest Losses during Storage of Grain Crops to Strengthen Food Security in Developing Countries. Foods **6**(1).

Kussul, N., Lavreniuk, M., Kolotii, A., Skakun, S., Rakoid, O., & Shumilo, L. (2020). A workflow for Sustainable Development Goals indicators assessment based on high-resolution satellite data. *International Journal of Digital Earth, 13*(2), 309–321.

Laborte, A. G., Schipper, R. A., Van Ittersum, M. K., Van Den Berg, M. M., Van Keulen, H., Prins, A. G., & Hossain, M. (2009). Farmers' welfare, food production and the environment: A model-based assessment of the effects of new technologies in the northern Philippines. *NJAS - Wageningen Journal of Life Sciences, 56*(4), 345–373.

Laborte, A. G., Van Ittersum, M. K., & Van den Berg, M. M. (2007). Multi-scale analysis of agricultural development: A modelling approach for Ilocos Norte, Philippines. *Agricultural Systems, 94*(3), 862–873.

Lázár, A. N., Clarke, D., Adams, H., Akanda, A. R., Szabo, S., Nicholls, R. J., Matthews, Z., Begum, D., Saleh, A. F. M., Abedin, M. A., Payo, A., Streatfield, P. K., Hutton, C., Mondal, M. S., & Moslehuddin, A. Z. M. (2015). Agricultural livelihoods in coastal Bangladesh under climate and environmental change: A model framework. *Environmental Science: Processes & Impacts, 17*(6), 1018–1031.

Lin, Y. P., Petway, J. R., Anthony, J., Mukhtar, H., Liao, S. W., Chou, C. F., & Ho, Y. F. (2017). Blockchain: The evolutionary next step for ICT e-agriculture. *Environments, 4*(3), 50–53.

Liu, Z., Zhang, Y., Xu, S., Zhang, H., Tan, Y., Ma, C., Song, R., Jiang, L., & Yi, C. (2017). A 3D printed smartphone optosensing platform for point-of-need food safety inspection. *Analytica Chimica Acta, 966*, 81–89.

Loures, L., A. Chamizo, P. Ferreira, A. Loures, R. Castanho and T. Panagopoulos (2020). Assessing the Effectiveness of Precision Agriculture Management Systems in Mediterranean Small Farms. Sustainability **12**(9).

Malek. and Caline. (2015). UAE's first agricultural policy to benefit farming sustainability and profitability. The National. from https://www.thenational.ae/uae/environment/uaes-first-agricultural-policy-to-benefit-farming-sustainability-and-profitability.

Marie-Sainte, S. L., Alalyani, N., Alotaibi, S., Ghouzali, S., & Abunadi, I. (2019). Arabic natural language processing and machine learning-based systems. *IEEE Access, 7*, 7011–7020.

Marín-González, O., Parsons, D., Arnes-Prieto, E., & Díaz-Ambrona, C. G. H. (2018). Building and evaluation of a dynamic model for assessing impact of smallholder endowments on food security in agricultural systems in highland areas of central America (SASHACA). *Agricultural Systems, 164*, 152–164.

Markou, M., A. Michailidis, E. Loizou, S. A. Nastis, D. Lazaridou, G. Kountios, M. S. Allahyari, A. Stylianou, G. Papadavid and K. Mattas (2020). Applying a Delphi-Type approach to estimate the adaptation cost on agriculture to climate change in cyprus. Atmosphere **11**(5).

Marouni, H. (2017). RFID and sensor network automation in the food industry: Ensuring quality and safety through supply chain visibility. *Quality Progress, 50*(1), 60–61.

Marvin, H. J. P., Janssen, E. M., Bouzembrak, Y., Hendriksen, P. J. M., & Staats, M. (2017). Big data in food safety: An overview. *Critical Reviews in Food Science and Nutrition, 57*(11), 2286–2295.

Masiero, S. (2015). Redesigning the Indian food security system through e-governance: The case of Kerala. *World Development, 67*, 126–137.

Mavani, N. R., J. M. Ali, S. Othman, M. A. Hussain, H. Hashim and N. A. Rahman (2021). Application of Artificial Intelligence in Food Industry—a Guideline. Food Engineering Reviews: 1–42.

Morris, B. (2003). The components of the Wired Spanning Forest are recurrent. *Probability Theory and Related Fields, 125*(2), 259–265.

Mulla, D. J. (2013). Twenty five years of remote sensing in precision agriculture: Key advances and remaining knowledge gaps. *Biosystems Engineering, 114*(4), 358–371.

Nakandala, D., Samaranayake, P., Lau, H., & Ramanathan, K. (2017). Modelling information flow and sharing matrix for fresh food supply chains. *Business Process Management Journal, 23*(1), 108–129. https://doi.org/10.1108/BPMJ-1109-2015-0130

Nicholson, C. F., Stephens, E. C., Kopainsky, B., Jones, A. D., Parsons, D., & Garrett, J. (2021). Food security outcomes in agricultural systems models: Current status and recommended improvements. *Agricultural Systems, 188*, 103028.

Nkunzimana, T., B. J. M. Rodríguez, C. E. Custodio, J. M. Rodríguez-Llanes, M. Meroni, T. Negre, Y. Gomez, S. Paloma and L. David (2018). Quantitative Methods for Integrated Food and Nutrition Security Measurements. essons to be learned!, doi:https://doi.org/10.2760/168627.

Nukala, R., A. Shields, U. McCarthy and S. Ward (2015). An IoT based approach towards global food safety and security. The 14th IT&T Conference **10–17**.

OECD. (2021). Data for Development Profiles: Official Development Assistance for Data and Statistical Systems OECD Publishing, Paris, https://doi.org/10.1787/84baa8f3-en

Okori, W. and J. Obua Machine learning classification technique for famine prediction, Citeseer.

Onan, A. (2020b). Sentiment Analysis in Turkish Based on Weighted Word Embeddings. 2020b 28th Signal Processing and Communications Applications Conference (SIU).

Onan, A. (2020c). Sentiment analysis on product reviews based on weighted word embeddings and deep neural networks. Concurrency and Computation: Practice and Experience **n/a**(n/a): e5909.

Onan, A. (2020a). Mining opinions from instructor evaluation reviews: A deep learning approach. *Computer Applications in Engineering Education, 28*(1), 117–138.

Onan, A. (2021). Sentiment analysis on massive open online course evaluations: A text mining and deep learning approach. *Computer Applications in Engineering Education, 29*(3), 572–589.

Onan, A., Korukoğlu, S., & Bulut, H. (2016). Ensemble of keyword extraction methods and classifiers in text classification. *Expert Systems with Applications, 57*, 232–247.

Onan, A., & Toçoğlu, M. A. (2021). Weighted word embeddings and clustering-based identification of question topics in MOOC discussion forum posts. *Computer Applications in Engineering Education, 29*(4), 675–689.

Pal, A., & Kant, K. (2019). Using blockchain for provenance and traceability in internet of things-integrated food logistics. *Computer, 52*(12), 94–98.

Pawlak, K. and M. Kołodziejczak (2020). The Role of Agriculture in Ensuring Food Security in Developing Countries: Considerations in the Context of the Problem of Sustainable Food Production. Sustainability **12**(13).

Phiri, D., M. Simwanda, S. Salekin, V. R. Nyirenda, Y. Murayama and M. Ranagalage (2020). Sentinel-2 data for land cover/use mapping: A review. *Remote Sensing* **12**(14).

Pongnumkul, S., Chaovalit, P., & Surasvadi, N. (2015). Applications of smartphone-based sensors in agriculture: A systematic review of research. *Journal of Sensors, 2015*, 195308.

Prakash, R., & Gupta, L. (2014). Role of crop insurance in national food security. *International Journal of Banking, Risk and Insurance, 2*(1), 39–44.

Priya, N., & Geetha, G. (2017). Dynamic programming based resource optimization in agricultural big data for crop yield maximization. *Journal of Computational and Theoretical Nanoscience, 14*(9), 4464–4470.

Ranganathan, T., A. K. Mishra and A. Kumar (2018). Crop insurance and food security: evidence from rice farmers in Eastern India. Agricultural and Applied Economics Association, **281173**: Atlanta.
Röös, E., Bajželj, B., Smith, P., Patel, M., Little, D., & Garnett, T. (2017). Greedy or needy? Land use and climate impacts of food in 2050 under different livestock futures. *Global Environmental Change, 47*, 1–12.
Rosegrant Mark, W., & Cline Sarah, A. (2003). Global food security: Challenges and policies. *Science, 302*(5652), 1917–1919.
Rosenzweig, C., Jones, J. W., Hatfield, J. L., Ruane, A. C., & Thornburn, K. J. (2013). The Agricultural Model Intercomparison and Improvement Project (AgMIP): Protocols and pilot studies. *Agricultural and Forest Meteorology, 170*, 166–182.
Schmidhuber, J., Tubiello, F. N. (2007). Global food security under climate change. PNAS **104**: 19703–19708. https://doi.org/10.11073/pnas.0701976104.
Security., A. D. T. A. o. F. (2016). Oxford Business Group, Oxford Business Group. 19 May 2016 https://www.oxfordbusinessgroup.com/analysis/securing-supply-food-security-issue-and-government-and-private-sector-are-deploying-strategies.
Shaikh, S., M. Butala, R. Butala and M. Creado (2019). AgroVita using Blockchain. 2019 IEEE 5th International Conference for Convergence in Technology (I2CT).
Shan, L. C., J. L. Schiro, K. Zhong and P. Wall (2020). What makes smartphone games successful in food information communication? NPJ Science of Food **4**(1): 2.
Shekhar, S., J. Colletti, F. Muñoz-Arriola, L. Ramaswamy, C. Krintz, L. Varshney and D. Richardson (2017). Intelligent Infrastructure for Smart Agriculture: An Integrated Food, Energy and Water System, Computing Community Consortium. https://arxiv.org/ftp/arxiv/papers/1705/1705.01993.pdf.
Shekhar, S., Feiner, S., & Aref, W. (2015). Spatial computing. *Communications of the ACM, 59*(1), 72–81.
Silva, A. F. S., & Rocha, F. R. P. (2020). A novel approach to detect milk adulteration based on the determination of protein content by smartphone-based digital image colorimetry. *Food Control, 115*, 107299.
Singh, P., P. C. Pandey, G. P. Petropoulos, A. Pavlides, P. K. Srivastava, N. Koutsias, K. A. K. Deng and Y. Bao (2020). 8 - Hyperspectral remote sensing in precision agriculture: present status, challenges, and future trends. Hyperspectral Remote Sensing. P. C. Pandey, P. K. Srivastava, H. Balzter, B. Bhattacharya and G. P. Petropoulos, Elsevier**:** 121–146.
Singh, A., Shukla, N., & Mishra, N. (2018). Social media data analytics to improve supply chain management in food industries. *Transportation Research Part e: Logistics and Transportation Review, 114*, 398–415.
Song, Y.-H., Yu, H.-Q., Tan, Y.-C., Lv, W., Fang, D.-H., & Liu, D. (2020). Similarity matching of food safety incidents in China: Aspects of rapid emergency response and food safety. *Food Control, 115*, 107275.
Soon, J. M. (2020). Consumers' awareness and trust toward food safety news on social media in Malaysia. *Journal of Food Protection, 83*(3), 452–459.
Stone, J., & Rahimifard, S. (2018). Resilience in agri-food supply chains: A critical analysis of the literature and synthesis of a novel framework. *Supply Chain Management: An International Journal, 23*(3), 207–238.
Strawn, L. K., E. W. Brown, J. R. David and H. C. Den Bakker. Big Datain Food Safety and
Subudhi, B. N., Rout, D. K., & Ghosh, A. (2019). Big data analytics for video surveillance. *Multimedia Tools and Applications, 78*(18), 26129–26162.
Talavera, J. M., L. E. Tobón, J. A. Gómez, M. A. Culman, J. M. Aranda, D. T. Parra, L. A. Quiroz, A. Hoyos and L. E. Garreta (2017). Review of IoT applications in agro-industrial and environmental fields. Computers and Electronics in Agriculture **142**(Part A): 283–297.
Tao, G., Tan, H., Song, Y., & Lin, D. (2018). Research and application of Big Data-based co-regulation model in food safety governance. *Shipin Kexue/food Science, 39*, 272–279.
Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., Schindler, D., Schlesinger, W. H., Simberloff, D., & Swackhamer, D. (2001). Forecasting agriculturally driven global environmental change. *Science, 292*(5515), 281–284.
Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge by means of systematic review. *British Journal of Management, 14*, 207–222.
UNICEF. (2019). The State of the World's Children. Children, food and nutrition: growing well in a changing world. **New York, USA.** (https://www.unicef.org/media/63016/file/SOWC-2019.pdf).
van Delden, S. H., M. SharathKumar, M. Butturini, L. J. A. Graamans, E. Heuvelink, M. Kacira, E. Kaiser, R. S. Klamer, L. Klerkx, G. Kootstra, A. Loeber, R. E. Schouten, C. Stanghellini, W. van Ieperen, J. C. Verdonk, S. Vialet-Chabrand, E. J. Woltering, R. van de Zedde, Y. Zhang and L. F. M. Marcelis (2021). Current status and future challenges in implementing and upscaling vertical farming systems. Nature Food.

UNICEF. (2020). The State of Food Security and Nutrition in the World 2020. Transforming food systems for affordable healthy diets. Rome, FAO. (also available at https://doi.org/10.4060/ca9692en).

Upton, J. B., Cissé, J. D., & Barrett, C. B. (2016). Food security as resilience: Reconciling definition and measurement. *Agricultural Economics, 47*(S1), 135–147.

van Meijl, H., Shutes, L., Valin, H., Stehfest, E., van Dijk, M., Kuiper, M., Tabeau, A., van Zeist, W.-J., Hasegawa, T., & Havlik, P. (2020). Modelling alternative futures of global food security: Insights from FOODSECURE. *Global Food Security, 25*, 100358.

Vanderroost, M., Ragaert, P., Verwaeren, J., De Meulenaer, B., De Baets, B., & Devlieghere, F. (2017). The digitization of a food package's life cycle: Existing and emerging computer systems in the logistics and post-logistics phase. *Computers in Industry, 87*, 15–30.

Vatsavai, R. R., A. Ganguly, V. Chandola, A. Stefanidis, S. Klasky and S. Shekhar (2012). Spatiotemporal data mining in the era of big spatial data: algorithms and applications. Proceedings of the 1st ACM SIGSPATIAL International Workshop on Analytics for Big Geospatial Data. Redondo Beach, California, Association for Computing Machinery**:** 1–10.

von Braun, J. (2007). *The World Food Situation*. New Driving Forces and Required Actions (IFPRI.

Wam. (2017). Food security tops UAE's priorities, says Abu Dhabi Crown Prince. Emirates 247 News **Feb 7,** : https://www.emirates247.com/news/emirates/foodsecurity-tops-uae-s-priorities-says-abu-dhabi-crown-prince-2017-2002-2007-2011.647735.

Wang, H., Xu, Z., Fujita, H., & Liu, S. (2016). Towards felicitous decision making: An overview on challenges and trends of Big Data. *Information Sciences, 367–368*, 747–765.

WFP. (2020). The State of Food Security and Nutrition in the World 2020. Transforming food systems for affordable healthy diets. Rome, FAO. (also available at https://doi.org/10.4060/ca9692en).

Wheeler, T., & von Braun, J. (2013). Climate change impacts on global food security. *Science, 341*, 508. https://doi.org/10.1126/science.1239402

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M. J. (2017). Big data in smart farming: a review. *Agricultural Systems, 153*, 69–80.

WPP. (2015). World Population Prospects, The 2015 revision: Key findings and advance tables. Department of Economic and Social Affairs Population Division, United Nations, 2015. [Online]. Available: https://esa.un.org/unpd/wpp/publications/files/key_findings_wpp_2015.pdf.

Wunderlich, S. M., & Martinez, N. M. (2018). Conserving natural resources through food loss reduction: Production and consumption stages of the food supply chain. *International Soil and Water Conservation Research, 6*(4), 331–339.

Xie, Y., E. Eftelioglu, R. Y. Ali, X. Tang, Y. Li and R. Doshi (2017). Transdisciplinary Foundations of Geospatial Data Science. ISPRS International Journal of Geo-Information **6**(12).

Ye, Y., Wu, T., Jiang, X., Cao, J., Ling, X., Mei, Q., Chen, H., Han, D., Xu, J.-J., & Shen, Y. (2020). Portable smartphone-based QDs for the visual onsite monitoring of fluoroquinolone antibiotics in actual food and environmental samples. *ACS Applied Materials & Interfaces, 12*(12), 14552–14562.

Yuan, J., Lu, Y., Cao, X., & Cui, H. (2020). Regulating wildlife conservation and food safety to prevent human exposure to novel virus. *Ecosystem Health and Sustainability, 6*(1), 1741325.

Zscheischler, J., Martius, O., Westra, S., Bevacqua, E., Raymond, C., Horton, R. M., van den Hurk, B., AghaKouchak, A., Jézéquel, A., Mahecha, M. D., Maraun, D., Ramos, A. M., Ridder, N. N., Thiery, W., & Vignotto, E. (2020). A typology of compound weather and climate events. *Nature Reviews Earth & Environment, 1*(7), 333–347.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.