Sustainable Food Systems: Recent Advances, Assessment Techniques, and Methodological Compositions

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Abstract

Sustainability in food system is a grand challenge in our time. Delivering food and nutrition in a secure and sustainable manner across the eco-environmental and social pillars of sustainability is by far an ambitious goal. Understanding the developments in sustainable food system is crucial to undertake informed decisions. To this end, this paper aims to provide a comprehensive review of sustainability in the food industries covering sustainability's three dimensions: environmental, socio-economic, and eco-environmental aspects. A four-method approach has been used to assess the papers found on the Scopus database, limiting the review for the past ten years of research. For each dimension, the most used assessment tools used by researchers are mentioned under each dimension section. Besides variable selection approaches covered in the research review, modeling and optimization techniques have been listed.

Keywords
Food Systems, Sustainability Assessment, Eco-efficiency Assessment, Environmental Assessment, Social Assessment.

1. Introduction
Food is an essential need for creatures in this universe. Securing and sustaining food production is a significant demand for survival and should acquire more attention. It has been noticed that the food supply chain has been jeopardized recently and lost its efficiency, which is mainly caused by greenhouse gas emissions (GHG), deforestation, water pollution, biodiversity loss, uneven water extraction and carbon footprint. The carbon footprint continues to grow as a result of the continued use of conventional vehicles and the failure to switch to electric vehicles, which have proven to be environmentally friendly (Al-Buenain et al., 2021;Kucukvar et al., 2021a;Al-Obadi et al., 2021;Onat et al., 2021; Kutty et al., 2021a). Food consumption sustainability necessitates an understanding of multidimensional environmental, economic, and social impacts through the use of a comprehensive and inclusive sustainability assessment and model - based framework (Abdella et al., 2020a). Food production needs clean air and water and healthy soils and climate to stand and sustain; however, its sustainability requires a high conscious and intentional decision considering the continuous societal growth(Kutty et al., 2020d). Sustainable development is needed significantly as it balances present and future generations' requirements. A sustainable farming system offers food security and nutrition for all while preserving the economic, social, and environmental foundations necessary to provide food security and nutrition for future generations. Sustainable development of food terms was launched between 1950 and 1960; meanwhile, the green revolution exported high-technology agriculture. This paper aims to review the most used tools, techniques, and models used to assess the three sustainability dimensions among food industries: socio-economic, environmental, and eco-environmental.

2. Method
A four-method approach was followed to study the assessment tools used for quantifying the agriculture sustainability performance for the three dimensions of sustainability: social, economic, and environmental. This paper has listed all the assessment tools used to assess each sustainability dimension to determine any food system. In addition, the Scopus database has been used to look up research papers covering this topic. The process for selecting articles goes through 4 stages, as illustrated in figure 1: Identifying keywords, skimming, selecting relevant articles, and interpreting results into the document. "Food System," "Sustainability," "Assessment Tools," and "Life Cycle Assessment" are the main

keywords used for searching papers. Plenty of documents from plenty of journals have been found, articles that cover non-relevant industries have been excluded having only the ones covering the area of research.

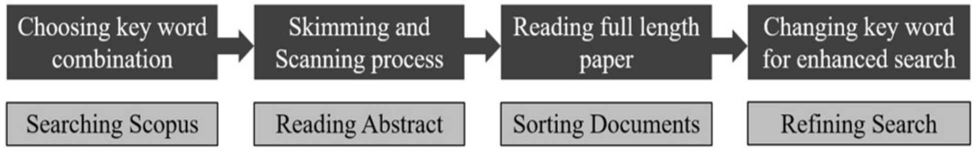

Figure 1. Review method

3. Food system sustainability assessment

Several tools and techniques have been used in the literature over the years to understand the food system's sustainability and assess the sustainability dimensions. Promoting green consumption and production practices at various stages of the FSC is necessary to achieve global food security and sustainbility, a number of challenges must be addressed, ranging from food waste accumulation in the food supply chain (FSC) to addressing gender inequalities and climate-related concerns in (Kutty et al., 2020b). This research has divided the tools and techniques used in the study over three categories for better understanding: environmental assessment, socio-economic assessment, and eco-environmental assessment. Each type summarizes the tools, techniques, and studies found in the Scopus database for the last decade.

3.1 Environmental Assessment

As indicated by Food and agriculture organizations, a sustainable food system should positively or neutral impact the environment. In this section, all the tools and techniques used to quantify and assess the food system's environmental impact will be mentioned to improve these systems further to reduce emissions, improve plant, soil, water, and animal health, biodiversity, and food loss. An increase of greenhouse gases (GHG) has been indicated in China between 1989 and 2017 caused by food production and consumption shown by using bottom-up process-based life cycle assessment (LCA) followed by top-down hybrid economic input-output (EIOA) then using a combination of LCA and EIA to determine all kinds of environmental emissions which result in discovering that Changing farming techniques and encouraging households to intake a more healthy diet could help to significantly reduce GHG emissions (Zhang et al., 2022). Also with respect to emissions, according to the findings of Alsarayreh et al., (2020) a growth in population and urbanization beside the land use and average years of schooling have a negative influence on CO2 emissions which should be considered and maintained in the upcoming sustainable food systems. Stone et al. (2021) studied the three vegetables production systems(small, medium, and large scale), and 18 vegetables crops normally grew in Des Moines, Iowa, to examine their environmental impact and make improvement decisions that mainly should solve the discovered differences in global warming potentianl as well energy and water use that contribute in the increase of emissions. Another analysis of grapes production done to analyze the environmental impact using the LCA approach, including three models (early harvesting, ordinary harvesting, and delayed harvesting) that relied on the Italian system (Roselli et al., 2020). Another study evaluated the potential environmental savings that could be achieved in southern Sweden on broccoli crops if specific actions have been taken using the LCA approach (Eriksson et al., 2021). Another novel bottom-up approach that utilizes a hybrid Urban Metabolism - Life Cycle Analysis (UM-LCA) assessment to assess the food system's environmental impact on land use, freshwater quality, and global warming by Stelwagen et al. (2021). In Malaysia, the ecological effects of the production processes of rice crops have been studied using LCA to assess their performance (Harun et al., 2021).

3.2 Socio-Economic Assessment

Social-economic sustainability is used to establish a safe and prosperous workplace that supports humanity's wellness and needs (Kucukvar et al., 2021; Kutty et al., 2020c). Considering food sectors, it has been recognized that social sustainability is assessed and measured along the food supply chain (FSC) that consist of five stages: production, processing, wholesale, retailer/food services, and consumer (see Figure 2) (Desiderio et al., 2021). Social impact on sustainability could be understood once being analyzed on each stage of the food supply chain as mentioned by Desiderio and several authors in their systematic review that investigated social sustainability in the food sector and realized that most papers are done in that area studies tools used to assess the social impact in specific stages of the FSC only, without considering its effect on others (Desiderio et al., 2021).

Figure 2. Food supply chain stages.

Considering the growth of population living in the urban areas, which is expected to increase by 2050 to reach 70% of people as indicated by the Food and Agriculture Organization. That increase will lead to enormous challenges facing conventional food production and supply chain that drive food and nutrition insecurity to urban and rural residents. Not using the resources efficiently due to the impractical practices of farmers and staffing along the FSC systems is the reason behind that. These unsustainable practices and degraded natural resources can, once fixed and standardized, link rural and urban communities since they are key in designing stable and comprehensive linkages between them. Recently, few countries and organizations acknowledged the importance of sustainable food systems and initiated guidelines and efficient practices to improve the food sector. For example, Milan urban Food Policy pact let over 120 cities get involved in developing food systems on the bases of sustainability and social justice as well during the UN Conference on Housing and Sustainable Urban Development in 2016, a new urban agenda was established to regulate the international efforts revolving around urbanization for the coming two decades. Moving to local initiatives that were adopted by a few countries, Sri Lanka, for instance, had initiated a fertilizer plant for generating compost from the solid wastes collected from cities. Sri Lanka urban council placed this plant in the rural area in order to provide farmers with an easily accessible and organic fertilizer, whereas in Argentina, they focus on teaching farmers effective agricultural practices besides providing them with technical and financial support, which was launched by the municipality of Rosario in order to switch to ecological agriculture (FAO,2017). In the United States, people lack access to fresh food stores or take long distance to reach them, as discovered by Benez-Secanho et. al, (2021), who studied this phenomenon in the state of Georgia, which suffers the most from fresh food deficiency. Sophisticated space-related tools in geographical information systems (GIS) are used to spot fresh food stores and consider the population density as the dependent variable in the spatial lag regression model to figure out the factors affecting the accessibility of fresh food in Georgia (Benez-Secanho et al., 2021). Another universal assessment tool developed by the Food and Agricultural organization of the united nations (FAO) to assess the sustainability systems across each sustainability dimension is the Sustainability Assessment of Food and Agriculture systems (SAFA). It has been used among government, academia and research, private sectors, and research and projects as it helps to implement SAFA guidelines designed by FAO (FAO,2016). Response-Inducing Sustainability Evaluation (RISE) is used to assess the sustainability dimensions across farming operations discovered by the Swiss college of Agriculture in 2011. It's an interview-based way that collects information about 54 different parameters rated by farmers using a scale from 1 (worst) to 100 (perfect) are then being summarized to ten indicators their scores are displayed in a radar chart for further studies (Grenz et al., 2012). An economic analysis has been done using life cycle costing assessments of agriculture food systems specialized in grapes crops production (Roselli et al., 2020).

3.3 Eco-Environmental Assessment

A critical dimension of sustainability is the eco-environmental dimension, a combination of the economic and environmental impact of the system (Saling, 2016; Kutty et al., 2020). Eco-efficiency is defined as a proportion of economic output to environmental effect (Abdella et al., 2021f). Being able to assess and quantify its benefits in terms of materials and products significantly influences future improvement and takes further resolutions. It does require a closer holistic quantitative look at the system to be able to build new processes and products that adopt sustainable principles(Elhmoud et al., 2020; Elhmoud et al., 2020a). Many techniques were established to analyze the entire product life cycle from the early stages to the implementation. Eco-efficiency assessment has been used to set standards for industries and products sustainability by researchers, as identified by Abdella et al. (2020). A novel approach using Economic Input-Output Life Cycle Assessment (EIO-LCA) have been used to assess the effects of consumption and production tasks considering all possible impact from the supply chain (Abdella et al., 2020). This approach is considered to be the top-down strategy that utilizes both environmental indicators coupled with monetary flows to make a decision (Kucukvar et al., 2019). EIO-LCA, associated with Data Envelopment Analysis (DEA), has been used by Egilmez et al. (2014) to assess the sustainability dimensions in the United States for food manufacturing industries. Another methodology adopted by Park et al. (2016) utilized ecologically-based life cycle assessment (Eco-LCA) to establish a sustainability benchmarking model for 54 agriculture and food organizations in the united states that provide a benchmark for land and water footprints beside ecological resource consumption and atmospheric emissions. Eco-LCA is considered a complement to the EIO-LCA since it has additional ecological footprint categories for renewable and non-renewable resources (Tatari & Kucukvar, 2011). To address the difficulties of regression-based weights methods that considered to be one of the recent sustainability models and give valuable relative weights for eco-efficiency composite indicators, an unique weighting methodology integrating linear mixed-effect models with Johnson's relative weights was developed by Abdella and several researchers (Abdella et al., 2021g) . Life cycle assessment coupled with economic equilibrium modeling to prepare a feasible, realistic future plan for the aquaculture sector have been studied by Bohnes et al. (2022), whereas Spykman et al. (2021) have initiated a newly modular method for assessing the eco-efficiency of the production of dried Hermetia illucens larvae followed by environmental life cycle and cost assessment to analyze these two sustainability dimensions.

4. Modeling and optimization techniques

Several modeling techniques have been applied in the area of food system assessments. Modeling and optimization techniques help identify the relationships between indicators collected and utilized with the system's responses, which in turn contribute to minimize production costs and enhance quality. One of the most used techniques is Data envelopment analysis (DEA). DEA models have been used extensively to clarify and cope with the challenges that face food systems locally, regionally, and globally. For example, several researchers used the DEA model to investigate the food and beverage industry performance efficiency in Thailand and Vietnam to understand its capability and suggest productivity improvements coupled with resampling method to quantify the efficiency of 40 enterprises, 20 Vietnamese and 20 Thai companies, as indicated by Wang et al., (2020). Another modeling technique that has been recently developed used by Olagunju et al. (2021) "Directed Acyclic Graphs (DAG) "beside a Vector Error Correction Model (VECM), which is used to assess the relationship between phosphate rocks, plant fertilizers, and wheat selling prices to give perception for the concerned people about how to respond to phosphate rocks supply shocks. Müller et al. (2020) used the following multiple modeling techniques meta-modeling techniques, non-equilibrium approaches, and behavioral-based modeling endeavors to establish a detailed reflection on three multiple subjects on food security volatility, technology, and transformation. A system dynamic (SD) modeling approach was used by Sampedro et al. (2020) to determine the primary reasons that drive Galapagos island food systems to develop future plans and test the impact on the supply system structures. Lastly, few researchers in the united states have used simulation models to visualize food system capacity and evaluate its performance (Conrad et al., 2018).

5. Indicators and variable selection approaches

The models built for quick monitoring of results can benefit from variable selection approaches since they simplify the modeling process and improve the accuracy of the models (Abdella et al., 2016h;Abdur-Rouf K et al., 2018; Abdella et al., 2019i). This literature highlights some widely used variable selection approaches and their uses. Using variable selection techniques within the analysis removes the irrelevant attributes, which reduces the cost of processing unrequired data on the model (Sagar et al., 2021). However, choosing an indicator set that gives a complete system picture is challenging. Considering many indicators would raise the expenses of collecting and analyzing them to study the system (Reisi et al., 2014). The variables can be indicators reflecting a particular set of data to explore or measure a model, where indicators must be limited, valuable, and well figured out. Utilizing many indicators is undesirable and complicates decision-making (Reisi et al., 2014). Grenz et al. (2009) have identified the most common indicators that researchers have used to investigate the sustainability dimensions of food industries, as illustrated in Figure 3.

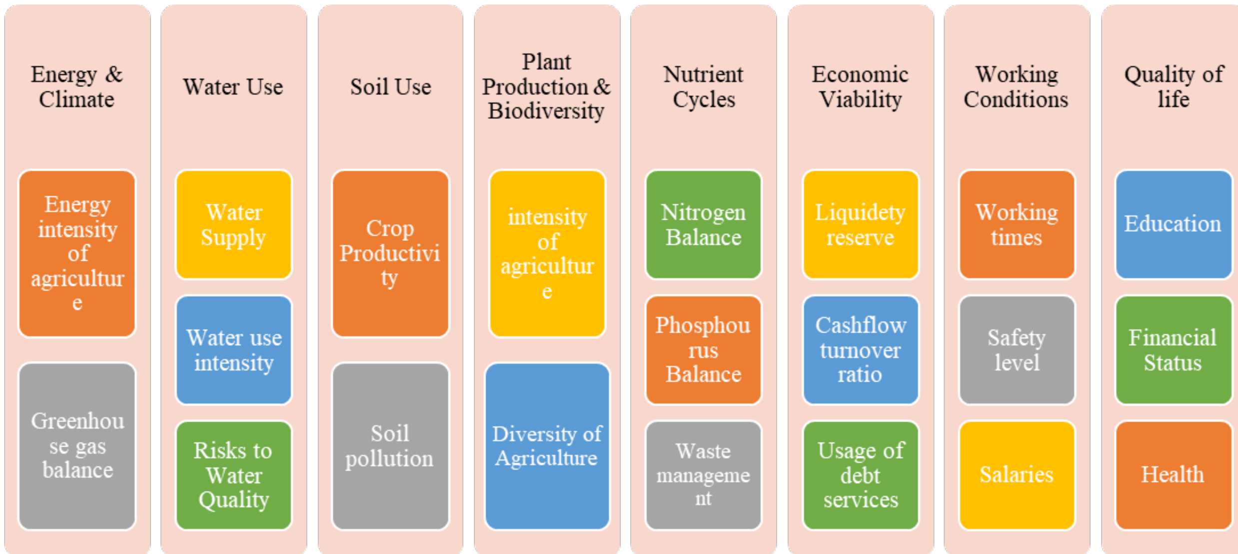

Figure 1 : Indicators used to assess food industries Sustainbility

One of the most widespread approaches used is the analytical hierarchy process (AHP) which is a method that associates weights to the indicators in the model. Still, this method is subjective and inconsistent because it is based on various individuals' viewpoints (Reisi et al., 2014). Nevertheless, it has been applied on the process of selecting transport sustainability indicators to evaluate transport sustainability strategies in local governments in Taiwan, where the weights of the indicators and the selection of them for the governments has been developed through a panel of committee members (Shiau et al., 2013). Another paper developing performance metrics for evaluating transportation sustainability has used AHP to assign relative weights to the variables, often determined by an expert panel based on theoretical backgrounds and considerations. However, this can pose the same problems as choosing a weighting pattern by a panel of experts (Zheng et al., 2013). The principle component technique (PCA) compares distinct indicators on many aspects and ranks them (Reisi et al., 2014). The least absolute shrinkage and selecting operator (LASSO) is another method used mainly to set certain variables to further using it as a regression technique, where LASSO studies the correlation between the independent variable (x) and the dependent variable (y) to select the most valuable variables (Marami Milani et al., 2016; Sagar et al., 2021; Abdella et al., 2020). To find the potentially relevant indicators based on exploratory data analysis, the Adaptive LASSO approach is used before the prediction of air quality and pollutants in multiple cities in India, where the use of adaptive LASSO resulted in pointing essential components that affect the air that measured (Sethi et al., 2021). Variable selection approaches are recently applied in many sustainability studies to select the best-fit indicators to measure the progress on sustainability (Reisi et al., 2014). For example, the LASSO approach is utilized in a paper to determine the best regression models between milk's essential components (protein, fat, and milk yield) as predictions and environmental factors as predictors (Marami Milani et al., 2016). Another study done to measure the impact of weather conditions on pedestrian injury used LASSO technique coupled with cross-validation approach (Abdella et al., 2020d).

6. Conclusion and Future Research

As noticed, there has been a great interest in using advanced statistical approaches for sustainability assessment over the years rather than relying on traditional methods that fail to detect failure indicators and identify the source of the conflict (Abdella et al., 2017c; Al-Sheeb et al., 2019). As a result, various advance techniques with different purposes have been adopted to assess sustainability dimensions. The most used techniques for assessing the environmental impact were the life cycle assessments that gives a holistic view derived from a detailed study of the product entire life. Similarly for socio-economic assessments a plenty of techniques where used besides the support of goverments in delivering regulations coupled with international standards established by FAO to insure and secure manpower safety, wellness and income. What have been used mainly were sophisticated space-related tools in geographical information systems (GIS), assessment tool developed by the Food and Agricultural organization which are SAFA & RISE beside life cycle costing. Whereas for evaluating the eco-environmental influence various tools and techniques were developed by researchers that includes Economic Input-Output Life Cycle Assessment (EIO-LCA) coupled with Data Envelopment Analysis (DEA). Another methodology utilized for doing the assessment and it considered to be a complement to the EIO-LCA which is the ecologically-based life cycle assessment (Eco-LCA) as well as weighting methodology integrating linear mixed-effect models with Johnson's relative weights. Lastly, life cycle evaluations, in combination with other methodologies, have been applied in a variety of ways for eco-environmental assessments. Moving to the most used optimization techniques and models that include data envelopment analysis (DEA). DEA models have been used extensively to clarify and cope with the challenges that face food systems locally, regionally, and globally. Another modeling technique that has been recently developed "Directed Acyclic Graphs (DAG) "beside a Vector Error Correction Model (VECM), which is used to assess the relationships between indicators. Another researchers used multiple modeling techniques that utilizes meta-modeling techniques, non-equilibrium approaches, and behavioral-based modeling. Finally, the most used variable selection approaches are AHP and LASSO methodologies.

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