Tools and Techniques for Food Security and Sustainability Related Assessments: A focus on the Data and Food Waste Management System

Adeeb A. Kutty
Mechanical and Industrial Engineering Department
College of Engineering, Qatar University
Doha, Qatar
akutty@qu.edu.qa

Galal M. Abdalla
Mechanical and Industrial Engineering Department
College of Engineering, Qatar University
Doha, Qatar
gmg5005@qu.edu.qa

Abstract

Achieving global food security requires addressing series of challenges, from food waste accumulation in the food supply chain (FSC) to tackling the gender disparities and climate-related concerns to promote sustainable consumption and production practices at several stages of the FSC. The paper presents a macroscopic review on several tools and techniques for improved decision making in food security-related projects focusing on areas of food waste management for circular food supply chain and for proper information management systems to tackle the prevalent challenges. Food waste prevention measures are also discussed covering all the three sustainability pillars. Food waste prevention strategies are effective in reducing the greenhouse gas (GHG) emissions and are considered effective in food waste treatment than the conventional food waste reduction practices. Food waste management and information management systems are regarded as a cross-cutting argument of high relevance for food sustainability-related research and policy implementation. The results show that the study conducted can stay as the basis for developing customizable toolkits and methodologies for region-specific food security and sustainability related challenges.

Keywords: Food security, Sustainability, Food Waste Management, Circular Food Supply Chain, Sustainable Consumption

1. Introduction

Food security and sustainable practices are development goals that form a part of any progressing economy resulting from individual actions such as farming, fisheries, poultry, forestry, and other development activities (FAO, 2015). Distortions in the earth's system dynamics can drastically affect multiple socio-economic and environmental parameters (FAO, 2008). These result in food insecurities that arise due to fragmented impacts on climate, land use patterns, production patterns on agricultural lands, and market values.

Identifying insecure food hotspots can aid in assessing the underlining causes associated with food insecurity and unsustainable practices (WFP, 2019). Picturizing vulnerable situations can help frame better operational and execution models (Kutty et al., 2020). Such attempts require a combination of conventional tools with advanced modern technologies and methods. Additionally, proper information management helps in tackling food insecurity challenges and achieve sustainability in production and consumption practices. Cutting down the food waste in the FSC can also help bridge the gap between food availability and demand by a surplus of 20% by 2050 (Searchinger, et al., 2018). FSC's have started adopting waste valorization strategies to promote circular economy principles where waste generated at each stage in the supply chain is used as an input to fuel subsequent levels in the supply chain, thus minimizing waste.

All these require proper data to be collected, monitored, analyzed, mapped, and visualized at several stages in the FSC. Data plays a vital role in delivering high-level insights about the prevailing insecurities across several areas and help in understanding changes both in the long term and short-term periods. A wide variety of tools and techniques exist in grey literature and academic articles that are used for monitoring and evaluating food wastes, the impact of climate changes on agricultural yields, disruptions in food supply chains, and cohesion in information management systems. A harmonized understanding of these tools and techniques to conduct better analysis and tackle these challenges is essential.

This research paper aims to bring out a macroscopic overview of several data management system tools and techniques used for food security-related projects. The research extends its focus on several tools, techniques, predictive models, and methods also related to the area of food waste management and disruptions in the FSC in focus to food security and circular economy.

The paper follows the structure were: Section 1 brings a brief introduction followed by Section 2 which highlights the motivation behind undertaking the research pointing towards the need to implement sustainable practices in tackling food insecurities. Section 3 describes the method used to undertake the macroscopic study followed by Section 4 discussing about several data management system tools and techniques. Section 5 section covers a review of tools, techniques, predictive models, and methods related to the area of food waste management and disruptions in the FSC in focus to food security and circular economy. Section 6 deals with food waste prevention measures for household food waste (HFW) and municipal food waste (MFW). The final section, Section 7 brings to limelight some futuristic measures to focus and encapsulates the research.

2. Research motivation

The data produced in food security-related projects include a) climate-related data for agricultural disaster analysis and risk management b) food production and consumption data c) food supply and demand data d) commodity price and trade-related data.

The information generated needs to be secured, and the data produced in food security-related projects need to be conscientiously assessed for technically supporting the IF system, basically, even after the project completion phase. In order to develop customizable database management systems, tools, data mapping systems, data visualization platforms, methodologies and sustainable solutions for food security-related projects tailored in accordance to several geographic variations and technological capacity, a better understanding of various tools, systems, methods and techniques used in related projects, scholarly articles and grey literature need to be framed.

Proper food waste assessment at multiple levels of the FSC requires proper tools. For this, proper knowledge and understanding of the existing tools and techniques for tracking and assessing food waste at several stages of the FSC is essential. These tools help to gather better insights in customizing region and domain-specific tool kits and valorizing strategies for the circular supply chain.

An extensive Scopus and ISI Web of Science database search with an extended search on several technical reports conducted during the study highlights that no research area has yet focused on bringing an overall review of the existing tools and techniques related to sustainable food security projects. Thus, a macroscopic understanding of this body of knowledge is essential to implement sustainable practices in tackling food insecurities. This justifies well the rationale of the research.

3. Method

This paper presents a macroscopic review of literature in the area of food security, related to the tools and techniques focusing on the data management systems and food waste management in the FSC as an attempt to address the research objectives. In addition, a review on the sustainable food waste prevention measures focusing on household food waste is also presented. Initially, the paper identifies the research objectives, formulates the research questions to be addressed, and develops a set of criteria (both inclusion and exclusion) that determines the choice of selection to fit the context they address.

A search using keywords in the Scopus online database, including a combination of words such as "Food Security," "Sustainability," "Food supply chain," "Circularity," "food waste" etc., for selecting peer-reviewed articles were conducted. The authors have selected peer reviewed journal and conference articles in the English language, as the inclusion criteria for the research. We have excluded articles in other languages (Spanish, Portuguese, Chinese, French, and German) than English. This search was conducted to obtain several tools, techniques, methods, and methodologies focusing on areas of food waste management for circular food supply chain and for proper data/information management systems.

The search yielded a total of 1,032 articles, of which 124 articles were related to the selection criterion and were used for further investigation after skimming through the abstract. Further investigation leads to the break down of articles to 67 documents based on their novelty and applicability in the area of food security and food circularity, rather than focusing on discussing the conventional tools and methods that were felt least relevant. Finally, all the valuable findings were manuscript into a macroscopic review paper. Several articles from magazines, book sections, annual government statistical reports, and online articles were used to support the writing process that was excluded in the initial selection criteria of the study.

4. Data management system tools and techniques

This section covers a brief review of several data analysis, visualization, mapping, and management tools used in the area of food security to support sustainability practices. Data visualization tools are predictive tools used to better understand the data analysis that relates to food insecurity with several socio-economic factors. Analyzing a collective set of data in the right way can bring powerful results and insights to the research in the area of food security. Empirical assessment software's such as SPSS (Statistical Package for the Social Sciences), GraphPad Prism, Minitab, and MATLAB are some of the widely used powerful data analysis and visualization software. These packages find a great deal of applicability in the field of food safety and security (Wang et al., 2015). Network plot functions are usually visualized using tool R programming, while Circos R. facilitates data visualization in discoid layouts (Xiao et al., 2013). Visualization software like Gephi, IBM Many Eyes, PanXpan, GraphViz, and Tableau are commonly used for commercial purposes due to their user-friendly interface.

All common data analytics and visualization tools can be used to handle data in food security related studies (Marvin et al., 2016; Wang et al., 2015). Machine learning and Artificial intelligence are used when formulating complex algorithms to predict decisions or build predictive models using a large volume of data (Marvin et al., 2017). Artificial intelligence and machine learning algorithms use data analysis method types such as Bayesian Networks (Chen & Qiao, 2015), Topological analysis (Marvin, et al., 2016), Neural Networks, transfer learning, manifold learning, and Restricted Boltzmann Machine. An object-oriented scripted programming language such as Python offers a great deal of data visualization tools and is regarded as one of the best choices for data visualization due to the wide variety of libraries offered by it.

Data mapping is done by transporting the data from analytical tools such as Microsoft Excel, SAS, Apache Spark, R or Tableau into certain mapping application platforms like the DevInfo- a web-based data mapping and visualization platform developed by UNICEF or using geographic information systems (GIS) platforms such as MapInfo Pro, ArcGIS, QGIS, Maptitude, ArcView or GeoMedia.

Cost-effective techniques such as cyber-physical sensing manage to deliver powerful results in monitoring, predicting, and regulating the quality of food and feed production on the harvested lands (Hirani, et al., 2018). Soil degradation can drastically affect the agroecosystem. Menšík et al. (2018) use Principal Compound Analysis (PCA) as a tool to assess the change in soil quality and monitor the level of soil degradation. In order to monitor the physiological processes determining the crop functionality as a part of the agricultural data analysis process, image capturing technologies such as the "automatic feature extraction system" developed by Van Pham, Lee, & King (2019) are used. Changes in cropland use patterns drastically affect food security. Visualization and monitoring tools such as the "shape-matching cropping index mapping method" developed by Liu et al., (2018) can be used to study the land-use intensity.

There are also several customized software packages for data analysis and visualizations in the area of food safety and security like the Key Indicator Data System (KIDS) used for congregating, mapping and dissipating several food insecurities and vulnerability indicators, developed by FAO- World Agriculture Information Centre; Dynamic Atlas, info management and publishing package containing a collection of tools used for managing complex/unstructured information and metadata; and GeoNetwork, a spatial data, and information management catalog system that enables the exchange of geographic information and thematical maps to a wider audience (GeoNetwork Opensource, 2019).

5. Circular Food Security strategies

The circular economy model aims at minimizing the waste and energy resources during the several stages of a FSC, catering to the disruptions in the FSC, and optimizing it. In an attempt to skyrocket the transition towards a circular economy, several types of research have been done in the past couple of years in the area of food security using novel techniques, methods, tools, and application platforms. This section covers a review of tools, techniques, predictive models, and methods related to the area of food waste management and disruptions in the FSC in focus to food security and circular economy.

Addressing the level of uncertainty in the FSC emulates process efficiency. In the research published by Bottani et al., (2019), a "bi-objective mixed-integer optimization" has been proposed to design a resilient and sustainable food supply chain, where the model utilizes an Ant Colony Optimization technique for multi-product adoption into the supply chain. A multi-product adoption requires proper demand prediction. Wang (2015) used an improved "cloud particle swarm optimization algorithm" to predict multiple demands in the FSC. Identifying the disruptions and elements that account to the risk, such as waste generation in a networked system, is essential in order to apply certain mitigative strategies (Lu et al., 2019). Owen et al., (2018) employed a combined input-output analysis (IOA) and structured path analysis technique to investigate the impact generated at various points in the supply chain due to the cross interaction between energy, food, and water, where several multiregional input-output databases were used. Bouzembrak & Marvin (2019) developed a Bayesian Network-based predictive model using machine learning algorithms to predict the unexpected level of hazards in a food supply chain network. Guo et al., (2015) used an Artificial Neural Networks (ANNs) and Support Vector Machines (SVMs) to develop predictive models to monitor the total nitrogen concentration in the combined food and water waste, thus helping formulate strategies for reduced total nitrogen concentrations, hence balancing the networked supply chain. Valorizing food waste as a bi-product into the FSC entails tremendous scope in achieving sustainability, thus helping formulate sustainable food security strategies for a circular economy. Martín et al. (2017) developed a Multi-Criteria Decision Analysis (MCDA) tool that combines Analytic Hierarchy Process (AHP) with Geographic information system (GIS) optimization for implementing valorization strategies on food waste in the regional supply chain. Ohlsson (2004) uses a Life Cycle Assessment (LCA) to identify the waste produced and disseminated through several stages in a FSC. While Nie et al., (2018) used a combined Cost-Benefit Analysis (CBA) with LCA and AHP to categorize the waste with respect to their impact generation on the environmental, economic and social pillars of sustainability simultaneously. Springer & Schmitt (2018) employed a combined approach enhancing the "Rectangular Choice-of-Technologies" model with a Material Flow Analysis (MFA), LCA, and regional IOA to segregate waste based on their usage capacity for promoting green supply chain strategy.

Quantifying the level of greenhouse gas (GHG) emission along the various levels of the FSC is essential to improve the food system. Inaba et al. (2009) used a hybrid-LCA approach with a particulate flow inventory analysis in the food waste management system to investigate the level of CO_2 emission. While Boehm et al., (2018) examined the concentration of GHG emissions across the food value chain and the impact these emissions hold in the "spending by food variants" in the United States using an Economic IO-LCA technique.

6. Sustainable food waste prevention measures

Several measures have been implemented in the past that are fairly efficient to reduce the food waste worldwide. However, a very little information exist on the sustainable food waste reduction measures based on the three main pillars of sustainability namely; the economic, environment and social dimensions. This has hindered sustainability practitioners in understanding what measures can be prioritized for sustainable food waste reduction in long term. Reducing the food waste along the food chain comes with a transaction cost. The preventive measures applied should yield an economic incentive and outweigh the cost. This subsection thus deals with food waste prevention measures for household food waste (HFW) and municipal food waste (MFW).

6.1 Environmental dimension

Reducing the food waste accounts for eliminating the end-of-life (EOL) stage in the life cycle of the food chain. An MFA combined with LCA was used by Sadeleer, Brattebø, & Callewaert, (2020) to study the benefits associated with reducing food waste when compared to recycling strategies such as anerobic digestion (AD) and thermal waste treatment. The study concluded adopting household food waste prevention rather than attempting to optimize the food waste in the value chain. Results show that nearly 15-30% of GHG emissions are reduced by attempting to reduce the food waste. Similar results were found in the LCA conducted by Wang et al., (2020) to reduce GHG emissions through practices such as waste treatment, recycling and prevention. Measures such as segregating HFW and MFW from thermally treated waste, treating HFW and MSW using AD, and using material recovery plants to retreat the thermal waste has resulted in a reduction of 421.9 kg CO_2-eq./Ca of GHG emissions. Thus, proving these measures efficient in preventing food waste in long run.

Composting techniques such as windrow composting and blended AD methods have shown significant results in reducing GHG emissions related to food waste thus, helping prevent food waste accumulation in the life chain. An Environmental Impact Assessment (EIA) using a hybrid Life Cycle Sustainability Analysis (H-LCSA) was used to assess the impacts and savings associated with these composting techniques by Al-Rumaihi et al., (2020). A similar approach combined with economic allocation was used to study the impact of converting food and vegetable waste (FVW) into vermicomposting by E.A.Tedesco et al., (2019). The bioconversion of FVW into feed for earthworms in the soil show promising results in reducing food waste, gradually preventing the food waste when multi breaded in the soil for long term. Nano packaging technique to enhance the shelf life promise considerable reduction in food waste. Zhang et al. (2019) used LCA combined with behavioral economics to study the impact of nano packaging technique on shelf life extension to mitigate the carbon foot print associated with its use stage.

6.2 Economic dimension

Food waste prevention measures need to be calculated based on the economic savings on disposal cost, neglected embodied cost, and other associated economic costs to support the environmental dimension (Kucukvar et al., 2019; Abdella et al., 2020). The administrative costs with the cost incurred in segregating the waste and its proper treatment can be classed under the embodied cost in food waste prevention. Implementation costs include the fixed cost and variable costs associated with food waste prevention measures such as implementing a new technology, waste awareness campaign costs, logistic costs etc.

The avoided disposal costs can be calculated using Life Cycle Costing (LCC) approach. This can even include futuristic costs as well that occurs through the life cycle of a process along with the cost incurred with the collection and disposal of waste in the life chain. The cost associated with poor emptiability was calculated in terms of value added using an LCC approach integrated with Multi-Criteria Decision Analysis (MCDA) by Wohner et al., (2020) for food packaging systems. A quarter waste visual method combined with LCC was used to assess the cost related to food production in school canteens by García-Herrero, Menna, & Vittuari, (2019). Such assessment approaches considers cost related to material acquisition, waste segregation and disposal costs, and labor costs. Similarly, land fill reduction, a popular waste reduction method minimizes life cycle disposal costs up to 75% (C.Slorach et al., 2020). A combined LCSA and LCC was used to arrive at the results. Costs associated with the management systems such as the food waste AD systems and composting systems can be determined through a societal LCC and EIA-LCC approaches (Edwards et al., 2018).

A marginal abatement cost curve (MACC) helps in identifying the ecological savings associated with food waste reduction and prevention measures. A visualization based on the cost saved to the waste reduced/prevented is facilitated in the curve. Monetary data is considered for the evaluation purpose were the calculated figures can help in adding to the benefits related to the prevention of waste in the FSC. Here a Cost-Benefit Analysis (CBA) is used combined with other sustainability assessment tools.

6.3 Social dimension

Several social measures can be adopted for sustainable results in food waste prevention that stay next to the ecological and economic measures such as;

a. Surplus food redistribution: To identify the value of food redistributed, a Social Life Cycle Assessment (SLCA) was used by Bergström et al., (2020) considering the case of food banks, so that the social value can be assessed. Reallocation of surplus food to reusable end-life product with high quality accounts for a high social value due to the vast amount of job opportunities created.
b. Food valorization: Technical collaboration, sharing knowledge and several stakeholder involvement are crucial when implementing food waste valorization measures due to the socio-economic feasibility that arise in the implementation and reutilization of food waste. A mix of SLCA and social life cycle costing (SLCC) can be used to gauge the costs associated with these valorization schemes (Martin, et al., 2018).
c. Behavior change: Certain sustainability evaluation key performance indicator (SE-KPI) exist in monitoring "consumer behavior change"
    1. Net benefits associated with food waste prevented to the cost of action

2. Number of people changing behavior to the cost of action
3. Labor productivity ratio as a result of possible improvement actions.

The Likert scaling method can be used to rate the efficiency and effectiveness associated with the performance of the indicators. The socio-economic return associated with implementing behavioral change strategies account for sustainable results in long run.

d. Supply chain efficiency: Closing the FSC with surplus food and associated waste is a promising practice to eliminate food waste (Teigiserova, Hamelin, & Thomsen, 2019). Integrated sustainability assessment approaches such as LCSA, SLCC and CBA can be used to monitor the food waste generated at various levels of the FSC. The identified food waste can be eliminated by applying circular economy strategies thus making the food supply chain more efficient.

7. Conclusions and Remarks

The study conducted a macroscopic review based on a "search and analysis" technique in prominent databases and internet search bars for scholarly articles and grey literature, respectively, that deal with several tools and techniques related to information management systems and food waste valorization in the FSC. The review clearly shows that apart from specific techniques, methods and measures used for food waste related sustainability assessment, most tools are customized for objective specific applications such as SimaPro and GaBi. These are pre-calculated packages that are simplified for analysts to ease the work and does not include in the scope of this research. The tools discussed in this review contain concatenated methods that generate several sustainability indicators. In addition to the tools and measures stated in this review from scholarly articles, some other prominent tools and methods have also been listed in Table 1. These tools or methods can be used to carry out food sustainability assessment for cicular food security practices and waste prevention. These cover all the pillars of sustainability including the socio-economic and ecological dimensions of sustainability.

Table 1. Additional tools or methods for sustainability assessment related to food waste prevention and circularity

SL.No.	Type	Tools or Methods	Abbreviation
1.	Integrated methods	a) "COMbining environmental Performance indicators, LIfe cycle approach and Multi-criteria to assess the overall ENvironmental impacT"	COMPLIMENT
		b) EcoDesign	EcoD
		c) Eco-Efficiency Analysis	EEA
		d) Life cycle iNdeX	LinX
		e) Product Sustainability Assessment	PROSA
		f) Product Oriented Environmental Management system	POEMS
		g) Socio-Eco-Efficiency Analysis	SEEBALANCE
2.	Hybrid methods	a) "Combined Environmentally Extended Input-Output Analysis with Life Cycle Assessment"	CEEIOA-LCA
		b) "CEEIOA-LCA with General Equilibrium model"	CEEIOA-LCA/GEM
		c) Life Cycle Activity Analysis	LCAA
3.	Integrated tools	a) "Global Environmental Management Initiative Sustainable Development Planner"	GEMISD Planner
		b) Future Fit Business Benchmark	FutureFitBB

Table 1. Additional tools or methods for sustainability assessment related to food waste prevention and circularity

SL.No.	Type	Tools or Methods	Abbreviation
4.	Others	a) Carbon Footprint Analysis	CFA
		b) Emergy Analysis	EA
		c) Ecological Footprint Analysis	E-FA
		d) Environmental Life Cycle Costing	E-LCC
		e) Exergetic LCA	E-LCA
5.	Customised packages	a) EcoSolvent Tool	EcoSolvent
		b) Integrated Waste Management-2	IWM-2
		c) Organic WAste REsearch	ORWARE
		d) Waste Reduction Algorithm	WAR

Information management tools and techniques in addition to an extended focus on methods, methodologies, and tools for food waste management in the FSC has been proposed concerning their applicability (if proven worthy in the past) for supporting the development of region-specific customizable toolkits, frameworks, and methodologies for improved evidence-based decision making. The paper rules out tools and techniques that narrow down its applicability context for specific project applications and the ones that ignore the technical capacity for regional and national development. The research recommends considering the technical capacity and requisites while designing management strategies for acquired data and harmonized circular supply chains. Integrated management systems that combine multiple tools by extending the existing models and technologies need to be crafted for country-specific applicability. The developed technology needs to be made as an open source for extending its application to geographic regions that face similar threats and challenges in driving the systems to a more global context. A proper Strength, Weakness, Opportunities, and Threat (SWOT) analysis on the existing management systems, tools, methods, models, and technologies is highly recommended. This holds high-level significance in making predictive strategies for decision making and remodeling the current systems.

In a nutshell, this research stays as a basis for future research in the area of food security, ensuring sustainable production and consumption practices (in accordance to UN Sustainable Development Goal- UN SDG 12) for researchers and policymakers that intend to broaden their knowledge in the area of tools and techniques used in sustainable food security-related projects. Moreover, the authors suggest the extension of time line monitoring, such as time-series analysis and forecasting and online control charts, for assessing of the fluctuations in the sustainability performance over time (Abdella et al., 2014-2019; Kim et al., 2019). Such tools would be helpful for detecting deviations from the target level of sustainability and hence identify the time when an intervention becomes urgent.

References

Abdella, G. M., Yang, K., Alaeddini, A., Multivariate Adaptive Approach for Monitoring Simple Linear Profiles, International Journal of Data Analysis Techniques and Strategies, Vol. 6(1), pp. 2-14, 2014.

Abdella, G, M., Al-Khalifa, K. N., Kim J., Hamouda, A. M. S. Double EWMA based Polynomial Quality Profiles Monitoring. Quality and Reliability Engineering International. Vol. 38(8), pp. 2639–2652, 2016.

Abdella, G. M., Kim, J., Kim, S., Al-Khalifa, K. N., Jeong, M. K., Hamouda, A. M., & Elsayed, E. A. An adaptive thresholding-based process variability monitoring. Journal of Quality Technology, 51, 1-14, 2019

Abdella, G. M., Kucukvar, M., Onat, N. C., Al-Yafay, H. M., and Bulak, M. E., Sustainability assessment and modeling based on supervised machine learning techniques: The case for food consumption, J. Clean. Prod., vol. 251, Apr. 2020.

Al-Rumaihi, A., McKay, G., Mackey, H. R., and Al-Ansari, T., Environmental Impact Assessment of Food Waste Management Using Two Composting Techniques, Sustainability, Vol. 12, no. 4, 2020

Bennbea, S., Wazwaz, A., Abujarbou, A., Abdella, G. M., & Musharavati, F., Towards Sustainable Society: Design of Food Waste Recycling Machine. The Proceedings of the International Conference on Industrial Engineering and Operations Management, Bandung, Indonesia, March 6-8, pp. 2495–2508, 2018

Bergström, P., Malefors, C., Strid, I., Hanssen, O. J., and Eriksson, M., Sustainability assessment of food redistribution initiatives in Sweden, Resources, Vol. 9, no. 3, 2020

Boehm, R., Wilde, P. E., Ploeg, M. V., Costello, C., and Cash, S. B., A Macroscopic Life Cycle Assessment of Greenhouse Gas Emissions from U.S. Household Food Choices, Food Policy, Vol. 79, pp. 67-76, 2018

Bottani, E., Murino, T., Schiavo, M., & Akkerman, R., Resilient food supply chain design: Modelling framework and metaheuristic solution approach. Computers & Industrial Engineering, Vol. 135, pp. 177-198, 2019

Bouzembrak, Y., and Marvin, H. J., Impact of drivers of change, including climatic factors, on the occurrence of chemical food safety hazards in fruits and vegetables: A Bayesian Network approach. Food Control, Vol. 97, pp. 67-76, 2019

C.Slorach, P., K.Jeswani, H., Cuéllar-Franca, R., and Azapagic, A., Assessing the economic and environmental sustainability of household food waste management in the UK: Current situation and future scenarios, Science of the Total Environment, 710, 2020

Chen, Y., and Qiao, J., Protein-protein interaction network analysis and identifying regulation microRNAs in asthmatic children. Allergol Immunopathol (Madr), Vol. 43, no. 6, pp. 584-92, 2015

E.A.Tedesco, D., Conti, C., Lovarelli, D., Biazzi, E., and Bacenetti, J., Bioconversion of fruit and vegetable waste into earthworms as a new protein source: The environmental impact of earthworm meal production. Science of the Total Environment, Vol. 683, pp. 690-698, 2019

Edwards, J., Burn, S., Crossin, E., and Othman, M., Life cycle costing of municipal food waste management systems: The effect of environmental externalities and transfer costs using local government case studies, Resources, Conservation and Recycling, pp. 118-129, 2018

FAO., Climate Change and Food security: A framework document. United Nations, Rome. Available: http://www.fao.org/forestry/15538-079b31d45081fe9c3dbc6ff34de4807e4.pdf, 2009

FAO., Global food losses and food waste - Extent, Causes and Prevention. Rome: United Nations. Available: https://reliefweb.int/report/world/global-food-losses-and-food-waste-extent-causes-and-prevention, 2011

FAO., Information systems for Food security and Nutrition. United Nations. Available: http://www.fao.org/3/a-au836e.pdf, 2015

García-Herrero, L., Menna, F. D., and Vittuari, M., Food waste at school. The environmental and cost impact of a canteen meal, Waste Management, Vol. 100, pp. 249-258, 2019

GeoNetwork Opensource., OSGeo Project. Available: https://geonetwork-opensource.org/. 2019

Guo, H., Jeong, K., Lim, J., Jo, J., Kim, Y. M., Park, J.-p., . . . Cho, K. H., Prediction of effluent concentration in a wastewater treatment plant using machine learning models. Journal of Environmental Sciences, Vol. 32, pp. 90-101, 2015

Hirani, P., Balivada, S., Chauhan, R., Shaikh, G., Murthy, L., Balhara, A., . . . Guha, S., Using Cyber Physical Systems to Map Water Quality over Large Water Bodies. Proceedings of the 17th IEEE SENSORS Conference, New Delhi, India, 2018

Inaba, R., Nansai, K., Fujii, M., and Hashimoto, S., Hybrid life-cycle assessment (LCA) of CO2 emission with management alternatives for household food wastes in Japan. Waste Management & Research, Vol. 28, no. 6, pp. 496-507. 2009

Kim, J., Abdella, G, M., Kim, S., Al-Khalifa, K. N., Hamouda, A. M. S. Control charts for variability monitoring in high-dimensional processes. Computers & Industrial Engineering, Vol. 130, pp. 309-316, 2019

Krishnan, R., Agarwal, R., Bajada, C., and Arshinder, K., Redesigning a food supply chain for environmental sustainability- An analysis of resource use and recovery. Journal of Cleaner Production, 2018

Kucukvar, M.m Onat, N. C., Abdella, G. M., Tatari, O., Assessing regional and global environmental footprints and value added of the largest food producers in the world, Resour. Conserv. Recycl., vol. 144, pp. 187–197, 2019.

Kutty, A. A., Abdella, G. M., Kucukvar, M., Onat, N. C., and Bulu, M., A system thinking approach for harmonizing smart and sustainable city initiatives with United Nations sustainable development goals, Sustainable Development, 2020

Liu, J., He, X., Liang, F., & Li, T., Cropland use change analysis in Shaanxi Province of China based on the shape-matching cropping index mapping method. 38th Annual IEEE International Geoscience and Remote Sensing Symposium, IGARSS 2018, pp. 3011-3014, Valencia, Spain, 2018

Lu, X., Horn, A. L., Su, J., & Jiang, J., A Universal Measure for Network Traceability. Omega, Vol. 87, pp. 191-204. 2019

Martin, D. S., Bald, C., Cebrian, M., Iñarra, B., Orive, M., Ramos, S., and Zufía, J., Principles for developing a safe and sustainable valorization of food waste for animal feed: Second generation feedstuff, Handbook of Famine, Starvation, and Nutrient Deprivation, pp. 1-20, 2018

Martín, D. S., Orive, M., Martinez, E., Iñarra, B., Ramos, S., González, N., . . . Zufía, J., Decision Making Supporting Tool Combining AHP Method with GIS for Implementing Food Waste Valorisation Strategies. Waste and Biomass Valorization, Vol. 8, no. 5, pp. 1555–1567, 2017.

Marvin, H. J., Janssen, E. M., Bouzembrak, Y., Hendriksen, P. J., and Staats, M., Big data in food safety: An overview. Critical reviews in food science and nutrition, Vol. 57, no. 11, pp. 2286-2295, 2017

Marvin, H., Bouzembrak, Y., Janssen, E., Fels-Klerx, H. V., Asselt, E. V., and Kleter, G., A holistic approach to food safety risks: Food fraud as an example. Food Research International, Vol. 89(Pt 1), pp. 463-470, 2016

Menšík, L., Hlisnikovský, L., Pospíšilová, L., and Kunzová, E., The effect of application of organic manures and mineral fertilizers on the state of soil organic matter and nutrients in the long-term field experimen. Journal of Soils and Sediments, Vol. 18, no. 8, pp. 2813-2822, 2018.

Nie, Y., Wu, Y., Zhao, J., Zhao, J., Chen, X., Maraseni, T., and Qian, G., Is the finer the better for municipal solid waste (MSW) classification in view of recyclable constituents? A macroscopic social, economic and environmental analysis. Waste Management, Vol. 79, pp. 472-480, 2018

Ohlsson, T., Food waste management by life cycle assessment of the food chain. Journal of Food Science, Vol. 69, no. 3, 107-109, 2004

Owen, A., Scott, K., and Barrett, J., Identifying critical supply chains and final products: An input-output approach to exploring the energy-water-food nexus. Applied Energy, Vol. 210, pp. 632-642, 2018

Sadeleer, I., Brattebø, H., and Callewaert, P., Waste prevention, energy recovery or recycling - Directions for household food waste management in light of circular economy policy, Resources, Conservation and Recycling, Vol. 160, 2020

Searchinger, T., Waiter, R., Hanson, C., Ranganathan, J., Dumas, P., and Matthews, E., Creating a sustainable food future: a menu of solutions to feed nearly 10 billion people by 2050 - synthesis report. World Resource Institute. Available: https://apo.org.au/node/230536, 2018

Springer, N. P., and Schmitt, J., The price of byproducts: Distinguishing co-products from waste using the rectangular choice-of-technologies model. Resources, Conservation and Recycling, Vol. 138, pp. 231-237, 2018

Teigiserova, D. A., Hamelin, L., and Thomsen, M., Towards transparent valorization of food surplus, waste and loss: Clarifying definitions, food waste hierarchy, and role in the circular economy, Science of The Total Environment, 2020

UNDESA., Growing at a slower pace, world population is expected to reach 9.7 billion in 2050 and could peak at nearly 11 billion around 2100. United Nations Department of Economics and Social Affairs, Available: https://www.un.org/development/desa/en/news/population/world-population-prospects-2019.html, 2019

Van Pham, T., Lee, B., and King, S., A Comparison of Effectiveness Between 2-Dimensional and 3-Dimensional Data Visualization in Detecting Plant Architectural Characteristics. 21st International Conference on Human-Computer Interaction, HCI International 2019, pp. 223-236, Orlando, United States, 2019

Wang, D., He, J., Tang, Y.-T., Higgitt, D., and Robinson, D., Life cycle assessment of municipal solid waste management in Nottingham, England: Past and future perspectives, Journal of Cleaner Production, Vol. 251. 2020

Wang, H., Research on demand prediction of fresh food supply chain based on improved particle swarm optimization algorithm. Advance Journal of Food Science and Technology, Vol. 7, no. 10, pp. 804-809, 2015

Wang, Q., Hou, P., Zhang, F., and Wang, C., Integrated Monitoring and Assessment Framework of Regional Ecosystem under the Global Climate Change Background. (D. Jiang, Ed.) Advances in Meteorology, pp. 1-8. 2014

Wang, Y., Yang, B., Luo, Y., He, J., & Tan, H., The Application of Big data Mining in Risk Warning for Food Safety. Asian Agricultural Research, Vol.7, no. 8, Available: http://ageconsearch.umn.edu/record/210801/files/21.PDF, 2015

WFP., Food Security Analysis. Available: World Food Programme: https://www.wfp.org/food-security-analysis, 2019

Wohner, B., Gabriel, V. H., Krenn, B., Krauter, V., and Tacker, M., Environmental and economic assessment of food-packaging systems with a focus on food waste. Case study on tomato ketchup, Science of the Total Environment,Vol. 738, 2020

Xiao, M., Prabakaran, P., Chen, W., Kessing, B., and Dimitrov, D. S., Deep sequencing and Circos analyses of antibody libraries reveal antigen-driven selection of Ig VH genes during HIV-1 infection. Experimental and Molecular Pathology, Vol. 95, no. 3, pp. 357-363, 2013

Zhang, B. Y., Tong, Y., Singh, S., Cai, H., and Jen-YiHuang., Assessment of carbon footprint of nano-packaging considering potential food waste reduction due to shelf life extension. Resources, Conservation and Recycling, Vol. 149, pp. 322-331, 2019

Biographies

Adeeb A. Kutty is an accomplished professional with a bachelor's degree from the University of Calicut, India, in Electrical and Electronics Engineering and a master's degree holder in Technology and Engineering Management from Universitat Rovira i Virgili, Tarragona, Kingdom of Spain. He is currently doing his Ph.D. in Engineering Management and works as a Graduate Teaching and Research Assistant in the Department of Industrial Engineering at Qatar University. His area of research interest includes sustainability, food security and waste management, smart cities, autonomous electric vehicles, transportation, and project management.

Dr. Galal M. Abdella serves as the Assistant Professor in the Department of Industrial Engineering, College of Engineering, Qatar University. He is currently the graduate program coordinator for Engineering Management Program at Qatar University. His research area has always been centered on utilizing mathematics and advanced statistical data analysis for high dimensional data processing, circular economy and food security, modeling and simulating rare events, quality data modeling and analysis, and project resource management.