Navigating the Diet-Environment-Health Trilemma: Insights from Zoology and Food Systems Science for Sustainable Agri-Food Transitions

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Abstract

The food industry's 31% contribution to greenhouse gas emissions and pollution has led to a decline in insect populations and soil fertility by over 70% and 50%, respectively. To address this, transformative efforts in agri-food systems are being made, including technologies like climate-sensitive crops, smart farming, and insect farming. Traditional knowledge is also being incorporated into sustainable practices, preserving 80% of terrestrial biological variety. Kleiner's paleodietary approach advocates green and nutrient-sensitive diets to combat obesity-related disorders, comparing animal consumption to alternative protein sources like insect farming and cultured meats. Biomimicry is also discussed, including architectural designs, vertical farming, grazing, crop rotation, and crop pollination. The chapter demonstrates how ecological science, policy reform, meals, and frameworks can be used to achieve the Sustainable Development Goals (SDGs), including reducing food loss and waste, improving equitable distribution and consumption of nutritious meals, and developing low-GHG and sustainable food production systems.

Keywords: sustainable food systems, biodiversity, climate-resilient crops, precision agriculture, Indigenous knowledge

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Introduction

The interplay between nutrition, environment, and health forms a crucial trilemma that is fundamental to human survival and sustainability. Food intake, a basic human necessity, plays a role in many physiological processes such as immune responses, metabolism, and disease prevention, and is sensitive to nutritional status (Shao et al., 2021). Consumption of unhealthy food products, including processed foods, sugary products, and unhealthy fats, increases the body's risk of critical diseases, including obesity, diabetes, and heart disease. Such eating patterns, however, are not created in a vacuum, instead, they are influenced by environmental and socioeconomic conditions. For example, the company's choice to employ Meal Kits is greatly determined by factors such as limited access to quality foods, marketing of undesirable foods, general availability of fresh and balanced diets, and affordability considerations (Sonmez and Taylor Jr, 2024). Further, pollution of air and water, climate change, and habitat loss only make the health of the public worse. For instance, climate change causes food insecurity, particularly facilitating the evolution of diseases and increasing vulnerability to toxins that lead to respiratory and cardiovascular diseases, thus creating a vicious cycle (Saad-Hussein et al., 2025).

To tackle this trilemma, it is necessary to apply a cross-disciplinary framework of zoo-ecology as well as Food Systems Analysis. It provides knowledge on species distribution and interactions, behaviors, and contributions like pollination and biotic pest control and driving values and principles for diversified sustainable agriculture food systems (Rehman et al., 2022). Food Systems Science, in contrast, integrates ecological, economic, and social approaches to create measures that would minimize humankind's negative effect on the environment while elevating the standard of living. Such an interdisciplinary approach raises the question of studies where ecological systems, zoological sciences, and food systems meet to provide solutions for ecological problems and public health. With such synergistic approaches, it becomes feasible to speak of such concerns as sustainable agriculture, the impact of contemporary food production and distribution systems, proper nutrition, and the conservation of people's and the environment's health (Deguine et al., 2017).

The Evolutionary Basis of Human Diets

Comparing cultural and genetic points of view on human diets helps to explain the connection between nutrition, behavior, and diet.

Cross-sectional research into other animals, especially primates, shows similar digestive systems that exist in different habitats (Modrackova et al., 2021). Modern primate diets, such as fruits, leaves, and, at some times, small mammals or insects, correspond to the theoretical patterns of scarce food search in areas of geographical location. Modern man's diet however includes what early species of Homo did not, processed foods, sugars, and unhealthy fats among others (Alt et al., 2022). This shift is the basis of the evolutionary grievance theory that postulates that our metabolic structure remains more appropriately wired on the natural, whole foods of the Palaeolithic era. These historical adaptations are rather preposterous compared to modern dietary practices, which point out the fact that current epidemics of obesity, diabetes, and cardiovascular disorders that tragically affect human populations can be attributed to a bias of modern food environments toward elements that did not exist in ancestral diets (Dietert, 2021).

It will further be seen how the habits that animals adopt for searching for food contain useful pointers towards healthy food consumption. Most of the species eat food in a way that ensures that their resources fit naturally into the environment and concerning available foods, they change their food habits according to the season and prevailing climate. Of these principles, humans can adopt the idea of eating a diet that is rich in variety, season-based diets, and localized diets with minimal dependence on industrial or commercialized products (Solovieva et al., 2025). It is an evolutionary nutrition approach and consequently reduces the current destructive footprint of the food industry.

Environmental Footprint of Modern Diets

Environmental Interactions of contemporary diets provide a perfect example of how diet choice shapes planetary boundaries concerning Biodiversity, Climate, and Resources. Red meat and animal-based products generally have large footprints and are associated with a wide range of environmental impacts. For example, the production of 1kg of beef requires 20 times as many resources as the production of a gram of legumes and leads to emissions of approximately 25 times that of greenhouse gases (Jain et al., 2024). Large-scale production of industrialized animals and extensive soybean production have facilitated deforestation in the basin, and this has had a knock-on effect on habitat and species loss, especially in the Brazilian part of the basin. Likewise, the AMRI flagged the mud-walled rice paddies of Asia as sources of both methane and water pollution owing to monoculture (Crona et al., 2023; Ibrahim et al., 2023). Such examples highlight the importance of dietary changes that do not harm the environment. These environmental challenges can also be addressed by changing to plant-based diets and beginning to depend less on animal products, many of which are resource-intensive.

This study shows that applying ecological factors to agricultural practices can augment sustainability tactics. Some examples include the use of advanced knowledge of pollinators, such as bees, in the improvement of crop production and reinforcement of necessary sustainable practices. Research on grazing systems is applicable in systems that enable the conservation of soils and prevent overgrazing to enhance the externalities within ecosystems (Blanco and Lal, 2023). Furthermore, acquiring new knowledge and adopting bio-based strategies as concepts for the sustainable organization of food search and consumption are the peculiarities of this study. Figure 1 depicts that applying these outlined policies will go a long way toward achieving a world where humanity will not only be fed but the environment will also be maintained, thus restoring the required balance for food security and ecological diversity.

Greenhouse Gas Emission Reduction via Plant-Based Diets

$$E_{reduction}=(E_{animal\text{-}based}-E_{plant\text{-}based}) \times C$$

where $E_{animal\text{-}based}$ is the emission per unit of animal-based products (Ereduction) achieved by substituting animal-based diets of plant-based products, Eplant-based is the emission per unit of animal-based products, $E_{plant\text{-}based}$ is the emission per unit of plant-based products, and C is the consumption level in units.

Table 1 provides an in-depth analysis of the environmental impact of animal- and plant-based diets, including water use, land use, greenhouse gas emissions, and potential reduction benefits on a global scale.

Table 1: Comprehensive comparison of environmental impacts between diet types

Diet Type	Water Use (L/kg)	Land Use (m^2/kg)	Emissions (kg CO_2 e/kg)	Energy Use (MJ/kg)	Reduction Potential in GHG Emissions (%)
Animal-based (Beef)	15,400	30	25	50	-
Animal-based (Poultry)	4,300	7	5	18	60
Plant-Based (Legumes)	1,250	2	1	2	80
Plant-Based (Cereals)	2,400	3	1.6	3.5	70
Plant-Based (Vegetables)	322	0.2	0.3	1	90

Animal Welfare in Food Systems

Animal welfare, situated at the intersection of consumption, nature, and health, plays a crucial role in modern food systems. Chick's ethical considerations primarily focus on the well-being of animals in regions employing industrial livestock farming methods. Research indicates that these systems subject animals to considerable stress, behavioral restrictions, and overcrowding, raising significant concerns about their ability to meet acceptable animal treatment standards. An effective approach involves integrating traditional wildlife population management practices with strategies that mimic natural cattle population organization. Rotative stocking density, greater pasture quality, and refining methods of animal feeding and grazing can improve welfare while fulfilling the principles of ethical management of animals, which embrace care and stewardship of animal lives (Vlaicu et al., 2024).

Apart from ethical aspects, animal protection contributes to environmental health, as well as being protective of people's health. Stress-related diseases of livestock entail the use of antibiotics, which are widely applied in problematic segments such as intensive farming; the misuse leads to the development of antibiotic-resistant pathogens that are threatening human health. However, the very limitations in industrial farming, overgrazing, and vegetation cutting all hinder occurrences of erosive aspects of the environment, including water and soil erosion and the felling of trees (Padhiary and Kumar, 2024). Most of these practices help in matters related to the emission of greenhouse gases and the quality of soil. When scaling up processes and systems that support a more sustainable and fair system, the authors agree with the three-pronged assessment of improving animal welfare, environmental conditions within the new food systems, and the health impact that would lead to change for the benefit of animals, consumers, and producers.

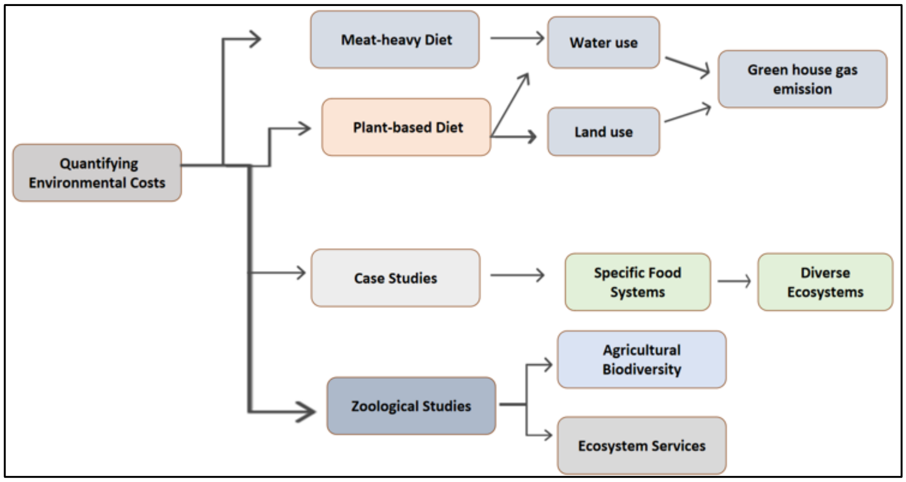

Fig. 1: Environmental Footprint of Modern Diets

Challenges Solving Food Systems through Biology

Bio-inspired solutions are defined as new and creative ideas that are taken directly from natural solutions, which are good working solutions for proper food system problems. For instance, investigations have been made on the rumen where a well-organized microbial consortium performs the decay process of plant material to obtain energy and nutrients without bargaining for methane emissions. It has promoted the establishment of nutritional supplements and microbial therapy to curb the effects of cattle farming on the atmosphere. A lot of research is being done on the natural, low-inflation, agricultural production models that work similarly. Yadav et al. (2023) illustrate how advancement in biological science can positively help in animal breeding and on the other hand reduce the impacts of conventional breeding on the environment.

The application of such biologically motivated methods is best illustrated by the case of ant colony algorithms in agricultural management. That has been highlighted by Karunathilake et al. (2023) Where ants were understood to have incredible techniques in navigation and managerial work that have been enhanced to enrich precision agriculture. They enhanced the optimum use of fertilizers, pest and disease control, as well as the planting practices that enhance crop production and utilization of available resources. In this regard, massive strategies that mimic a lot from ants also encompass Smartfood, giving equitable and timely delivery of food supply chains without a hitch. These innovations, copying having organized and behaving in the colony like ants, demonstrate that the systems in nature can be used to solve the acute issues of today's agriculture.

This table outlines the quantitative benefits of sustainable agricultural practices, focusing on yield improvement, reduction in greenhouse gas emissions, and resource-use efficiency.

Table 2: Productivity and emission benefits of advanced sustainable practices

Practice	Yield Improvement (%)	Emission Reduction (%)	Resource Use Reduction (%)	Soil Organic Matter Increase (%)	Cost Savings (%)
Rotational Grazing	25	30	25	15	20
Precision Agriculture	20	50	30	10	25
Vertical Farming	75	90	95	8	40
Agroforestry	30	35	20	20	15
Conservation Tillage	15	25	18	30	12

Food Web Disruptions and Their Implications

People's agricultural practices have upset the natural food webs, making the ecological and economic difficulties more strident, thus showing a weakness in ecosystem support. The apex predators are at the forefront of starting trophic cascades, however, their population has reduced by 50% in the past hundred years, mainly because of habitat loss and hunting (Ordiz et al., 2021). This has led to overgrazing and lots of crop damage by herbivores like deer and rodents due to the reduced penetration by carnivores to control their numbers. For example, an uncontrolled population of rodents damaging agricultural habitats is known to cause the world's cereal crop loss by 5%-10% per year, equivalent to $30B (Singleton et al., 2021). In addition, pesticide toxicity contributes to the death of pest predators like ladybugs and spiders and affects beneficial insects; this has occasioned major pest problems that have reduced the yield of crops like cotton and maize by 20%-40% (Stanley et al., 2016). These imbalances show the impact of food web change on agricultural productivity, species protection, and sustainability.

It is made worse by the chemical method of pest control through pesticides that reduce other non-target species that can eat pests and those that pollinate plants. For example, bee populations that help to increase the yield of $235 billion of crops globally through pollination have declined by almost 40% in areas with monoculture farming and the use of pesticides (Khalifa et al., 2021). Likewise, bugs that participate in the decomposition process and recycling of nutrients, thus enhancing the health of soil output have subsequently resulted in poor fertility and high use of artificial fertilizers. In response, specific proposals for change focused on nodes in the food web are required as per an integrated ecological agriculture plan. One of the possible solutions now being considered is re-wilding, which involves restocking the large predators, such as the wolves, where the effect of this experiment reflected an improved flora coverage in Yellowstone National Park and its surrounding ecosystem to the tune of 20% (Clark-Wolf and Hebblewhite, 2022). Further, agroecological practices, resource conservation, rotation, and integrated pest management have been effective in increasing yields by 10%-15% and reducing pesticide use by 30%-50% (Zhou et al., 2024). Hence, an increase in ecosystem reliance and the resulting promotion of biological control mechanisms, including habitat rehabilitation, reintroduction of pest-suppressing species, and decreased application of synthetic pest control, are the key steps toward sustainable food security. The practice of agroecology of enhanced yield and food production, and conservation of species, will yield harmonized positive trends of food security globally, and the conservation of species both in the plant and animal kingdom, by effective utilization of the earth's resources.

Sustainable Protein Alternatives

New sources of sustainable proteins are emerging as the world seeks to feed a growing population while also trying to manage negative environmental impacts that are inherently linked with traditional livestock industries. Entomophagy, also known as insect farming, has recently received attention as a source of nutrition and has ecological importance. When it comes to proteins from insects such as crickets and mealworms, we find ourselves in the same ballpark as conventional livestock, the difference being that these sources are far more environmentally friendly than traditional livestock. For example, it takes just 1.5 pounds of feed and generates only 1/10th the amount of methane as poultry and only 1/20th that of beef to produce 1kg of insect protein (Fu et al., 2025). It is stated that shifting from insect-based competitors to protein could decrease the utilization of agricultural areas by 10-20%. Although the usage area of agricultural land is taken up by livestock breeding and feed production by around 80% (Duguma and Janssens, 2021). However, the problem of scalability remains unresolved because consumer acceptance, processing technologies, and regulation requirements should be further developed to facilitate increased employment.

Cultured meat, also referred to as cultured meat, is another revolutionary concept to produce sustainable protein sources. As labeled meat, stem cells and tissue engineering copy the equivalent of authentic meat in texture, taste, and nutrient density without the necessity to breed animals. Cellular agriculture could lower greenhouse gas emissions by as much as 96% and water use by approximately 82% from current beef production (El Wali et al., 2024). In addition, cultured meat can solve aspects such as animal suffering, torture, and low antibiotic usage, which are characteristic of industrially fattened meat. However, the current cost of producing lab-grown meat has not reduced much, and estimates place lab-grown meat at a notch higher than conventional meat by 10-20 times. Bioreactor technology is expected to improve, and the size of production LLCs is expected to reduce costs, thus making cultured meat an option in the future (Garrison et al., 2022).

Insect farming, as well as cellular agriculture, is an innovative approach to overcoming some of these problems and creating a new food system. Fast-packed insects provide immediate scalability and low-cost production, which serves as a solution to food insecurity in regions of the working poor. On the other end, lab-grown meats come to consumers in high-income countries as a fitting answer to ethical and sustainable replacements for traditional meats. Hence, these protein sources could equally interplay in global food plans, which could bring down the environmental cost of protein production by 30%-50 % by 2050 (Li et al., 2025).

Nutritional Ecology and Health

Nutritional ecology provides insights into how various foods interact with our gut microbiomes and overall bodily health. A balanced diet sustains the gut's ecological system, promoting effective digestion, robust immunity, and potentially mental we ll-being. Studies comparing food consumption patterns reveal that individuals who consume fruits, vegetables, and fermented products ha ve 30% greater gut microorganism diversity than those who eat processed foods (Leeuwendaal et al., 2022). This diversity reduces the likelihood of conditions such as obesity, inflammatory bowel disease, and depression. Conversely, diets high in processed sug ars and unhealthy fats disrupt gut health by interfering with the digestion and metabolism of essential nutrients. Addressing these disturbances through dietary approaches could significantly decrease the global prevalence of chronic diseases, which currently account fo r 60% of mortality according to WHO statistics (Wang et al., 2023).

Zoonotic diseases are influencing nutritional ecology, with their emergence linked to ecosystem disruptions and unsustainable food chains. A day in the park: The wildlife-human interface and spillover of emerging infectious diseases of zoonotic origin, including COVID-19 (Tazerji et al., 2022). For example, insufficient regulation of wet markets and CAFOs increases pathogen transmission, leading to ongoing outbreaks that cost the global economy billions of US dollars. Solutions include implementing stringent LT safety measures, enhancing biosecurity in livestock farming, and regulating wildlife trade. Moreover, increased investment in integrated farming practices that minimize human-animal contact can substantially reduce spillover rates.

Health disparities and hunger persist worldwide due to inefficient food distribution networks. Currently, over 870 million people experience malnutrition, while one-third of all prepared food goes to waste, indicating systemic issues (Mahmoudifar et al., 2025). Addressing malnutrition and related health disparities is possible by ensuring vulnerable populations have access to safe, nutritious, and affordable food. The outcomes of studies by Gupta (2024) Indicate that the effectiveness of various societal nutrition-based interventions, including school feeding programs and those that come under community-supported agriculture, decreases malnutrition levels among households earning less than $2 a day by 20%-40%. Moreover, sustaining local food processing to support local food systems and adopting ICT in supply chains neutralizes future global food shocks (Bisoffi et al., 2021). In these areas, global society wishes to get rid of health inequalities in the distribution and access to food and develop more than the status quo environments that exist today, as shown in Figure 2.

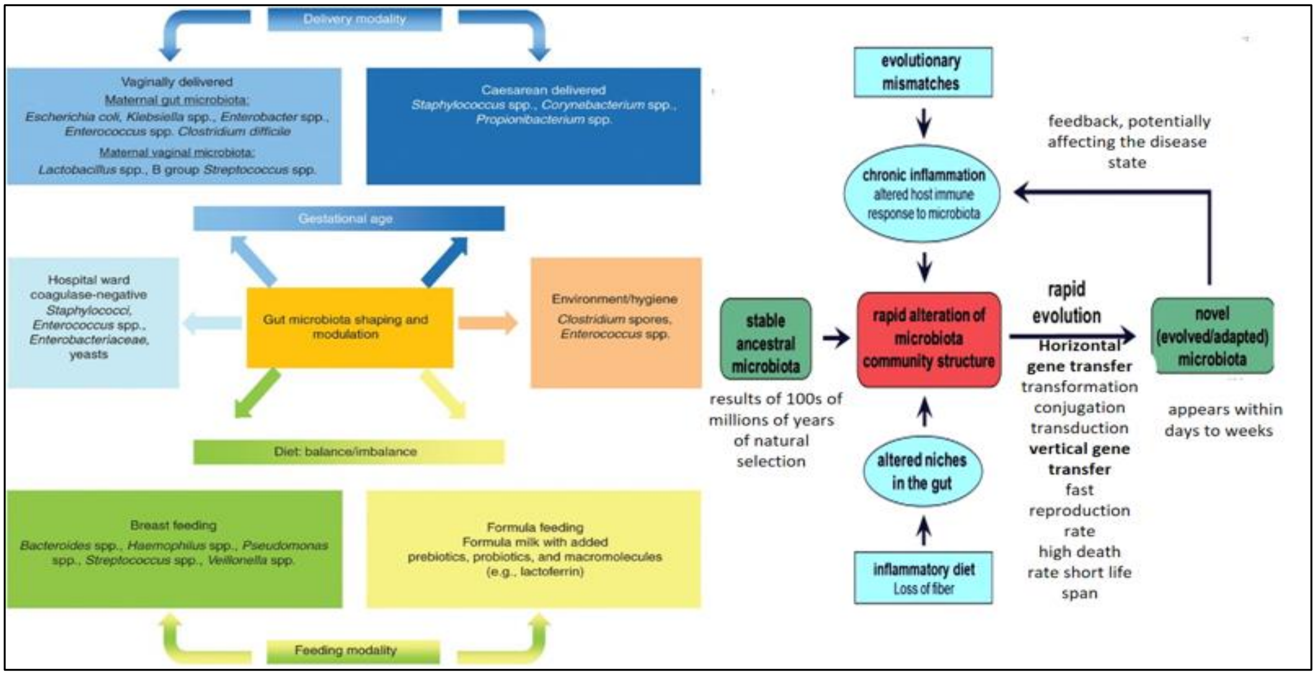

Fig. 2: Nutritional Ecology and Health

Climate Change and Adaptive Food Strategies

Climate change is now affecting food systems differently worldwide and increasing the need to implement strategies that will enhance food availability and production. Higher susceptibility of crops to climate change, including effects of heat, floods, and water deficits, enhances the need for climate-resilient crops. For example, drought-tolerant maize decreased yield reduction by as much as 30% during dry seasons in water-stricken areas, while Flood-tolerant rice developed for monsoon-ravaged South Asian fields has saved the crops of 18 million farmers from being flooded (Koppa and Amarnath, 2021; Piscitelli et al., 2021). Such new crops not only solve food accessibility problems but are also resource-friendly; moisture-appropriate crops can only need the 20%-40% water supply of other crops (Mitra et al., 2024). Also, these innovations make it possible to diversify diets by moving from the traditional GIs to those that can ensure balanced nutrient intakes in the face of an interfering climate. Accompanying these advances in agriculture, scientific investigations into animal thermometer sensitivity aid fisheries and animal-raising activities. For example, through selective breeding to improve tropical fish farming, heat-resistant fish breeds have raised yield by 15%-25% (Juiputta et al., 2023).

Technological and ecological approaches further bolster food system resilience against climate change. Precision agriculture, which integrates satellite data and IoT, enhances resource efficiency by reducing water and fertilizer use by 30%-50% while doubling crop yields (Getahun et al., 2024). Vertical farming addresses urban agriculture challenges, producing 75% more food per square meter than conventional farming and potentially conserving up to 95% of water resources. Conservation practices like no-till farming and cover cropping increase organic matter, improving cation exchange capacity, pH, carbon sequestration, and crop production. Mimicking honeybees for pollination and employing predatory beetles and insects for pest control have been shown to boost yields by 20%-30% without chemical inputs (Khalifa et al., 2021). When implemented comprehensively, these adaptive measures not only mitigate current climate change impacts but also establish a foundation for a more robust and resilient food system capable of withstanding future challenges.

Food Security Index Improvement via Sustainable Practices

$$Y_{index} = \frac{Y_{sustainable} - Y_{conventional}}{Y_{conventional}} \times 100$$

This equation determines the percentage improvement in the food security index (F_{index}) from sustainable practices, where $Y_{sustainable}$ and $Y_{conventional}$ represent yields under sustainable and conventional practices, respectively.

The Hidden Costs of Agricultural Monocultures

Modern, large-scale monoculture farming, despite its technological advancements, overlooks hidden ecological and economic disadvantages that prove counterproductive over time. One of the most alarming consequences is the decline in biodiversity, with insect populations dropping by 70% and bird populations by 30% in monoculture fields over the last 20 years (Boyle et al., 2025). These losses disrupt the food chain and ecosystem processes crucial for agriculture, such as pollination and predation, valued at $235 billion annually. Furthermore, monocultures require extensive land clearing, leading to a 17% loss of forest land in tropical regions, primarily for soybean cultivation and animal feed production (Suarez and Gwozdz, 2023). This habitat destruction not only displaces numerous species but also contributes to climate change through increased CO_2 emissions (Jha and Dev, 2024). Soil quality is severely impacted as well; synthetic fertilizers and chemicals deplete organic content, reducing fertility by half in areas of intensive production and harming beneficial organisms like earthworms and microbes (Pahalvi et al., 2021).

The heterogeneity loss also affects the social and economic planes. The single-crop production systems make farming systems vulnerable to pest diseases, challenges, and market hazards. For instance, a steep drop in corn oil prices in 2008 led to a $6 billion wipeout for producers in the United States, a tale that proved the heartbreaking fate that comes with non-diversification (Johansen, 2023). Some pests, including the fall armyworm, whose an impact on monoculture systems, resulting in the loss of more than $10 billion per year (Djeddour et al., 2021). Furthermore, high chemical input rates common in monocultures result in added costs of environmental remediation, and pesticide contamination of water, which is estimated to set the U.S. economy back $2 billion annually (Glibert, 2020). It is on this note that altering modes of production, for example, through agroforestry or intercropping, could help do away with these. Research shows that such systems bring yields by 20%-30%, decrease pests by 40%, and nitrogen use by 25% (Papadopoulos et al., 2024). Such approaches not only ensure the stability of the ecological environment but also help to build a buffer against climate impacts and sustain agricultural output and gross domestic products in global crises.

Indigenous Knowledge and Traditional Food Systems

It remains important that sustainable agriculture is built from the ground up with the ecological knowledge already available within Indigenous communities. For this reason, indigenous peoples play a critical role in conservation, as a sizeable fraction, 67%, of the world's biodiversity is in indigenous territories (Resende et al., 2021). This, together with responsible usage, has shown to have numerous ecological and economic gains, including, but not limited to, rotation grazing, intercropping, and usage and harvesting. Thus, rotational stocking practices of nomadic pastoralists increase SOC by 20%-30% and forage mass by 0%-15% (Gebremedhn et al., 2022). Likewise, the Indigenous farmers practicing mixed cropping systems in the sub-Saharan Africa region can improve the yield by up to 40% as compared to the pure cropping systems, which also reduce the pest incidence by up to 25%, according to (Khumalo et al., 2025). They also improve the capacity to adapt to such climate fluctuations and protect vulnerable food sources for populations with mostly climate-vulnerable production systems. Furthermore, indigenous small-scale fishery management practices of Pacific islanders have been found to efficiently maintain fish stock for several generations; small-scale fisheries feed over 200 million human beings today.

The integration of TEK with scientific elements, technology, and innovative solutions could quickly solve some of the world's pressing issues, like hunger, biodiversity loss, and climate change. For instance, the combination of mixed cropping practices with modern dynamic methods, such as precision agriculture, would reduce fertilizer usage by 30% but improve output (Getahun et al., 2024). Besides, some aspects of Indigenous agroforestry, which can sequester between five to ten metric tons of CO_2 per hectare per year, are useful in countering the current fight against climate change (Sahoo et al., 2022). Research undertaken in the Amazon basin has also shown that combining Indigenous peoples' traditional forest protection techniques with the use of satellites limits deforestation by between 40% and 60% (González and Kröger, 2023). These collaborations also increase socio-economic sustainability as well as maintain cultural heritage and provide employment. There is an opportunity to synchronize Indigenous Peoples' orally prescribed food knowledge transference and the modern science-driven practice for the lasting establishment of food security solutions that meet the global demographic demands and specifications of the 21st century (Sindelar, 2024).

Strategies to create a long-term framework for a sound global food regime support the United Nation's Sustainable Development Goals, particularly SDG 2: Zero Hunger, SDG 13: Climate Action, and SDG 3: Good Health and Well-being (Raman et al., 2024). The substitution of these policies requires these objectives to be met in a harmonized manner concerning environmental conservation, nutrition as well and public health. This current globalized food chain contributed to 31% of the total greenhouse gas emissions and requires policy changes (Chachei, 2024). Likewise, 700 million people are undernourished, and 2.4 billion are considered overweight. This shows that inequality in food distribution and health facilities is still apparent here and there (Leddin, 2024). Solving these problems sparks ethical questions, for instance, placing a carbon tax on agricultural emissions that will see many poor farmers and other vulnerable groups suffer. Feeding the people through subsidies, organic productions, and taxing unhealthy foods, such as processed foods, is not only going to benefit society but will also help prevent the deteriorating outcomes of the food industry on the environment.

Conclusion

This means that the solutions that encompass the biological, chemical, and physical facets of nutrition, environment, and health cannot be standardized. Instead, they require a lot of innovation and usually call for professionals with applications in food systems science, zoology, and sustainable agriculture. Whole food chains emit greenhouse gases, and millions of people go hungry; shifting to a sustainable diet and consuming more plant-based foods has the potential to reduce emissions by 50% and increase food availability. Food supply systems rely on global genetic and species conservation and pollination, as well as nutrient recycling in the ecosystem. Technological advancements in agriculture, for instance, precision agriculture and the use of blockchain technologies, have the potential of using resources efficiently and reducing losses, meeting present productivity in food production that is lost to wastage. To successfully effect these objectives, the system changes entail designing fair ethical policies for disparities, diversity, and sustainability, as well as recognizing Indigenous knowledge systems. Engaging human capital for sustainability is feasible to build a strong, resilient, just, and nutrition-secured food system to meet future requirements.

References

Alt, K. W., Al-Ahmad, A., & Woelber, J. P. (2022). Nutrition and health in human evolution–past to present. *Nutrients*, *14*(17), 3594. https://doi.org/10.3390/nu14173594

Bisoffi, S., Ahrné, L., Aschemann-Witzel, J., Báldi, A., Cuhls, K., Declerck, F., Duncan, J., Hansen, H. O., Hudson, R. L., & Kohl, J. (2021). COVID-19 and sustainable food systems: what should we learn before the next emergency. *Frontiers in Sustainable Food Systems*, *5*, 650987.

https://doi.org/10.3389/fsufs.2021.650987

Blanco, H., & Lal, R. (2023). Management of grazing lands. In *Soil conservation and management* (pp. 443-469). Springer. https://doi.org/10.1007/978-3-031-30341-8_18

Boyle, M. J., Bonebrake, T. C., Dias Da Silva, K., Dongmo, M. A., Machado França, F., Gregory, N., Kitching, R. L., Ledger, M. J., Lewis, O. T., & Sharp, A. C. (2025). Causes and consequences of insect decline in tropical forests. *Nature Reviews Biodiversity*, 1-17. https://doi.org/10.1038/s44358-025-00038-9

Chachei, K. (2024). Greenhouse gas emissions in the Indian agriculture sector and mitigation by best management practices and smart farming technologies—a review. *Environmental Science and Pollution Research*, *31*(32), 44489-44510. https://doi.org/10.1007/s11356-024-33975-7

Clark-Wolf, T., & Hebblewhite, M. (2022). Trophic cascades as a basis for rewilding. In *Routledge Handbook of Rewilding* (pp. 57-67). Routledge. https://www.taylorfrancis.com/chapters/edit/10.4324/9781003097822-8/trophic-cascades-basis-rewilding-clark-wolf-mark-hebblewhite

Crona, B. I., Wassénius, E., Jonell, M., Koehn, J. Z., Short, R., Tigchelaar, M., Daw, T. M., Golden, C. D., Gephart, J. A., & Allison, E. H. (2023). Four ways blue foods can help achieve food system ambitions across nations. *Nature*, *616*(7955), 104-112. https://doi.org/10.1038/s41586-023-05737-x

Deguine, J.-P., Gloanec, C., Laurent, P., Ratnadass, A., Aubertot, J.-N., Laurent, P., Aubertot, J.-N., Aubertot, J.-N., Aubertot, J.-N., & Doré, T. (2017). Agroecological transition keys. In *Agroecological Crop Protection* (pp. 163-246). Springer. https://doi.org/10.1016/bs.agron.2022.11.002

Dietert, R. R. (2021). Microbiome first approaches to rescue public health and reduce human suffering. Biomedicines, *9*(11), 1581. https://doi.org/10.3390/biomedicines9111581

Djeddour, D., Pratt, C., Makale, F., Rwomushana, I., & Day, R. (2021). The apple snail, Pomacea canaliculata: an evidence note on invasiveness and potential economic impacts for East Africa. CABI Work. Pap, *21*, 77. https://dx.doi.org/10.1079/CABICOMM-62-8149

Duguma, B., &Janssens, G. P. (2021). Assessment of livestock feed resources and coping strategies with dry season feed scarcity in mixed crop–livestock farming systems around the gilgel gibe catchment, Southwest Ethiopia. *Sustainability*, *13*(19), 10713. https://doi.org/10.3390/su131910713

El Wali, M., Rahimpour Golroudbary, S., Kraslawski, A., & Tuomisto, H. L. (2024). Transition to cellular agriculture reduces agriculture land use and greenhouse gas emissions but increases demand for critical materials. *Communications Earth & Environment*, *5*(1), 61. https://doi.org/10.1038/s43247-024-01227-8

Fu, C., Cheema, W. A., Mobashar, M., Shah, A. A., & Alqahtani, M. M. (2025). Insects as sustainable feed: enhancing animal nutrition and reducing livestock environmental impression. *Journal of Animal Physiology and Animal Nutrition*, *109*(2), 280-290. https://doi.org/10.1111/jpn.14055

Garrison, G. L., Biermacher, J. T., & Brorsen, B. W. (2022). How much will large-scale production of cell-cultured meat cost? *Journal of Agriculture and Food Resear*ch, *10*, 100358. http://dx.doi.org/10.1016/j.jafr.2022.100358

Gebremedhn, H. H., Kelkay, T. Z., Tesfay, Y., Tuffa, S., Dejene, S. W., Mensah, S., Devenish, A. J. M., & Egeru, A. (2022). Carbon stock and change rate under different grazing management practices in semiarid pastoral ecosystem of eastern Ethiopia. *Land*, *11*(5), 639. https://doi.org/10.3390/land11050639

Getahun, S., Kefale, H., & Gelaye, Y. (2024). Application of precision agriculture technologies for sustainable crop production and environmental sustainability: A systematic review. *The Scientific World Journal*, *2024*(1), 2126734. https://doi.org/10.1155/2024/2126734

Glibert, P. M. (2020). From hogs to HABs: impacts of industrial farming in the US on nitrogen and phosphorus and greenhouse gas pollution. *Biogeochemistry*, *150*(2), 139-180. https://doi.org/10.1007/s10533-020-00691-6

González, N. C., &Kröger, M. (2023). The adoption of earth-observation technologies for deforestation monitoring by Indigenous people: evidence from the Amazon. Globalizations, *20*(3), 415-431. https://doi.org/10.1080/14747731.2022.2093556

Gupta, S. D. (2024). *School Food Policies and Perspectives:* An examination of policy, funding models and caregivers' perceptions PhD Thesis, University of Saskatchewan Saskatoon, 2024. https://harvest.usask.ca/server/api/core/bitstreams/3605eec1-0fa1-4054-aaf1-934d4147aa2b/content

Ibrahim, L. A., Shaghaleh, H., Abu-Hashim, M., Elsadek, E. A., & Hamoud, Y. A. (2023). Exploring the integration of rice and aquatic species: Insights from global and national experiences. *Water*, *15*(15), 2750. https://doi.org/10.3390/w15152750

Jain, I., Kaur, R., Kumar, A., Paul, M., & Singh, N. (2024). Emerging protein sources and novel extraction techniques: a systematic review on sustainable approaches. *International Journal of Food Science & Technology*, *59*(10), 6797-6820. https://doi.org/10.1111/ijfs.17466

Jha, M. K., &Dev, M. (2024). Impacts of Climate Change. In *Smart Internet of Things for Environment and Healthcare* (pp. 139-159). Springer. http://dx.doi.org/10.1007/978-3-031-70102-3_10

Johansen, B. E. (2023). Specious Solutions and Speculations. In *Global Warming and the Climate Crisis: Science, Spirit, and Solutions* (pp. 243-301). Springer. http://dx.doi.org/10.1007/978-3-031-12354-2_6

Juiputta, J., Chankitisakul, V., & Boonkum, W. (2023). Appropriate genetic approaches for heat tolerance and maintaining good productivity in tropical poultry production: *A review. Veterinary Sciences*, *10*(10), 591. https://doi.org/10.3390/vetsci10100591

Karunathilake, E., Le, A. T., Heo, S., Chung, Y. S., & Mansoor, S. (2023). The path to smart farming: Innovations and opportunities in precision agriculture. *Agriculture*, *13*(8), 1593. https://doi.org/10.3390/agriculture13081593

Khalifa, S. A., Elshafiey, E. H., Shetaia, A. A., El-Wahed, A. a. A., Algethami, A. F., Musharraf, S. G., Alajmi, M. F., Zhao, C., Masry, S. H., & Abdel-Daim, M. M. (2021). Overview of bee pollination and its economic value for crop production. *Insects*, *12*(8), 688. https://doi.org/10.3390/insects12080688

Khumalo, T. A., Chakale, M. V., Asong, J. A., Aremu, A. O., & Amoo, S. O. (2025). Indigenous farming methods and crop management practices used by local farmers in Madibeng local municipality, South Africa. *Scientific Reports*, *15*(1), 8918. https://doi.org/10.1038/s41598-025-91210-w

Koppa, N., &Amarnath, G. (2021). Geospatial assessment of flood-tolerant rice varieties to guide climate adaptation strategies in India. *Climate*, *9*(10), 151. https://doi.org/10.3390/cli9100151

Leddin, D. (2024). The impact of climate change, pollution and biodiversity loss on digestive health and disease. Gastro Hep Advances. https://doi.org/10.1016/j.gastha.2024.01.018

Leeuwendaal, N. K., Stanton, C., O'toole, P. W., & Beresford, T. P. (2022). Fermented foods, health and the gut microbiome. *Nutrients*, *14*(7), 1527. https://doi.org/10.3390/nu14071527

Li, Y., Liu, X., Zhang, J., Yang, Z., Zhou, C., Wu, P., Li, C., Xu, X., Tang, C., & Zhou, G. (2025). Textured vegetable protein as a partial replacement for lean meat in salami analogues: Perspectives on physicochemical properties, flavour and proteome changes. *Food Chemistry*, *463*, 140844. https://doi.org/10.1016/j.foodchem.2024.140844

Mahmoudifar, K., Raeesi, A., Kiani, B., & Rezaie, M. (2025). Food waste in hospitals: implications and strategies for reduction: a systematic review. *Management of Environmental Quality: An International Journal*, *36*(1), 50-71. http://dx.doi.org/10.1108/MEQ-07-2023-0221

Mitra, A., Vangipuram, S. L., Bapatla, A. K., Bathalapalli, V. K., Mohanty, S. P., Kougianos, E., & Ray, C. (2024). Smart Agriculture: A Comprehensive Overview. *SN Computer Science*, *5*(8), 969. http://dx.doi.org/10.1007/s42979-024-03319-w

Modrackova, N., Stovicek, A., Burtscher, J., Bolechova, P., Killer, J., Domig, K. J., & Neuzil-Bunesova, V. (2021). The bifidobacterial distribution in the microbiome of captive primates reflects parvorder and feed specialization of the host. *Scientific reports*, *11*(1), 15273. https://doi.org/10.1038/s41598-021-94824-y

Ordiz, A., Aronsson, M., Persson, J., Støen, O.-G., Swenson, J. E., & Kindberg, J. (2021). Effects of human disturbance on terrestrial apex predators. *Diversity*, *13*(2), 68. https://doi.org/10.3390/d13020068

Padhiary, M., &Kumar, R. (2024). Assessing the environmental impacts of agriculture, industrial operations, and mining on agro-ecosystems. In *Smart Internet of Things for Environment and Healthcare* (pp. 107-126). Springer. http://dx.doi.org/10.1007/978-3-031-70102-3_8

Pahalvi, H. N., Rafiya, L., Rashid, S., Nisar, B., & Kamili, A. N. (2021). Chemical fertilizers and their impact on soil health. Microbiota and Biofertilizers, Vol 2: Ecofriendly tools for reclamation of degraded soil environs, 1-20. https://doi.org/10.1007/978-3-030-61010-4_1

Papadopoulos, G., Arduini, S., Uyar, H., Psiroukis, V., Kasimati, A., & Fountas, S. (2024). Economic and environmental benefits of digital agricultural technologies in crop production: A review. *Smart Agricultural Technology*, 100441. https://doi.org/10.1016/j.atech.2024.100441

Piscitelli, L., Colovic, M., Aly, A., Hamze, M., Todorovic, M., Cantore, V., & Albrizio, R. (2021). Adaptive agricultural strategies for facing water deficit in sweet maize production: a case study of a semi-arid mediterranean region. *Water*, *13*(22), 3285. https://doi.org/10.3390/w13223285

Raman, R., Manalil, S., Dénes, D. L., & Nedungadi, P. (2024). The role of forestry sciences in combating climate change and advancing sustainable development goals. *Frontiers in Forests and Global Change*, *7*, 1409667. https://doi.org/10.3389/ffgc.2024.1409667

Rehman, A., Farooq, M., Lee, D.-J., & Siddique, K. H. (2022). Sustainable agricultural practices for food security and ecosystem services. *Environmental Science and Pollution Research*, *29*(56), 84076-84095. https://doi.org/10.1007/s11356-022-23635-z

Resende, F. M., Cimon-Morin, J., Poulin, M., Meyer, L., Joner, D. C., & Loyola, R. (2021). The importance of protected areas and Indigenous lands in securing ecosystem services and biodiversity in the Cerrado. Ecosystem Services, *49*, 101282. DOI: 10.1016/j.ecoser.2021.101282

Saad-Hussein, A., Anwer, W., Au, W., Neira, M., Marnewick, J. L., & Abdul, N. S. (2025). Climate Change Impacts on Environmental Toxins, and Its Health Effects. In *Climate Change Impacts on Toxins and Health Effects* (pp. 13-61). Springer. http://dx.doi.org/10.1007/978-981-96-3416-3_2

Sahoo, G., Swamy, S. L., Wani, A. M., & Mishra, A. (2022). Agroforestry systems for carbon sequestration and food security: implications for climate change mitigation. In *Soil health and environmental sustainability: application of geospatial technology* (pp. 503-528). Springer. http://dx.doi.org/10.1007/978-3-031-09270-1

Shao, T., Verma, H. K., Pande, B., Costanzo, V., Ye, W., Cai, Y., & Bhaskar, L. (2021). Physical activity and nutritional influence on immune function: an important strategy to improve immunity and health status. *Frontiers in Physiology*, *12*, 751374. https://doi.org/10.3389/fphys.2021.751374

Sindelar, R. D. (2024). Genomics, other "OMIC" technologies, precision medicine, and additional biotechnology-related techniques. In *Pharmaceutical Biotechnology: Fundamentals and Applications* (pp. 209-254). Springer. https://doi.org/10.1007/978-1-4614-6486-0_8

Singleton, G. R., Lorica, R. P., Htwe, N. M., & Stuart, A. M. (2021). Rodent management and cereal production in Asia: Balancing food security and conservation. *Pest Management Science*, *77*(10), 4249-4261. https://doi.org/10.1002/ps.6462

Solovieva, I., Miteva-Bölter, P., Knez, M., Bessai, A.-K., Barilli, E., Kasperczyk, N., Ranic, M., Gurinovic, M., Luna Casado, P. J., & Alba Morales, N. (2025). Exploring the Potential and Challenges of Lathyrus sativus (Grass Pea) in European Agri-Food Value Chains: A Cross-Country Analysis. *Sustainability*, *17*(8), 3283. https://doi.org/10.3390/su17083283

Sonmez, D., &Taylor Jr, S. (2024). Nutrition and nature: means-End theory in crafting sustainable and health-conscious meal kit experiences. *Sustainability*, *16*(8), 3327. https://doi.org/10.3390/su16083327

Stanley, J., Preetha, G., Stanley, J., & Preetha, G. (2016). Pesticide toxicity to arthropod predators: Exposure, toxicity and risk assessment methodologies. Pesticide Toxicity to Non-target Organisms: Exposure, Toxicity and Risk Assessment Methodologies, 1-98. http://dx.doi.org/10.1007/978-94-017-7752-0_1

Suarez, A., &Gwozdz, W. (2023). On the relation between monocultures and ecosystem services in the Global South: A review. Biological Conservation, *278*, 109870. http://dx.doi.org/10.1016/j.biocon.2022.109870

Tazerji, S. S., Nardini, R., Safdar, M., Shehata, A. A., & Duarte, P. M. (2022). An overview of anthropogenic actions as drivers for emerging and re-emerging zoonotic diseases. *Pathogens*, *11*(11), 1376. https://doi.org/10.3390/pathogens11111376

Vlaicu, P. A., Gras, M. A., Untea, A. E., Lefter, N. A., & Rotar, M. C. (2024). Advancing livestock technology: intelligent systemization for enhanced productivity, welfare, and sustainability. *AgriEngineering*, *6*(2), 1479-1496. https://doi.org/10.3390/agriengineering6020084

Wang, P., Song, M., Eliassen, A. H., Wang, M., Fung, T. T., Clinton, S. K., Rimm, E. B., Hu, F. B., Willett, W. C., & Tabung, F. K. (2023). Optimal dietary patterns for prevention of chronic disease. *Nature Medicine*, *29*(3), 719-728. https://doi.org/10.1038/s41591-023-02235-5

Yadav, M. R., Kumar, S., Lal, M. K., Kumar, D., Kumar, R., Yadav, R. K., Kumar, S., Nanda, G., Singh, J., & Udawat, P. (2023). Mechanistic understanding of leakage and consequences and recent technological advances in improving nitrogen use efficiency in cereals. *Agronomy*, *13*(2), 527. https://doi.org/10.3390/agronomy13020527

Zhou, W., Arcot, Y., Medina, R. F., Bernal, J., Cisneros-Zevallos, L., & Akbulut, M. E. (2024). Integrated pest management: an update on the sustainability approach to crop protection. *ACS omega*, *9*(40), 41130-41147. https://doi.org/10.1021/acsomega.4c06628?urlappend=%3Fref%3DPDF&jav=VoR&rel=cite-as